Sustainability aspects of ten bedded pack dairy barns in The Netherlands

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Samenvatting: Een vrijloopstal onderscheidt zich ten opzichte van een ligboxenstal doordat het geen ligboxen heeft en geen mestkelders onder de roostervloer (referentie systeem). Het liggedeelte is tevens de mestopslag. Een vrijloopstal heeft daardoor een andere impact op de duurzaamheidsaspecten: economie, welzijn, melkkwaliteit, mestkwaliteit en milieu. In deze studie zijn deze duurzaamheidsaspecten onderzocht op 10 praktijkbedrijven met een vrijloopstal in Nederland. Vijf bedrijven gebruiken houtsnippers als bodemmateriaal, vier bedrijven gebruiken compost van een composteringsbedrijf en één bedrijf gebruikt stro. De houtsnippers worden gecomposteerd met de mest van de koeien, de warmte die ontstaat tijdens het composteringsproces zorgt voor extra verdamping van het vocht uit het bodemmateriaal en zorgt dat de toplaag droog blijft. Twee van de vijf bodems met houtsnippers beheersen het composteringsproces met een ventilatiesysteem door lucht vanuit de onderlaag in het ligbed te blazen, de twee andere bedrijven zuigen lucht door het ligbed. Een bedrijf belucht de bodem niet. De bodems met compost en stro absorberen het vocht.

Economie

De investeringskosten van een vrijloopstal met compost als ligbed zijn ongeveer dezelfde als van een 2+2 rijige ligboxenstal. De kosten voor het dak zijn hoger, omdat de benodigde m^2 per koe van de hele stal meer dan twee keer zoveel is, maar de kosten voor mestopslag zijn lager omdat het ligbed tevens mestopslag is. De investeringskosten van een vrijloopstal die houtsnippers composteert zijn echter € 640 per koe hoger dan die van de genoemde ligboxenstal, doordat de bodem van het liggedeelte van beton is in plaats van een waterdichte folie zoals bij een compostbodem. De totale jaarlijkse kosten (voor de stal, machines, arbeid en bodemmateriaal) zijn € 125 per koe hoger bij houtsnippers en € 143 per koe hoger bij gebruik van compost. Deze jaarlijkse kosten zijn erg afhankelijk van de prijzen van het bodemmateriaal. De extra kosten van een vrijloopstal ten opzichte van een ligboxenstal worden gecompenseerd als het vervangingspercentage met 10% daalt, wat een realistische verwachting is gezien de ervaringen van de 10 praktijkedrijven.Op het moment dat dit rapport verschijnt zijn er echter onvoldoende data om een lagere veevervanging te kunnen aantonen.

Melk productie, gezondheid en welzijn

Het is onmogelijk in dit stadium definitieve conclusies te trekken over het effect van een vrijloopstal op de prestaties van de veestapel, de diergezondheid en de levensduur, om verschillende redenen. De periode dat de koeien gehuisvest zijn in een vrijloopstal is nog maar kort, de vorige huisvesting (ligboxenstal) was soms verouderd, andere factoren dan huisvesting spelen ook een rol en bovendien zijn andere veranderingen toegepast (zoals groei van de veestapel). Er zijn wel indicaties dat de koeien in een vrijloopstal minder minder huidbeschadigingen en vergelijkbare uiergezondheid hebben dan koeien in een ligboxenstal en dat de dieren profiteren van de extra ruimte (makkelijker om confrontaties met rang hogere dieren te vermijden). Gemiddeld hebben de 10 bedrijven met vrijloopstallen minder mastitis dan bedrijven met ligboxenstallen, en een laag antibioticumgebruik (o.a. door restrictief gebruik van droogzetpreparaten). De variatie tussen de bedrijven is echter groot. De verwachting is dat de klauwgezondheid verbetert, echter de locomotie score van de koeien in een vrijloopstal kan niet direct vergeleken worden met die van koeien op een roostervloer. Vrijloopstallen die goed gemanaged worden bieden goed lig comfort. De warmteontwikkeling in composterende bodems lijkt niet de kans op hitte stress te verhogen.

Melk kwaliteit

De sporen van thermofiele aerobe sporenvormende bacteriën (TAS), en in het bijzonder de hoog hitteresistente bacteriën (XTAS) binnen deze groep, zijn een risico voor de melkkwaliteit. De sporen van de XTAS bacteriën in het bodemmateriaal kunnen via de spenen in de melktank terecht komen. Een hoge concentratie van XTAS in de melk kan problemen geven met de houdbaarheid van bepaalde UHT (gesteriliseerde) zuivelproducten. Daarom heeft de Zuivelindustrie het gebruik van compost sterk afgeraden. Het gebruik van houtsnippers is wel mogelijk, omdat de concentratie van XTAS lager is dan bij compost, echter wel hoger dan bij gebruik van zaagsel in ligboxstallen.

NPK balansen, gasvormig N verlies

De N, P en K balansen zijn berekend op zes bedrijven met een vrijloopstal: vier met houtsnippers en twee met compost als bodemmateriaal. Het totale gasvormige N verlies uit de vrijloopstal varieerde tussen 19 en 63% wanneer het uitgedrukt is als percentage van de totale N excretie van de koeien op de stalvloer, tussen 17 en 35% wanneer het uitgedrukt is als percentage van de netto N input van de stalvloer (N excretie van de koeien + N vanuit het bodemmateriaal) en tussen 3.1 en 13.5 gram N verlies als het uitgedrukt is per kg geproduceerd melk. Het N verlies per kg melk is het laagst op de drie bedrijven met houtsnippers die tevens gebruik maken van een beluchtingssysteem. Het N verlies was lager in de bodem die lucht blaast dan de twee bedrijven die lucht door de bodem zuigen. Het N verlies in een ligboxenstal (referentie) varieert tussen 1.1 en 2.7 gram N per kg melk gebaseerd op emissiefactoren uit de literatuur.
Op het bedrijf met een ligboxenstal (referentie), draagt de emissie bij aanwending van drijfmest op het land aanzienlijk bij aan het totale N verlies op het bedrijf als geheel. Eerder onderzoek heeft aangetoond dat het gasvormig N verlies bij aanwending van 'compost' uit een vrijloopstal verwaarloosbaar is. Op bedrijfsniveau varieert het totale N verlies van een vrijloopstal tussen 3.9 en 14.7 gram N per kg melk en het N verlies van een bedrijf met een ligboxenstal varieert tussen 2.2 en 5.4 gram N per kg melk.

Mest kwaliteit karakteristieken

Het mengsel van gecomposteerd bodemmateriaal met mest van de koeien ('compost') in een vrijloopstal heeft gevolgen voor de geproduceerde mestkwaliteit en de strategie van mestaanwending. Het gebruik van bodemmateriaal verhoogt de N input tussen 11 en 246% en de P input tussen 8 en 334%, vergeleken met een ligboxenstal die geen organisch materiaal aanvoert. De N/P verhouding van 'compost' uit alle vrijloopstallen is lager dan van drijfmest uit een ligboxenstal. Het gevolg is dat minder N aangewend kan worden met 'compost' uit een vrijloopstal vergeleken met drijfmest, bij gelijke P gift. De C/N verhouding van 'compost' van alle vrijloopstallen was hoger dan de C/N verhouding van drijfmest. Dit geeft een indicatie dat de N van 'compost' trager mineraliseert dan N van drijfmest. De combinatie van een hogere C/N verhouding en een lagere N/P verhouding van 'compost' uit een vrijloopstal ten opzichte van drijfmest betekent voor de korte termijn dat er aanzienlijk minder N beschikbaar is van 'compost' dan van drijfmest, bij een gelijke P gift. Daarom is 'compost' uit een vrijloopstal minder geschikt als organische meststof voor gewassen op de korte termijn, maar meer geschikt als bodemverbeteraar op de lange termijn. Als het hogere N verlies door de 'compost' niet gecompenseerd wordt met N uit drijfmest of kunstmest of biologische N binders, zal er minder N beschikbaar komen voor de plant op de lange termijn, wat zal leiden tot lagere gewasopbrengsten.

Gasvormige emissies

Op tien bedrijven zijn de gasvormige verliezen gemeten met een box methode. Op drie bedrijven is de totale emissie op stalniveau gemeten. De box metingen betreffen in totaal 33 meetsessies in de jaren 2010 t/m 2013 en die op stal niveau betreffen zes metingen in de jaren 2012 en 2013. De ammoniakemissies gemeten met de box methode zijn uitgedrukt per m^2 op de bodems met houtsnippers, compost en stro lager dan van een ligboxenstal (referentie). De koeien hebben in een vrijloopstal echter meer m^2 beschikbaar. De ammoniak emissie uitgedrukt per koe is daardoor hoger, namelijk 146% vergeleken met de referentie (=100%) bij gebruik van houtsnippers, 227% bij gebruik van compost en 189% bij gebruik van stro als bodemmateriaal. De box metingen geven aan dat emissie van lachgas uit de stal 9 tot 16 keer hoger en de emissie van methaan aanzienlijk lager is dan de referentie. De emissies op stalniveau geven de absolute emissies aan van de gehele stal. De stalemissie bij gebruik van houtsnippers was 16,5 kg NH_3 per dier per jaar bij gebruik van SF_6 als tracer gas. De gemiddelde emissie van de twee bedrijven die compost gebruiken als bodemmateriaal varieerde tussen 8,9 en 42,4 kg NH_3 per dier per jaar bij respectievelijk gebruik van CO_2 en SF_6 als tracer gas.

Algemene conclusies

In onderstaand schema is een vergelijking gemaakt tussen de drie typen vrijloopstallen met verschillend bodemmateriaal ten opzichte van een ligboxenstal. De hogere kosten voor het gebouw en de aankoop van bodemmateriaal kunnen gecompenseerd worden door een langere levensduur van de koeien. In het algemeen is het dierenwelzijn in een vrijloopstal beter dan in een ligboxenstal door meer ruimte, minder obstakels en een bodem met meer grip. De concentratie van sporen van XTAS is te hoog in bodems met compost en daarom door de Zuivelindustrie afgeraden, maar compostering van houtsnippers is wel toegestaan. Om de milieuaspecten van de vrijloopstal te beoordelen zal op bedrijfsniveau gekeken moeten worden. De N verliezen in de stal (ammoniak en lachgas) zijn hoger, vooral bij gebruik van compost, maar zijn lager bij aanwending op het land ten opzichte van drijfmest. Het materiaal uit de stal ('compost') is een goede bodemverbeteraar op de lange termijn, maar voor de korte termijn is de beschikbaarheid van N lager. De conclusie ten aanzien van het perspectief van vrijloopstallen is voor compost negatief vanwege de te hoge risico's voor de melkkwaliteit en de hoge N verliezen in de stal. Het perspectief van gebruik van houtsnippers als bodemmateriaal in een vrijloopstal lijkt positief, mits het XTAS probleem opgelost wordt en de emissie van ammoniak en lachgas beperkt wordt. Om het perspectief van stro goed in te schatten is onderzoek op meer bedrijven nodig.

		Bodem materiaal		
		Houtsnippers	**Compost**	**Stro**
		5 bedrijven	*4 bedrijven*	*1 bedrijf*
Sustainability aspect	**Criteria**			
Economie	Investeringskosten			
	Jaarlijkse kosten			
	Levensduur			
Koe	Productie en gezondheid			
	Welzijn			
Melk kwaliteit	XTAS			
Milieu	N verlies stal			
	N verlies land			
	Ammoniak emissie stal			
	Lachgas emissie			
Mest kwaliteit	Bodemverbeteraar			
	N mineralisatie			

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Foreword

The bedded pack barn system is in full development in The Netherlands. The idea for a bedded pack barn originates from 2007, with inspiration from the USA and Israel. A lot has happened since then. Experimental farms started experimenting with different bedding materials. At the end of 2009 pioneering dairy farmers introduced the first bedded pack barns in the Netherlands. Participating in workshops and seminars more dairy farmers became enthusiastic. Initially, they were sceptical about keeping the top layer dry in the humid Dutch climate, but soon they noticed that there are ways to house dairy cows at bedded packs made of natural bedding materials and to keep the cows clean. The space for the cows on the soft bedding appealed to them and they also noticed the value of the bedding material as soil improver for the land. Meanwhile, in early 2014 about 40 bedded pack barns have been built in the Netherlands. Initially, in 2010, three pioneering farms were studied and this extended to ten pioneering farms in 2013. These pioneers have experience with different types of bedding materials. Researchers of Wageningen UR Livestock Research and NIZO food research performed measurements on various sustainability aspects at these farms. Do the positive expectations of the pioneering dairy farmers about improved animal welfare, animal health, longevity, economic results and manure quality come true? And what about emissions, in the barn and on the land? And the spores of thermophilic bacteria in the milk? The results in this report are described from the perspectives of the dairy farmer, the cow and the environment.
In this report the results of many measurements on commercial dairy farms are presented. The commercial farms mainly use wood chips or green waste compost as bedding material. The results of the study performed by NIZO food research addressing the risks of increased spore concentrations of thermophilic bacteria in the bedding material in bedded pack barns and in compost used as litter material in free stalls have been discussed with the Dairy industry in early 2014.Due to an increased concentration of these micro-organisms in compost Friesland Campina has decided to prohibit the use of compost or composted material starting January 1, 2015. The reason is that an increased concentration of spores of thermophilic bacteria may lead to decay of certain dairy products. Materials that can be composted in the barn, such as wood chips, are not covered by that ban. Further research on that subject is conducted in 2014. In the study presented in this report the results of beddings consisting of (green waste) compost, wood chips and straw are compared.
This research is financed by the Dutch Dairy Board (PZ) and the Ministry of Economic Affairs (EZ) in the framework of the research program Sustainable Dairy Chain. The study is guided by an advisory committee consisting of representatives from PZ, EZ, LTO, Courage and the project team consisting of researchers of Wageningen UR Livestock Research and NIZO food research.
On behalf of the advisory committee and the project team Bedded Pack Barns I hope you enjoy reading this report about state of the art of the research on Bedded Pack Barns.

Jos de Kleijne,
Dairy farmer and chairman advisory committee Bedded Pack Barns.

Summary

A bedded pack barn is a different type of housing for dairy cows compared to the common free stall barns with cubicles and slatted concrete floors with slurry storage underneath (reference system). A bedded pack barn presumably has a different impact on the sustainability aspects economics, animal welfare, milk quality, manure quality and environment. In the present study we have investigated these sustainability aspects on 10 bedded pack barns in the Netherlands. Five farms use wood chips as bedding material and five other farms use litter. The wood chips are composted in the barn and the heat of the composting process helps to evaporate moisture and keeps the top layer dry. Two of these five farms control their composting process by blowing air and two others by sucking air through the bedding. One farm does not use an aerating system. The other five farms use litter to keep the top layer dry. This litter relates to green waste compost at four farms and straw at one farm and is meant to absorb the moisture.

Economy

The investments in a bedded pack barn using compost as bedding are almost the same as a 2+2 row free stall barn. The costs for the roof are higher, because the area per cow is more than twice as much, but the costs for manure storage are lower because the lying area is also manure storage. The building costs for a barn that is composting wood chips, however, are € 640 per cow higher due to the concrete floor as bottom layer under the wood chips. The bottom layer under the compost bedding consists of a foil with sand, which is much cheaper. Compared to a free stall barn, the estimated total annual costs per cow (for the building, machinery, labour and bedding material) are € 125 per cow higher when using wood chips and € 143 per cow higher when using compost. These costs depend strongly on the prices of bedding material. The extra costs of the bedded pack barn compared to free stall barns may be compensated when the cow replacement rate decreases with 10%, as can realistically be expected. However, at the time this report was written, there was not enough data to prove this possible decrease in cow replacement. It is an expectation based on experiences of the farmers.

Milk production, health and welfare

It is impossible to draw definite conclusions about the effects of bedded pack barns on herd performance, health and longevity in this stage, because of the limited time span the herds are housed and monitored in their new barn, probable suboptimal circumstances in the old cubicle barns, the fact that these aspects are also influenced by other factors than housing and because most farms also implemented other changes (e.g. increasing herd size). There are indications that the cows in bedded pack barns have less integument lesions and similar udder health compared to cows kept in cubicle barns. Moreover, the animals can lie down and get up more easily and probably benefit from the increased space (e.g. making it easier to avoid aggressive confrontations with higher ranked herd mates). On average, the herds in the bedded pack barns have less matitis and low antibiotics usage compared to the average herd in a cubicle barn, but there is a large variation between the bedded pack herds. It is expected that claw health improves, but locomotion scores of cows in a bedded pack barn cannot directly be compared with those on alley floors. Well-managed bedded packs provide good lying comfort. Heat production in composting bedding does not seem to increase the occurrence of heat stress.

Milk Quality

The occurrence in bedding material of spores of thermofilic aerobic spore forming bacteria (TAS), and in particular the extremely high heat resistant spores (XTAS) within this group, is a risk for milk quality. The spores of XTAS bacteria in the bedding can be transmitted to the milk via the udder and

teats. A high concentration in the milk can lead to spoilage problems in certain UHT dairy products. Therefore the Dutch Dairy Organization strongly advises against the use of composted materials in dairy barns. Composting of wood chips in the bedded pack barn is still possible, because the concentration of XTAS is much lower than in compost, though higher than in sawdust bedding in cubicle stalls.

NPK balances, gaseous N loss

The N, P and K balances were calculated for six different bedded pack barns: four with wood chips and two with green waste compost as bedding material. Total gaseous N loss from the bedded pack barns varied between 19 and 63% when expressed as a percentage of the total N excretion by the cows on the barn floor, between 17 and 35% when expressed as a percentage of net N input on the barn floor (excreted N + N in bedding material) and between 3.1 and 13.5 g of N when expressed per kg of produced milk. N loss per kg of milk was the lowest for the three barns with wood chips as bedding material and using an aerating system. N loss from the barns that apply aeration by blowing was lower than N loss from the two barns that apply aeration by suction. N losses in a reference barn with comparable N excretion levels varied between 1.1 and 2.7 g N per kg of milk based on emission factors from literature.
On a reference farm, gaseous N loss after application of manure to farmland contributes considerably to total gaseous N loss from the farm. Previous research showed that gaseous N loss after application of bedded pack compost is negligible. On farm level, total N loss for the bedded pack barns varied between 3.9 and 14.7 g N per kg of milk, and N loss for a free stall barn varied between 2.2 and 5.4 g N per kg of milk.

Manure quality characteristics

The mixture of (extra) bedding material and composting of this material with the manure and urine of the cows in the bedded pack has consequences for the quality of the manure produced, and the manure application strategies. The use of bedding material in the bedded pack barn increased net N input between 11 to 246% and P input between 8 to 334%, compared to a reference free stall barn without the use of any organic bedding material. The N/P ratio of bedded pack compost on all farms was lower than the N/P ratio of liquid manure. As a consequence, less N can be applied with bedded pack compost compared to liquid manure, at an equal P application rate. C/N ratio of bedded pack compost on all farms was higher than C/N ratio of liquid manure. This indicates that N from bedded pack compost mineralises at lower rate than N from liquid manure. The combination of a higher C/N ratio and lower N/P ratio of bedded pack compost relative to liquid manure means that in the short term considerably less N is available from bedded pack compost compared to liquid manure, at an equal P application rate. Bedded pack compost therefore is less suitable as an organic fertilizer for crops in the short term and more suitable for improvement of soil quality on the long term. When the higher N loss from the bedded pack barn is not compensated by additional supply of N from manure, synthetic fertilizer or biological N fixation, N available for plant uptake will also decrease in the long term, resulting in a decrease in crop yields.

Gaseous emissions

Gaseous emissions from the bedding were measured at 10 farms using a flux chamber. Total barn emission was measured at 3 farms. With a flux chamber, in total 33 measurements were done at 10 farms from 2010 till 2013 and on barn level a total of 6 measurements at three farms in 2012 and 2013. The ammonia emissions per m^2 area available for cows based on flux chamber measurements from bedding with wood chips, compost and straw are lower than from a reference system (free stall). However the higher available area per cow leads to a higher emission per cow, namely 146% compared to the reference system (=100%) when using wood chips, 227% when using compost and 189% when using straw as bedding. The flux chamber measurements showed that the nitrous oxide emissions were 8 to 16 times higher and the methane emissions were considerably lower than the reference system. The barn emissions give insight in the absolute emission levels for a barn. The emission from the barn with wood chips was 16,5 kg NH_3 per animal per year with SF_6 used as a tracer gas. Average emission from the two farms using compost as bedding material varied between 8,9 and 42,4 kg NH_3 per animal per year using CO_2 and SF_6 as a tracer gas respectively.

General conclusions

A comparison between bedded pack barns with the three types of bedding material and the free stall is given below. The higher costs for the building and the bedding material can be compensated by a higher cow longevity. In general, animal welfare is better in bedded pack barns than in free stalls due to more space, less obstacles and a surface with more grip. The concentration of XTAS spores is too high in the compost bedding, but composting of wood chips or other material is still allowed. To evaluate the bedded back barn for environmental aspects we need to look at farm level instead of barn level. The N losses in the barn (ammonia and nitrous oxide) are higher, especially when using compost, but lower when applying the manure enriched bedding material on the field. This material is a good soil improver for the long term, but for the short-term N-release is too slow. The conclusions for the prospects of a bedded pack barn with compost bedding are negative because of the high risks for milk quality and the high losses of N in the barn. The prospects for a bedded pack barn with wood chips as bedding material appear to be positive, but only when XTAS problems are solved and ammonia and nitrous oxide emissions are reduced. To evaluate the use of straw research on more farms is needed.

		Bedding material		
		Wood chips	**Compost**	**Straw**
		5 farms	*4 farms*	*1 farm*
Sustainability aspect	**Criteria**			
Economics	Investment	Attention needed	Attention needed	Attention needed
	Yearly costs	Attention needed	Attention needed	Attention needed
	Longevity	Better	Better	Better
Cow	Production, health	Better	Better	Better
	Welfare	Better	Better	Better
Milk Quality	XTAS	Attention needed	Worse	Better
Environment	N losses stable	Attention needed	Worse	Attention needed
	N losses land	Better	Better	Better
	Ammonia emission stable	Attention needed	Worse	Attention needed
	Nitrous oxide emission	Attention needed	Attention needed	Attention needed
Manure quality	Soil improver	Better	Better	Better
	N mineralisation	Attention needed	Attention needed	Attention needed

Better (green)
Attention needed (orange)
Worse (red)

1 Introduction: the sustainability aspects of a bedded pack barn

1.1 History

In 2007 a group of Dutch dairy farmers started looking for a barn in which cows can become older without problems and enables production of excellent fertilizer for the land. In that year researchers inspired the dairy farmers through experiences from Minnesota, USA, with Compost Dairy Barns. There they used a bedded pack consisting of wood chips and sawdust, but the bedding material used (sawdust) was becoming more and more expensive. Therefore, a group of Dutch dairy farmers went on a study trip to Israel in 2008, searching for a cheaper bedding. In the Israeli climate farmers succeed to keep the cows clean on a bedded pack of dried manure. That is not possible in the humid climate in the Netherlands. Therefore, at the end of 2008, experimental farms started to experiment with three principles of drying the top layer of the bedding, namely: drainage, evaporation and absorption of moisture. Moreover, limiting the emissions was also a significant challenge. The results of experiments with a draining sand bedded pack, an evaporating composting bedded pack and an absorbing bedded pack with dried dredgings and reed are described in the brochure 'Prospects for bedded pack barns for dairy cattle', published in July 2011 (Galama et al, 2011).
The first pioneering dairy farmer in the Netherlands introduced a compost bedded pack at the end of 2009. He participated in the study trip to Israel. With the perspective on improved claw health this farmer started with using green waste compost as a bedding. The second pioneering dairy farmer in that year studied the USA experiences and reflected on the idea to stimulate the composting process with wood chips and to manage it with mechanical aeration. Inspired by these examples many commercial farms started introducing bedded packs with compost or wood chips from 2010 onwards. Through trial and error a lot of experience with managing these types of bedding is gained.

1.2 Reading guide

The current performance and future potential of the bedded pack barn in the Netherlands is assessed by scientific research on many different sustainability aspects such as economic results, welfare, health, milk quality, manure quality and emissions to the environment. These aspects have been studied in some or in all of the ten farms.

Chapter 2. Farm characteristics and types of bedding
The farms not only differ in type of bedding material, but also in farm design and farm management. Characteristics of the ten dairy farms involved in the study are outlined, with focus on the different types of bedding.

Chapter 3. Economy
The economic comparison of a Bedded Pack Barn with a free stall involves the investment costs of the barn, the costs of the bedding material, the effect of manure export and the effect of improved longevity of the cows through improved animal health and welfare. Annual costs of a bedding consisting of wood chips and green waste compost are compared to a free stall barn system.

Chapter 4. Cow production, health and welfare
Animal performance, health, welfare and longevity are described in Chapter 3.

Chapter 5. Milk quality: microbial contaminants (sporeforming bacteria)
For the processing of milk it is important to know whether there are potential risks of (microbial) contaminants in the bedding materials. Moreover, especially thermophilic aerobic spore formers (TAS) may be of risk for the shelf life of certain dairy products.

Chapter 6. NPK balances, gaseous N loss and manure quality characteristics
The nitrogen- and phosphate balance and the N loss is studied by measuring the supply of N and P by the bedding material and by the cows. By comparing the total supply with the fixation in bedding material the N loss can be studied. The implications for fertilization are also studied.

Chapter 7. Gaseous emissions
In Chapter 7 it is described in which form nitrogen is lost. Moreover, it describes mainly the results of the measurements of ammonia emissions from the barn.

2 Farm characteristics and types of bedding

Ten commercial dairy farms using a bedded pack barn participated in the study. The characteristics of these farms and bedding types are described. In 2013 various measurements were carried out at these farms, in some farms more than in others, depending on the aspect to be measured. The numbering of these farms in Table 1 is used throughout the report. The numbers 1 to 5 are beddings consisting of wood chips, 6 to 9 are beddings consisting of green waste compost and 10 is a straw bedding. In the years 2010 to 2012 three of these farms (number 1, 7 and 8) have been monitored intensely and these results are described in the following reports:

A series of four research reports “On farm development of bedded pack dairy barns in The Netherlands”.

Report nr.	Title	Authors
707	Introduction and first experiences on three farms	Galama, et al (2014)
708	Animal welfare and milk quality	Ouweltjes et al (2014)
709	Nutrient balances and manure quality of bedding material	De Boer et al (2014)
710	Gaseous emissions from housing (In preparation)	Van Dooren (in prep.)

2.1 Farm characteristics

Table 1 shows per farm the used number (1-10), important farm characteristics, bedding type and bedding management. The performance of the farms in relation to animal- and environmental aspects is not only determined by the housing system and the bedding material, but also by the farm design and the farm management. There is a lot of variation between farms in the choices they made concerning their housing system and their management. At one farm the bedded pack barn is used for the older cows only. At another farm the animals have a free choice between the free stall barn and the bedded pack barn. In addition, the method of milking also differs between farms. At six of the ten farms an automatic milking system is used, whereas at the other farms the cows are milked in a traditional milking parlour. Grazing is applied at four farms. One farm is experimenting with a small group of about 15 cows in the bedded pack barn. The most important farm characteristics are summarized in Table 1. Among the ten farms there are five farms that use wood chips, four farms supply green waste compost from a composting company and one farm uses a straw bedding.

Table 1
Farm characteristics of ten farms using a bedded pack barn (status 2012).

Farm number	1	2	3	4	5	6	7	8	9	10
Bedded pack barn since	Dec '09	Oct '11	Dec '11	Oct '12	Apr '10	June '11	June '10	Aug '10	Dec '12	Oct '11
Number of cows	60	110	50	105	75	55	185	80	15	65
Breed	various	HF	HF	HF	HF	various	various	various	HF	HF/Montb.
Size pack (in m2)	960	1700	750	1500	715	1230	5000	720	300	675
M2 per cow	16	15	12.5	14	9.4	22	27	8.7	20	10.5
Bedding material	wood chips	wood chips	wood chips	wood chips	Wood chips	compost	compost	compost	compost	straw
Aeration (woodchips)	blowing	blowing	sucking	sucking	no	-	-	-	-	-
Cows	lact. + dry	lact.	older cows	lact.	lact. choice	lact.	lact. + dry	lact. + dry	lact.	lact.
Machine used for top layer	mill	spade	cultivator	spade	mill	cultivator	mill	power harrow	cultivator	cultivator
Number of times/day	1	1	1	1	1	1	1	2	1	2
Feed alley	yes	yes	yes	yes	yes	yes	no	yes	yes	yes
Milking system	2x10	2x8	AMS	AMS	2x6	AMS	AMS	AMS	AMS	2x3
Grazing	no	yes	yes	no	no	yes	no	no	no	yes

2.2 Types of Bedding

Farmers have different ways in which they try to keep the top layer of the bedding dry, they use different materials and methods. Five out of the ten farms use wood chips as bedding material. They compost the wood chips in various ways. Bottom-up aeration of the bedded pack through tubes (blowing) enables a better control of the composting process. This is practiced on two farms. Besides active aeration by blowing there are two farms that apply aeration by sucking air through the bedded pack. The idea is both to control the composting process and to reduce emissions. One farm that uses wood chips does not apply aeration. However, like on the other farms the top layer of the bedded pack is worked daily, which also results in insertion of oxygen in the bedding and mixing of the manure with the bedding material. Moisture evaporates from the bedding by the heat that is released during the composting process.
Another principle of drying the top layer is absorption of moisture by use of green waste compost or straw bedding. The top layer of these bedded packs is also worked, which is different compared to the deep litter housing using straw, which has been used for many years already and which resulted in a lot of experience with this housing system.

Advice on management of the bedded pack

The practical advices of the dairy farmers with a composting or compost bedded pack are described in Wageningen UR Livestock Research report 707 “On farm development of bedded pack barns in the Netherlands – Introduction and first experiences on three farms” (Galama, et al, 2014). However, the advices on the use of green waste compost in dairy barns are not relevant anymore for the Dutch situation, because the use of compost is prohibited by the dairy industry (1st of January 2015). The reason is that an increased concentration of spores of thermophilic bacteria may lead to decay of certain dairy products. Alternative absorbing bedding material for cows may be for example straw or reed. In this study one farm using a straw bedding was participating.

3 Economy

The bedded pack barn affects many aspects in the farm management, namely the barn design, mechanization, the daily labour, the longevity of the cattle and the soil fertilizing. In this chapter the costs of a bedded pack barn using wood chips or green waste compost are compared to a free stall barn using matrasses in the cubicles and slatted floors. The annual costs of the buildings (the barn), mechanization, installations and labour are compared. In addition, the costs of the bedding material are related to the economic value of the bedding material as soil improver. Moreover, a possible higher production per cow and an increased longevity of the cows in the bedded pack barn are taken into account. By varying some of the basic values the sensitivity of the results is also indicated. The calculations are based on standard prices per meter, m^2 or m^3 of the used materials and sizes that suit a spacious 2+2 row free stall barn and a bedded pack barn having a feed alley along one side.

3.1 Investment costs per cow

Area and bottom layer of the bedded pack space
In the bedded pack barn the cows have 15 m2 available in the bedded pack area (see Table 2). Including the alleys with concrete slats along the feeding fence and the feed alley in total over 20 m^2 per cow is available. That is more than twice as much compared to a 2-row free stall barn with in total 9.6 m^2 per cow. Table 2 shows that the investment costs of the bedded pack barn using green waste compost as bedding material are comparable to the costs of a free stall barn and also that a bedded pack barn using wood chips is € 642 per cow more expensive. This is due to the concrete floor as bottom layer under the wood chips, which is € 600 per cow more expensive than a bottom layer consisting of foil with sand for use under a compost bedding. The reason is the large difference in price per m^2, which is € 45 per m^2 for a concrete floor and € 5 per m^2 for a foil and sand layer.

Table 2
Comparison of investment costs per cow (in €) between bedded pack barn and free stall barn

		Bedded pack barn	
Reference values	Free stall barn	Wood chips	Compost
m2 per cow resting area	3	15	15
m2 per cow in total	9.6	20.4	20.4
Investment costs per cow			
Superstructure, side walls, facades	1104	2137	2137
Manure storage (barn and external)	1580	796	796
Floor/bedding (resting- and feeding area)	468	930	330
Barn facilities	515	446	446
Total building costs per cow	3667	4309	3709
Difference bedded pack related to free stall per cow		642	42

Superstructure of bedded pack barn more expensive, substructure cheaper
The bedded pack barn is primarily more expensive due to higher costs of the superstructure as a result of more m^2 per cow. Both the free stall barn and the bedded pack barn have a so called 'foil greenhouse roof' as reference value in the calculations. Costs are set at € 80 per m^2 roof. The costs of the side walls and facades are also higher due to more m^2 per cow. The costs of manure storage are lower for the bedded pack barn, since the bedding is a storage facility for manure as well.

3.2 Annual costs per cow

For calculating the annual costs, the following is taken into account: 1) building costs; 2) costs for bedding material supply; 3) value of the bedding material for manure export; 4) costs for mechanization; 5) required labour to work the pack, to add material to the bedded pack and for application of the bedding material on the land.
The total annual costs of a bedded pack barn using wood chips and compost are respectively € 125 and € 143 per cow higher compared to a free stall barn (see Table 3).

Table 3
Comparison of annual costs per cow of free stall barn and bedded pack barn

Annual costs per cow	Free stall barn	Bedded pack barn	
		Wood chips	Compost
Buildings	348	410	353
Mechanization and facilities	45	66	102
Manure application	57	19	81
Manure sale	79	0	0
Bedding supply	15	168	120
Energy costs	8	40	50
Labour	76	51	66
Total annual costs per cow	628	753	771
Difference bedded pack related to free stall per cow		125	143

Mechanization costs in particular higher for bedded pack barns using compost
For both types of bedding a tractor and a cultivator are needed to cultivate the top layer. Extra equipment is necessary for the compost bedding. Besides a cultivator, a shovel and a manure truck are needed to add compost regularly. Extra investment costs are € 45000. For the bedded pack using wood chips extra facility costs of in total € 8100 for a blower and ventilation tubes are needed.

Costs of bedding material in relation to manure value
Important reference values for the economic comparison are the amount of bedding material that is used, the price of the bedding material and the value of the bedding material enriched with cow manure. The amount of bedding material used in the free stall barn is based on cubicles provided with cow mattresses and a little sawdust. The amount of wood chips used is lower than the amount of compost in the bedded pack barn, because the heat development during the composting process stimulates extra moisture evaporation. The compost bedded pack needs regular adding of bedding material to prevent the top layer to become too wet. The bedded pack consisting of wood chips also needs regular adding of material because the volume reduces by the composting process, however, less often than when moisture absorbing compost is used. Reference values are a consumption of 8.4 ton wood chips per cow per year and 12 ton compost per cow per year. This may vary a lot between farms.

The prices of bedding material may also differ strongly between regions, but are estimated higher for wood chips. The bedding material costs are €168 per cow per year for wood chips and € 120 per cow per year for compost.
The costs of bedding material are thus higher than in a free stall barn. However, in a bedded pack barn the bedding material is transformed into a fertilizer with value as soil improver and therefore there are no additional costs for manure sale removal. In the situation of a free stall barn the reference value of manure sale as set at 6.6 m^3 manure for the price of € 12 per m^3 which equals € 79 per cow. The assumption was that the bedding material, being 'compost enriched with manure', could be exported without any additional costs.

Compost can be replaced by straw or reed
Compost is moisture absorbing. This is also true for straw or reed. The costs of bedding material will then be different, however, the basic calculation remains much the same. The mechanization costs to add the compost will then have to be replaced by for instance an (automated) straw distributor. Furthermore, when the bottom layer is replaced by concrete units instead of foil with sand the annual costs increase with € 57 per cow. The costs increase less when bricks are used, namely with € 36 per cow.

Costs of application on the land
The application costs of the bedding material (litter mixed with manure) on the land differs per type of bedding. All compost purchased from a composting factory increases also the costs for application on the land, unless it can be sold to third parties. Compared to compost less wood chips are used in total. For this reason also less material has to be applied to the land. In addition, the volume of the bedded pack consisting of wood chips decreases due to the composting process. The application costs of composted wood chips are € 62 per cow lower compared to compost due to these two effects.

Energy costs higher and labour costs lower
The energy costs of a bedded pack barn are higher due to daily working the top layer and more mechanical ventilation compared to a free stall barn. The amount of required labour in a bedded pack barn is, despite the daily workings, not higher than in a free stall barn, because cleaning the cubicles requires somewhat more labour. In addition, dairy farmers with bedded pack barns indicate that the cows require less labour because they have less health problems.. However, in the economic comparison no attention could be paid to this, since there were insufficient data. Supplying compost more often takes a bit more labour and energy compared to wood chips.

3.3 Effect of higher lifetime production

The extra annual costs of the bedded pack barn may be compensated if better animal health and welfare result in a higher yield per cow, an increased longevity and thus an increased lifetime production. If the yield per cow increases 300 kg per year with a margin of € 20 per 100 kg milk and the stock replacement rate would decrease 10% (from 30 to 20%) this results in nearly € 200 profit per cow per year (see Table 4). According to some experiences in practice it seems feasible, however, these are still indicative observations.

Table 4
Compensation of annual costs assumed by higher yield per cow and decreased replacement.

	Bedded pack barn	
	Wood chips	Compost
Difference compared to free stall barn (see Table 3)	125	143
Correction higher yield per cow (+300 kg per cow)	-60	-60
Correction decreased replacement % (-10%)	-137	-137
Corrected difference compared to free stall barn	-72	-54

3.4 Sensitivity analysis

Comparison with deep-litter free stall barn
Table 4 shows that with the reference values and assumptions for yield per cow and longevity used, the annual costs of a bedded pack consisting of wood chips would be € 72 per cow lower compared to the free stall barn with cow mattresses (no additional sawdust) and those of the compost bedded pack would be € 54 per cow lower. When a comparison with a deep litter free stall barn is made the costs

per cow increase with € 200 per cow for first class sawdust and with € 40 per cow for sand as bedding material in the cubicles. Then the bedded pack barn becomes relatively cheaper.

Space per cow

The general guideline indicates that 15 m^2 per cow is optimal. With 10 m^2 per cow and an increased use of bedding material the annual costs per cow would decrease with € 150 to € 200 per cow, depending on the costs of bedding material. However, less than 10 to 12 m^2 per cow seems very difficult to achieve as it will be much more difficult to keep the top layer dry and clean.

Increased longevity

The net surplus increases with approximately € 137 per cow per year when the stock replacement rate decreases with 10% (see Table 4). It saves costs of young stock. Approximately half of this increase is contributed to a better margin and half by decreased housing costs for young stock. Farms having a manure surplus also save on costs of manure sale, unless the manure from the bedded pack has much extra value. Therefore, we do not consider a saving of manure sale costs for the bedded pack barn. When replacement decreases with 15% (from 30% to 15%) instead of 10% (from 30% to 20%) the benefit per cow will increase from € 137 to € 226 per cow and even to almost € 300 per cow if there is also a saving on manure sale costs (see Figure 1).

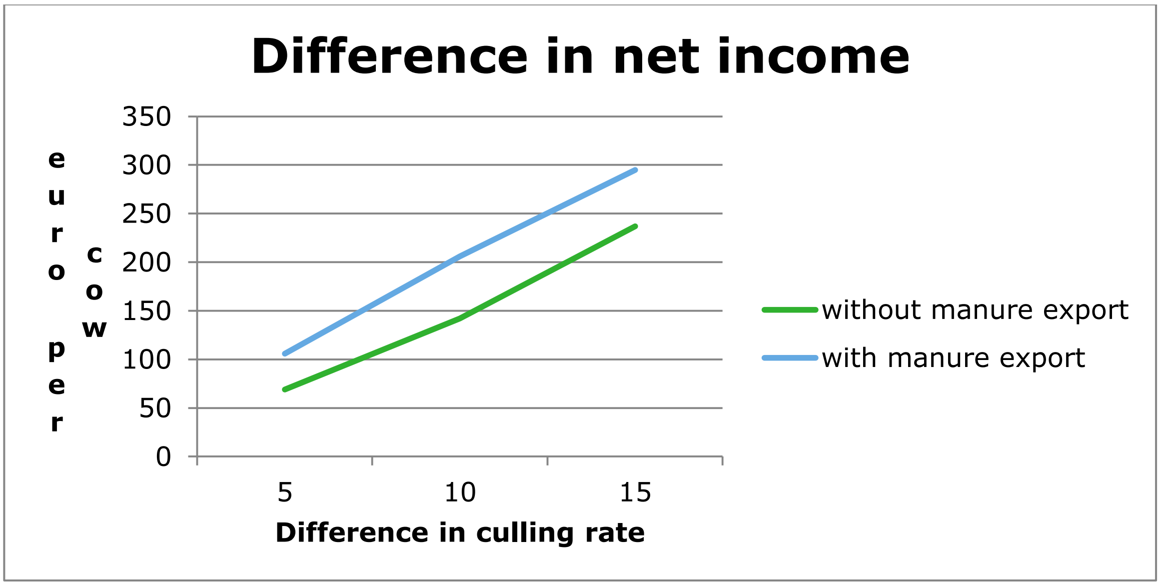

Figure 1*. Effect of a lower stock replacement rate on net surplus (in € per cow per year)*

3.5 Conclusions

Investment costs
The costs of 2+2 row free stall barn with cow mattresses having an equal superstructure as a bedded pack barn are estimated to be € 3667 per cow. Investment costs of a bedded pack barn using wood chips are € 642 per cow higher, particularly since the barn is twice as large and the bottom layer consists of concrete units. When the bottom layer is provided with foil and a sand layer, as with the bedding with compost material, the investment costs are comparable to those of a free stall barn. The superstructure of the bedded pack barn is more expensive, however, the costs for manure storage are lower.

Annual costs
The annual costs of a bedded pack barn, including building, machinery, labour and bedding material, using wood chips are € 125 per cow higher than the costs of a free stall barn and € 143 per cow higher when using compost. This difference is strongly dependent of the prices, in particular the price of the bedding material.

Effect of higher lifetime production
The extra annual costs of the bedded pack barn compared to the fee stall barn may be compensated when the yield per cow increases and the stock replacement rate decreases, in other words when the lifetime production increases. When the milk yield increases with 300 kg per cow and the stock replacement decreases with 10% (from 30% to 20%) the annual costs of the bedded pack barn are lower than those of the free stall barn, namely € 72 per cow lower using a wood chips bedded pack and € 54 per cow lower using a compost bedded pack. Based on practical experiences, this seems feasible.

Sensitivity analysis
When the bedded pack is compared to a deep litter free stall barn instead of using cow mattresses the annual costs of the free stall barn increase with € 200 per cow when sawdust is used and € 40 per cow when sand is used for littering the cubicles.
Less than 15 m^2 per cow resting area saves building costs, but extra bedding material is needed. The total costs decrease, provided that the costs of bedding material are limited. However, experiences gained in practice reveal that it is much more difficult to keep the top layer sufficiently dry when less than 15 m^2 per cow resting area is provided.
The benefit of an increased longevity may rise up to € 300 per cow when the stock replacement rate decreases 15% and there is a saving in manure sale costs of € 12 per m^3 liquid manure.

4 Cow production, health and welfare

4.1 Introduction

Currently the majority of Dutch dairy cows is housed in cubicle barns. Many studies have shown that cubicle barns, although they provide the animals freedom to move which is an important improvement compared to tie stalls, also have considerable disadvantages with regard to animal health and welfare (Ouweltjes et al., 2003), (Klaas et al., 2010). Some of the bottlenecks encountered with regard to animal welfare in cubicle barns can probably be solved by providing more space, softer flooring and improved lying comfort, but restrictions for the animals to lie down and get up are inherent to the concept of cubicle barns. Different sizes of cows within the same herd also limit the possibilities to adjust the cubicles in an optimal way for all animals. A type of housing that does not have these lying restrictions is the straw yard system, which in fact is the oldest kind of housing for farm animals. However, this type of housing is not considered as a suitable alternative for dairy cows because of high risks of mastitis (Leso et al., 2013) and large amounts of straw used (Ouweltjes et al., 2003). Bedded pack barns, where the bedding is cultivated daily to reduce the amount of bedding material required, have similar potential advantages for lying comfort. This type of housing has begun to develop recently in North America (Barberg et al., 2007), and now is also introduced in several European countries (Galama et al., 2011; Klaas and Bjerg, 2011; Leso et al., 2013). Practical experience in Italy (Leso et al., 2013) has shown that udder health improved compared to straw yards. One of the key motivations for farmers to build a bedded pack barn is to improve the housing conditions for their cows (Galama and Driehuis, 2011). (Black et al., 2013) also mention improvement of cow comfort and increase of longevity as important motivations for the development of compost bedded pack barns and farmers interest in these barns. However, many practical aspects of this type of housing are currently still not clear (Klaas and Bjerg, 2011). In this chapter we outline the current experiences on Dutch dairy farms regarding health and welfare.

4.2 Method

The data used in this overview of animal performance at bedded pack barns was obtained from several sources. Most of this data describes the situation on the ten farms in 2013, but for animal welfare the main inferences were obtained from observations carried out earlier as is described below. Where possible the figures of these farms were compared with national averages or other benchmarks. Figures on general herd characteristics, milk production and fertility were obtained from CRV, the organisation processing milk recording data and other animal related information. From the same organisation we also obtained information on culling and replacement. Information on health and management was provided by the participating farmers, bulk milk somatic cell counts were obtained from milk delivery overviews of the milk processing companies. Figures on antibiotics were obtained from the Dutch recording agency where famers are obliged to record their antibiotics usage. Welfare assessments according to the Welfare Quality® protocol were carried out on three farms (1, 7 and 8) in 2011 and again in 2012 by the same experienced observer from whom we also had assessment results from a number of farms with cubicle barns. This was part of an earlier bedded pack monitoring project. In addition, on nine of the ten farms that were monitored in 2013 welfare assessments were performed by a trained student. As a benchmark for these observations, we received information from assessments on cubicle farms done by the person who trained the student. Moreover, we have done additional observations on farm 1 to investigate if cows in a composting barn are more likely to experience heat stress due to heat production in the bedding layer. For this we assessed barn climate, bedding temperatures, skin temperatures, breathing frequencies and lying behaviour. The results are integrated and discussed below.

4.3 Results

4.3.1 General farms characteristics

Dairy farming is an economic activity, farmers try to make a living from the products that the cows produce. Therefore, the animals not only should have good health and welfare, but also have a good production and fertility. Benefits of improved health and welfare for the farmer are achieved through improved performance (production and fertility), increased longevity of the animals, less labour and treatment costs for treatments and more working pleasure. Similar to the majority of other Dutch dairy farmers (CRV, 2014), most of the ten farms included in this study are enrolled in the milk recording program and also have other performance figures (e.g. culling and fertility) calculated by CRV. Figures derived from annual statistics of the farms and national averages are presented in Table 5.

Table 5
Rolling farm averages obtained from national milk recording statistics for 2013[1]

Farm	#cows	Age at calving*	Kg milk	% fat	% protein	calving interval**
1	60	4.11	9166	4.05	3.36	414
2	122	4.04	8204	4.42	3.53	406
3	164	4.07	9405	4.51	3.60	414
4	108	4.02	9727	4.24	3.47	415
5	69	3.10	9189	4.21	3.65	388
7	186	4.10	7255	4.48	3.57	384
8	95	5.00	8726	4.45	3.53	447
10	65	5.03	8259	4.50	3.49	406
Average	109	4.07	8741	4.36	3.53	409
Netherlands	82	4.07	8335	4.38	3.54	418

*age in year.months
**calving interval in days

The figures in Table 5 refer to the period between September 1, 2012 and August 31, 2013. For herd 3 it must be mentioned that only part of the animals (about 33%, a selective group of older cows) were housed in a bedded pack barn, the other animals of that farm were housed in a conventional cubicle barn. For each farm only one set of figures was calculated based on all animals. For farm 4 and farm 9 the cows were introduced in the new bedded pack barn during the recording year. Thus, the figures in Table 5 may not exactly represent the performance of the animals in the bedded pack barns. Some of the farmers indicated that the bedded pack barn had made it easier for them to manage their herd and keep the animals in good health. Therefore their expectation is that it is feasible to increase longevity.

[1] Source: CRV

4.3.2 Mastitis incidence

For all bedded pack farms the number of cases of clinical mastitis during the last 12 months was requested from the farmers. From the information obtained we calculated percentages per farm. For comparison we used a figure derived from a national health monitoring program from the Dutch Animal Health Service. Because the majority of cows in the Netherlands are housed in cubicle barns this figure is thought to represent cubicle barns. We have no inferences for further refinement, e.g. to make a distinction between zero grazing farms and farms that apply grazing. The percentages are presented in Figure 2.

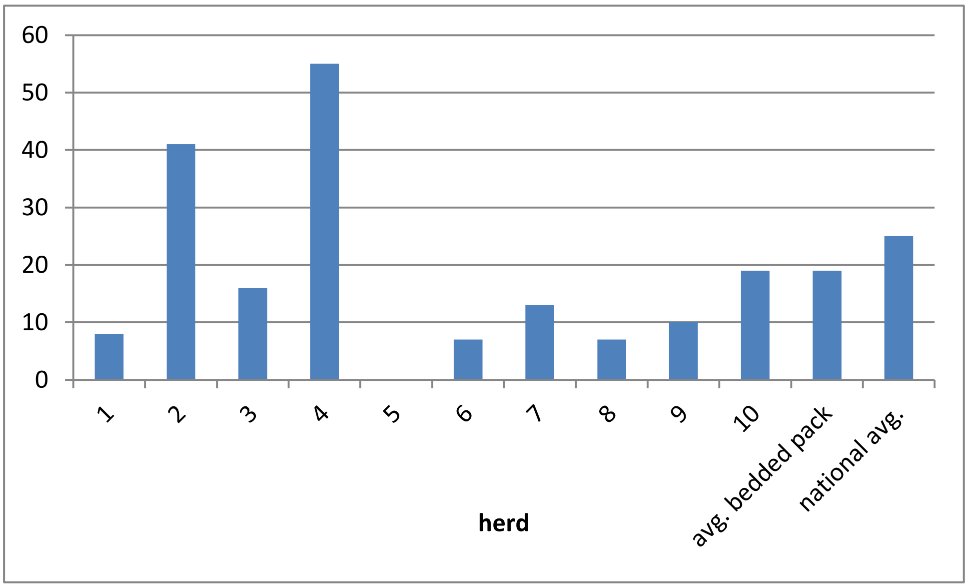

***Figure 2**. Percentage mastitis per farm per year*

For farm 5 we obtained no figure, because the farmer did not record cases systematically but only wrote notes on the cow calendar about treated cows. These notes were not archived. The other farms showed a wide range of mastitis incidence, from 7% (farms 6 and 8) up to 55% (farm 4). Farm 2 and 4 had much higher incidence than the other farms, but for both farms the incidence was already high before the cows were kept in the bedded pack barn. The farmer of farm 4 also started with automatic milking in the new barn, but he did not observe clear changes in the udder health of his herd. The farmer of farm 2 had the impression that udder health was related to the status of the bedding material, but this could not be investigated further because of lack of data. For both farms, but also for farms 6 and 8, selective dry cow therapy was used at the end of lactation. Despite the two farms with high incidence and the restrictive use of dry cow antibiotics (see below), the average mastitis percentage was below the national average of 25% and most farms had less than 20% mastitis incidence.

4.3.3 Antibiotics usage

Since 2012 all Dutch dairy farms have to record the amount and kind of antibiotics used for their animals in a national database. Moreover, there are restrictions regarding the amount of antibiotics they keep in stock, and together with their veterinarian they have to make prevention- and treatment plans. A similar approach is followed for the poultry and pig sectors. This to achieve a reduction in the antibiotics usage in the livestock industry, particularly of antibiotics that are of critical importance for public health (fluoroquinolones and the 3rd and 4th generation cephalosporins). The data recorded are used to determine benchmarks and farmers who use more than a certain threshold have to make an action plan to achieve a reduction. For all farms the average usage in Animal Defined Daily Dosages (ADDD/Y's) per farm per year is calculated every 3 months for monitoring purposes. The values for the bedded pack farms and the national average in the fall of 2013 are presented in Figure 3.

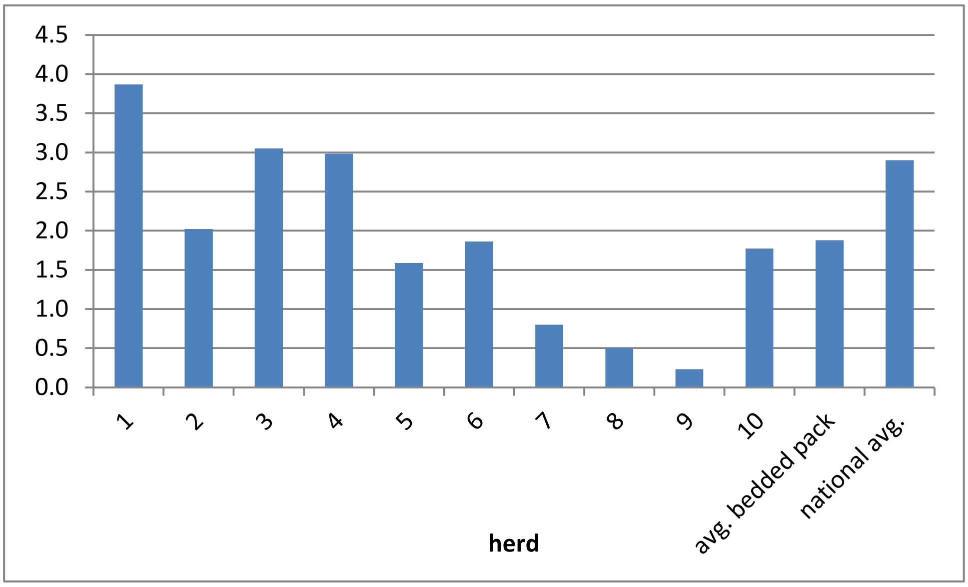

Figure 3. *Animal Defined Daily Dosage of antibiotics per year*

The authority responsible for monitoring antibiotics in the Dutch livestock sector has determined a target figure of 3 ADDD/Y or less for dairy farms in 2013, which was slightly above the average use (Autoriteit Diergeneesmiddelen, 2013). Only farm 1 had a higher usage, and the bedded pack farms on average had low antibiotics usage. Farms with a usage of 6 ADDD/Y or more had to immediately take action to achieve a future reduction, but none of the bedded pack farms came close to this figure. Thus, none of the bedded pack farmers was urged to change their health management to reduce the usage of antibiotics. The main reason for application of antibiotics on Dutch dairy farms is dry cow therapy, according to the figures in the database (67%). The low usage for farm 9 was partly caused by the fact that the farmer had a policy to buy cows in milk, and cull them when the somatic cell count increased too much without starting a treatment. Moreover, for none of the cows in this herd dry cow therapies were applied. Also in farms 5 and 7 no dry cow therapies were applied: in farm 5 the animals were milked continuously and in farm 7 the cows are not milked for 3 weeks, which is too short for application of dry cow therapy. Only three of the bedded pack farms (1, 3 and 10) applied standard dry cow therapies with antibiotics. The variation in Figure 3 indicates that usage for other purposes also could vary.

4.3.4 Bulk milk somatic cell counts

Dutch milk processors determine somatic cell counts (SCC) at least every 2 weeks in samples from bulk milk collected. Penalties are applied if the value exceeds 400.000 cells/ml. All farmers provided overviews of the figures determined by their dairy company, these are given in Figure 4.

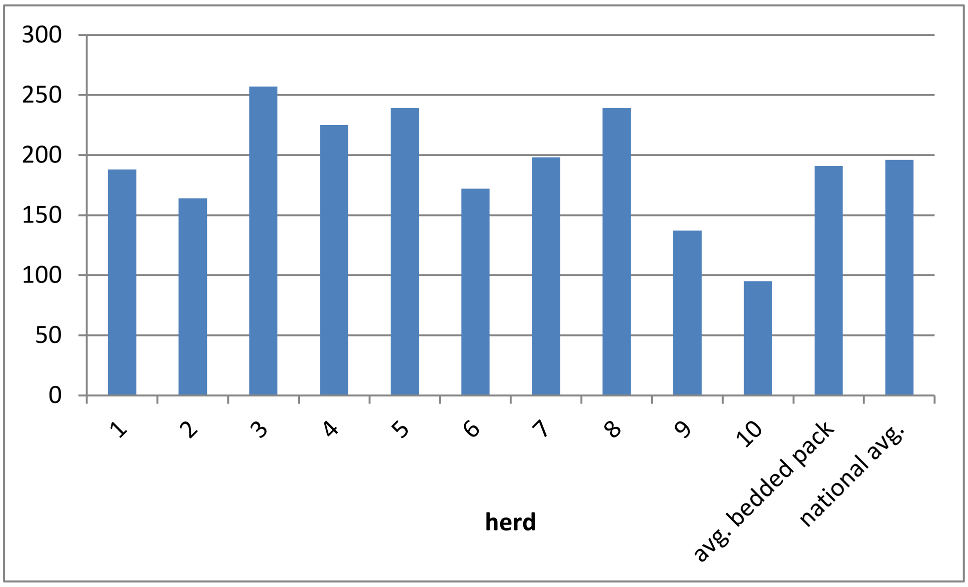

Figure 4. *Average bulk milk somatic cell count (*1000 cells/ml) in 2013*

The average bulk milk SCC's of the bedded pack farms was close to the national average, but there was considerable variation between farms. Farm 2 had a relatively low bulk milk SCC, despite the high incidence of mastitis. According to the farmer this was in line with the situation in the old barn for that farm. The other farmers also stated that bulk milk SCC was not changed since their cows were housed in the bedded pack barns. This despite the tendency to become more restrictive with the application of dry cow therapies.

4.3.5 Welfare assessments

The exact definition of animal welfare is hard to give, but in general there is agreement among animal welfare experts regarding the needs of animals to achieve good welfare. In the Welfare Quality® approach four principles and twelve underlying criteria (Table 6) are distinguished that should be fulfilled for good welfare (WelfareQuality®, 2009).

Table 6
Welfare Quality® principles and criteria for welfare assessments

Welfare principle	Welfare Criteria	
Good feeding	1	Absence of prolonged hunger
	2	Absence of prolonged thirst
Good housing	3	Comfort around resting
	4	Thermal comfort
	5	Ease of movement
Good health	6	Absence of injuries
	7	Absence of disease
	8	Absence of pain induced by management procedures
Appropriate behaviour	9	Expression of social behaviours
	10	Expression of other behaviours
	11	Good human-animal relationship
	12	Positive emotional state

The second principle already makes clear that housing conditions are important for fulfilment of the welfare criteria. However, also the first principle is partly determined by the barn environment: good feeding not only requires a sufficient quantity of feed of the right composition being fed, but also the opportunity for the animals to eat, which means a sufficient number of places at the feeding rack. Similarly, to prevent thirst there should be a sufficient amount of accessible drinkers providing good drinking water. On the other hand, lying comfort is also determined by the maintenance of the bedding and not only by the space provided. Also stocking density is an important parameter in cubicle barns. These considerations illustrate the complexity of relationships between housing and welfare measures as distinguished in the Welfare Quality® assessment protocols. Here we present results for a selection of the parameters that are assessed for which there is a close link with housing, mainly based on welfare assessments with the Welfare Quality® protocols carried out twice for three of the farms (1, 7 and 8) by an experienced assessor who also had carried out assessments for a number of herds kept in cubicle barns. These assessments were done in 2011 and 2012 for a preceding monitoring project. Additionally, inferences obtained from these observations are compared with the results from the assessments of the student in 2013 for these parameters.

Housing

For some measures clear differences were observed between the bedded pack farms and the cubicle farms. These measures were "time needed to lie down", "collisions with housing equipment during lying down" and "integument alterations". Figures for time needed to lie down are presented in Figure 5.

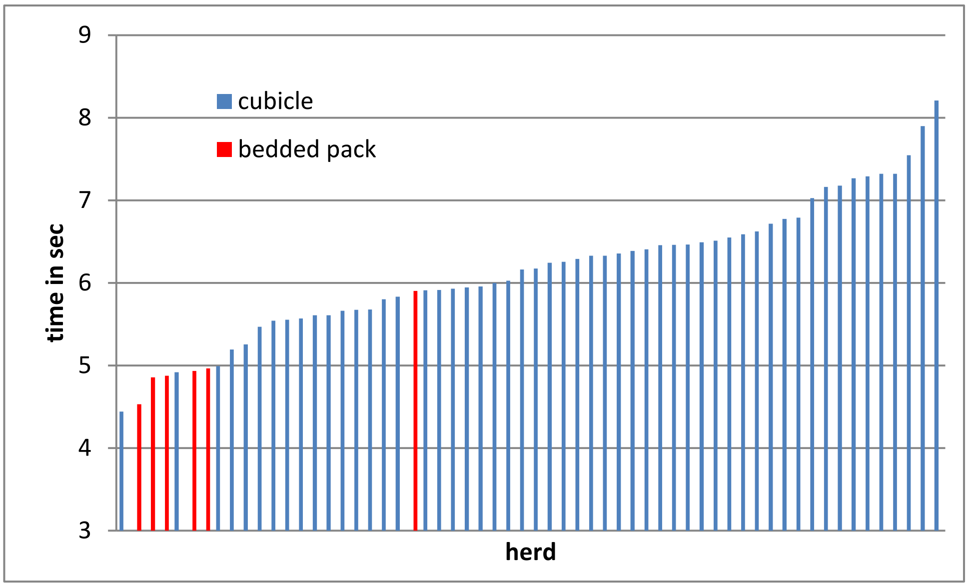

Figure 5*. Farm averages for time needed to lie down*

Although a few averages from cubicle barns were similar to the values for the bedded pack barns, the majority of the observations showed that lying down was quicker in the bedded pack barns. One observation in a bedded pack barn showed prolonged time to lie down. This was probably due to a poor supporting capacity of the bedding material at the time of observation, that made it more difficult for the animals to lie down. It is noteworthy to mention that the variation between cubicle barns was large, this is probably related to both the dimensions of the cubicles and the bedding material. Shorter times to lie down for the bedded pack barns compared to cubicle barns were confirmed by observations of the student in 9 of the 10 farms in 2013. Variation between the different bedded pack farms for those observations was small compared to the variation between cubicle barns that were assessed by the trainer of this observer, the average lying down times for bedded pack farms varied between 2.7 and 4.4 seconds.
Another parameter that is linked to comfort around resting is cleanliness of several body regions: udder, hind quarter and lower hind legs were scored according to the Welfare Quality® assessment protocols. The observations of the experienced observer showed no clear differences for farms 1, 7 and 8 with scores obtained for cows in cubicle barns. However, cleanliness of the animals in the bedded pack barns varied considerably for the same herd between the two observations. The farmers had experienced that cleanliness was linked with the condition of the bedding material. If the bedding material got more wet or the supporting capacity was reduced the animals would become dirtier. This could also explain why the observations of the student in 2013, carried out at the end of the indoor season, resulted in higher scores for cleanliness, i.e. dirtier animals when compared with cubicle barns.

Three distinct categories of integument alterations were scored: hairless patches, lesions and swellings. Moreover, five different body areas were taken into account: hock, hindquarter, neck/shoulder/back, carpus and flank/side/udder (WelfareQuality®, 2009). The number of alterations was counted for each area for the assessments by the experienced observer, total scores were calculated from these observations for each farm per observation (Figure 6).

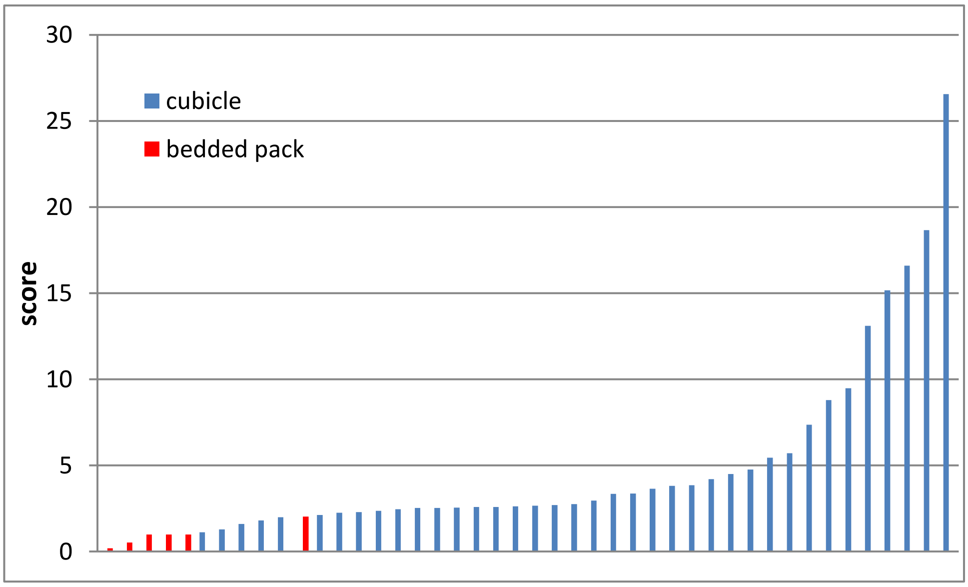

Figure 6. *Farm average total score for integument alterations*

The scores in Figure 6 clearly show that the animals in the bedded pack barns had few lesions on their skin. The highest score for bedded pack barns was obtained in a barn where a number of cows had a swelling in their neck due to a low feeding rack. The feeding rack was improved before the second assessment on that farm took place, therefore the second assessment had a lower average score. Some of the herds observed in cubicle barns for which scores are presented in Figure 6 consisted of horned cattle. Particularly for these herds the number of alterations was relatively high in the areas hindquarter, neck/shoulder/back and flank/side/udder. The additional assessments on nine bedded pack farms confirmed that there were relatively more cows without integument alterations in these herds compared to herds in cubicle barns. According to the farmers part of the alterations, e.g. hairless patches, had developed already in the old barns. In line with this, the highest proportion of cows with alterations in the students observations was found in the newest bedded pack barn which was in use for about 6 months at the time of observation. In the old barn these cows were overstocked. It is likely that both the absence of construction material in the lying area and the large floor surface per animal have contributed to the low scores.

Thermal comfort

Thermal comfort is one of the criteria mentioned in Welfare Quality®, but currently no measures are applied for it in the dairy cattle welfare assessment protocol. Despite this, thermal discomfort could occur particularly in composting barns. During the composting process the temperature in the bedding layer can raise to about 55 °C, and this could affect the heat exchange of the animals and cause heat stress. To investigate the impact of heat production in the bedding material, we measured bedding temperatures, air temperatures and air humidity (both in the barn and outside) and lying- and standing behaviour (with IceTag® sensors) in farm 1. Air temperature and humidity inside the barn were closely linked to outside temperature and humidity, so apparently the heat produced in the bedding layer did not accumulate in the barn. The cows in this herd had similar lying behaviour (lying times and bout lengths) compared to cows in cubicle barns. We investigated the relationship between a temperature humidity index (THI) calculated according to the formula of Ravagnolo et al.(2000) from air temperature and humidity in the barn and percentage of time standing, activity (steps/hour) and lying bout length obtained with the IceTags. Barn air temperatures ranged between 14 °C and 23

°C, relative humidity's between 70 and 100%. THI-values calculated varied between 55 and 71, and we found no evidence for heat stress in this range of THI-values. This suggested that the heat production in the bedding did not lower the temperature threshold for heat stress. We also recorded respiration rates of cows during lying bouts with the procedure described by Schütz et al. (2010). Increasing breathing frequency is one of the pathways to increase heat loss, and therefore is an indicator for heat stress. Average values ranged from 32.3 to 41.6 breaths per minute, these are low values compared to those reported by Berman (2005) and Schütz et al. (2010) and probably do not indicate heat stress (Brown-Brandl et al., 2006). To further investigate the impact of heat production in the bedding for the occurrence of heat stress we have also monitored skin temperatures during a number of lying and standing bouts for 5 cows in the composting bedded pack, 2 cows in a cubicle barn with matrasses as bedding and 2 cows in a straw yard without increased bedding temperatures. Two Ibutton® temperature sensors were attached to the skin on the left and right flanks in front of the udder, in such a way that normally only one of the sensors touched the bedding when the animal lays down in a normal lying position (Figure 7). Temperatures were logged every 5 minutes. Placement of the sensors was tested in a pilot experiment. Temperatures in the bedding were measured at 15 and 40 cm depth at the start of the data collection, and averaged 41.2 and 44.6 °C respectively.

Figure 7. *Placement of Ibutton® temperature sensor*

Together we obtained data for 432 lying bouts and the standing episodes in between these. The data showed a clear difference between lying and standing bouts: skin temperatures during standing were 32 – 33 °C, but increased gradually during lying bouts to 39 °C for the sensor that was in contact with the bedding. These temperatures were reached after 60 – 90 minutes of lying down. Temperature increases were very similar for the different kinds of bedding material, but on average were even larger for the straw yard and the matrasses. The sensors on the opposite side did not record temperature increases, and this enabled us to determine how often it occurred that cows stood up and got down again on the other side within 10 minutes. Contrary to our expectations this did occur more regularly for the cows in the cubicle barn and the straw yard (in 41% of the lying bouts) than for the cows in the bedded pack barn (21% of the lying bouts). Bout lengths were highly variable, but did not clearly differ between the bedded pack and the other barns. Skin temperatures went down to the normal level for standing cows within 5 minutes after getting up. From these results we conclude that the cows in this composting barn did not show any evidence for heat stress, the heat production in the bedding material did not make them more vulnerable for heat stress.

Lameness

Lameness scoring is also included in the Welfare Quality® protocol, with distinction between sound, moderately and severely lame. It was mentioned by the experienced observer that it is difficult to compare the scores for cows in cubicle barns and bedded pack barns. This is because the cows were scored where they were observed, and in the bedded pack barns at least part of the cows were scored in the bedding area. The place of observation substantially affected their gate: if the alleys were slippery also non-lame animals walked with short strides to avoid slipping, in the bedding animals sometimes had difficulty walking because the material was very soft and loose. Therefore a considerable percentage of the animals was scored as moderately lame by the experienced observer because their gate was imperfect: 13% for the bedded pack barns and 15% for the cubicle barns. However, the percentage of cows with good locomotion was higher in the bedded pack barns (83%)

than in the cubicle barns (76%), and the prevalence of severe lameness was higher for the cubicle barns (9% vs. 4%).

4.3.6 Culling and replacement

The Dutch farmers association has formulated the ambition to increase the average life span of dairy cows with 2 years (LTO Nederland, 2011). It is assumed that improved housing can contribute to realise this, the current situation with regard to culling and replacement for the bedded pack farms is reported below.
For the nine farms that participated in the milk recording program figures about culling and replacement were obtained from the data processing centre CRV. Replacement in this context means introduction of new animals in a herd, whether or not they replace animals that are culled. The overviews calculated provided figures for the last 12 months preceding the latest test day at the time of collection. Because the overviews were generated in December 2013 the figures are assumed to represent the situation in 2013. Moreover, national averages were given as reference values. A summary is presented in Figure 8.

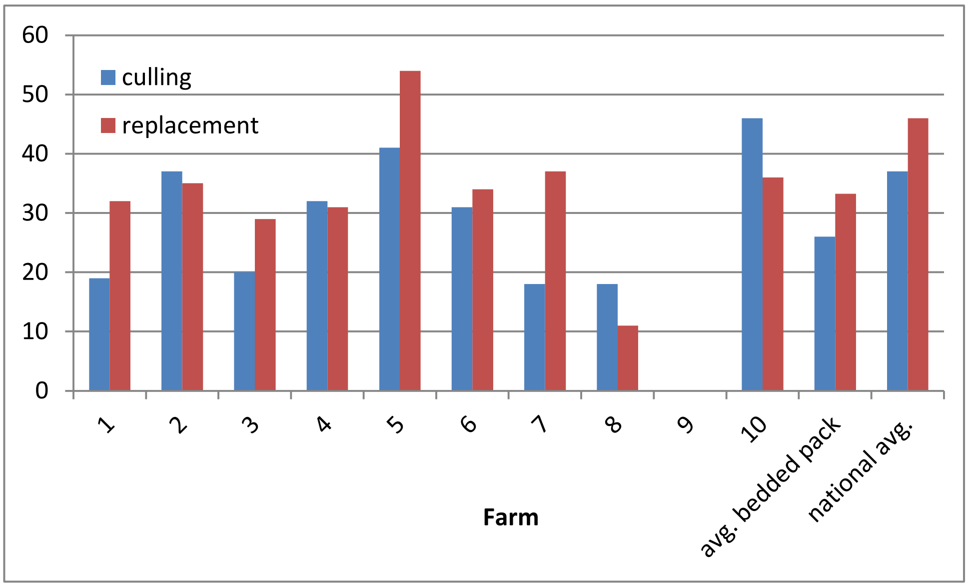

***Figure 8**. Percentages of culling and replacement per farm in 2013*

Figure 8 shows that the majority of the bedded pack farms had below average culling and replacement rates. Particularly farms 1, 3, 7 and 8 had low culling figures, and apart from farm 3 these were the farms with longest experience with a bedded pack barn. High culling percentages for farms 2, 5 and 10 were not due to poor longevity of the cows: their milk quota could be produced with less cows and some animals were sold for life (farms 2 and 10) or the farmer decided to buy young cows for foreseen expansion and culled some cows with good body condition for slaughter (farm 5). On average more animals were replaced than culled, which indicates that herd size tended to increase. In this regard the bedded pack farms were comparable to the national average, but the figures for culling and replacement probably have not stabilized and may not truly reflect the impact of the new barn on longevity. Most of the farmers expected that a culling rate of less than 20% will be feasible. In 2013 fertility was the most frequently indicated reason for culling (28%), and udder health was the second (20%). This was more or less in line with the national figures. Feet and leg problems were mentioned as the main reason for 6% of the animals culled, which was a low figure compared with the national figures.

4.4 Discussion

4.4.1 Farms

The herd size of the farms monitored for this study was above the national average, but also showed a considerable range. Despite the goal of the farmers to increase longevity of their cows and below average realised culling and replacement rates, the age at calving was equal to the national average. It must be realised that most of the farms had introduced the cows in the bedded pack barn recently, and potential benefits for health and longevity probably take more time to become apparent. Milk production was above the national average, but again the range was considerable. Farm 7 had lowest milk production, but also had the shortest calving intervals. The lower production of that farm is at least partly due to the dual purpose type of crossbred animals (with main contributions of Holstein and Montbeliarde breeds). Average calving intervals were somewhat below the national average. Five farmers (farms 2, 3, 4, 5 and 7) have indicated to apply a kind of fertility management support, it is not known how frequently this is applied on farms with cubicle barns. Farm 8 had long average calving intervals because there were some cows with extremely long intervals but good persistency in milk yield included. The farmer considered this to be an incident, these animals are culled by now.

4.4.2 Udder health

Our observations showed that udder health was not substantially different for the cows in bedded pack barns despite a low usage of antibiotics. Some of the farmers still applied standard dry cow therapy, but they will have to change their policy in the near future because only selective application of antibiotics is currently still allowed in the Netherlands. Those farmers are challenged to improve preventive management, because selective dry cow therapy provides less protection against new intramammary infections (Halasa et al., 2009b), although if applied properly the cure of existing infections remains effective (Halasa et al., 2009a). The results for the other bedded pack farms show that it is feasible to combine selective dry cow therapy for cows in a bedded pack barn with good overall udder health.

4.4.3 Cow behaviour

It was observed that in cubicle barns cows regularly attempted to lie down, but did not succeed. This was not observed in bedded pack barns. Such attempts are not accounted for in the average time to lie down, so these figures probably underestimate the benefits of lying areas without space limitations. Moreover, in cubicles about 33% of the lying down movements coincided with collisions with housing equipment and this was not observed in the bedded pack barns. Because of the large surface area per animal there were no restrictions with regard to the availability of lying space in the bedded packs. Measurements with IceTag® sensors on one farm (1) showed average lying bout lengths of 65 minutes, comparable with values we obtained for cows in cubicle barns. Moreover, these measurements indicated that the cows spent 55% of time standing, also similar to what we measured in a cubicle barn. This suggest that lying behaviour is not altered, but it should be mentioned that these measurements were carried out in a barn with a composting bedding. The heat production in the bedding could affect lying behaviour, for instance because of increased sensitivity for heat stress. However, our observations for respiration rates and skin temperatures show that this is unlikely. The study of Eckelkamp et al (2014) with similar equipment as we used to measure lying behaviour revealed that lying time increased after cows transitioned into a compost barn from a cubicle barn with pasture access. Fregonesi et al (2009) showed that the bedded pack area was also used for standing, and could reduce the time standing on concrete. Together, these observations indicate that lying comfort is at a high level in bedded pack barns although lying behaviour may be similar.

4.4.4 Claw health

Several bedded pack farmers reported that it was their experience that claw health had improved considerably since the cows were housed in the new barn, while in the mean time they had reduced the frequency of preventive trimming to once per year. This agrees with results reported by Lobeck et al (2011). Moreover, the farmers hardly culled cows due to claw and leg problems. For farm 3, where part of the animals were kept in a cubicle barn, cows were routinely trimmed every 7 months. Other herds were routinely trimmed once a year as a herd (farms 6, 7 and 8) or individually (farms 4 and 10), the rest of the farms only applied curative trimming. Herd trimming was done by professional claw trimmers, individual trimming by the farmers themselves. None of the farmers applied routine trimming of young stock. Only one farm (5) used footbaths to maintain claw health of the cows in the bedded pack barn (once every 2 weeks), and on farm 4 the hind feet of the cows were incidentally sprayed with a copper sulphate solution. In combination, the observations and experiences indicate that claw health probably improved in the bedded pack barns and was easier to manage, but probably due to effects of soft and loose bedding on locomotion this was not fully expressed in gait scores.

4.4.5 Management

Our observations in general revealed positive effects of bedded pack barns on cow health and welfare, which is in agreement with the impressions of the farmers. The biggest challenge is management of the bedding area in order to keep it clean, dry and comfortable. Whistance et al (2007) showed that cows in straw yards had a stronger tendency to avoid contact with manure than cows in a cubicle barn, but Lobeck et al (2011) reported that cows in bedded pack barns were dirtier than cows in cubicle barns. Our observations indicated that cleanliness was related to the bedding condition. Bedding management is important not only to provide a comfortable lying area, but also to maintain good udder health (Black et al., 2014). Particularly with regard to culling and replacement, and to a lesser extent regarding claw health, it probably takes more time to fully benefit from the positive effects of the improved conditions for the animals. Our results were in line with experiences reported by Leso et al (2013), despite that the motivations of the Italian farmers to build bedded pack barns were different and the way the bedding was managed also differed substantially. Also Barberg et al (2007) reported that famers were satisfied with their decision to build a compost barn and had realised their objectives. When comparing figures from before and after transitioning to a new barn, it should be taken into account that the situation before the transition usually is not optimal and this situation should not be regarded as representative for cubicle barns. Improvements in lying comfort probably could also have been realised in new and spacious cubicle barns with good bedding, but obstacles that restrict the animals and can cause lesions are inevitable in such barns. Moreover, as was the case in our study, changes in herd management, e.g. regarding trimming, the usage of footbaths and application of dry cow therapies, can coincide with the introduction of new housing. According to the farmers, care for claw health was considerably easier since cows were housed in the bedded pack barn. Differences between claw health before and after the change of housing do not express such effects, but these are very relevant for dairy farmers.

4.5 Conclusions

- The herds in the bedded pack barns on average had a lower mastitis incidence than herds kept in cubicle barns, but udder health remained similar after introduction of the animals in the new barns.

- Application of selective dry cow therapy is possible for cows in bedded pack barns while maintaining good udder health and bulk milk somatic cell counts.

- Well managed bedded pack lying areas provide good lying comfort. Heat production in composting bedding does not increase the occurrence of heat stress.

- Management of the bedding is the biggest challenge to keep the animals clean, care for the animals is easier in bedded pack barns compared to cubicle barns.

- Changes in housing often coincide with changes in management procedures, e.g. regarding the application of footbaths and trimming regimes. Therefore, when judging the impact of new housing on the animals management should also be taken into account. The evaluation should not solely be based on changes in e.g. incidences of claw disorders.

- Cows in bedded pack barns have low incidence of integument lesions compared to cows in cubicle barns.

- It is expected that claw health improves in bedded pack barns, but locomotion scores of cows in bedded pack areas are not easily comparable with those for cows scored on alley floors. Moreover, improvement of claw health after introducing the cows in new housing will take time. More time and data are needed to draw more definite conclusions regarding the impact of bedded pack barns on claw health.

- Similarly, it is expected that bedded pack barns will contribute to increased longevity, but the data currently available are insufficient to obtain reliable estimates of their effect on longevity. This is both caused by the limited time span the herds monitored for this study are housed in their new barns and the fact that culling has multiple causes, particularly while there still is a quotation on milk production.

5 Milk quality: microbial contaminants (sporeforming bacteria)

5.1 Routes of contamination

5.1.1 General

Barns contain different sources of bacteria that can contaminate the milk. The most important are manure, feed and bedding material. It is unavoidable that bacteria from these sources are also present on the cow skin, including the skin of the udder and teats. It is also inevitable that during milking a small fraction of these bacteria present on the teats end up in the milk. This route of microbial contamination is shown in Figure 9. Obviously, a good hygiene of the milking process is important to limit this way of milk contamination, but a 100% prevention is not possible in practice. Therefore, bacteria present in the bedding material will also occur in raw milk in low concentrations. The degree of milk contamination that occurs in this way is, on one hand, depending on the hygiene level during milking and, on the other hand, the concentration of bacteria in the bedding material.

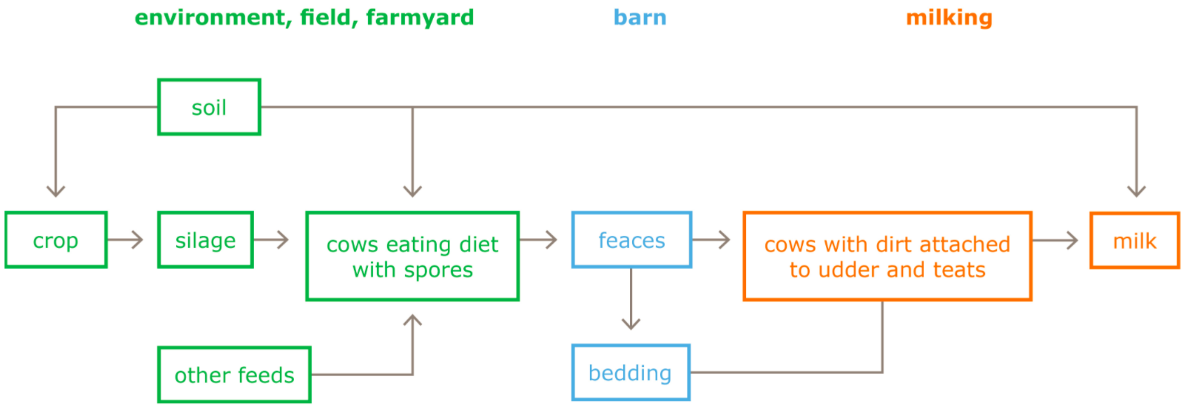

Figure 9. *Sources and routes of contamination of milk with bacteria and bacterial spores at the farm*

5.1.2 Sporeforming bacteria

The vast majority of bacteria that in this way end up in the milk during milking is not important for the quality of the dairy products. Those bacteria are killed by the pasteurisation of milk that is applied by the Dutch dairy companies in the processing of all milk. An exception to this are sporeforming bacteria. These bacteria have the ability to form spores under adverse conditions. Spores are resistant to extreme conditions, such as high temperature , and can survive very long. When circumstances become more favourable spores will germinate and then the bacteria can start growing again. An example in the dairy chain are the butyric acid bacteria. Spores of butyric acid bacteria coming from poor quality silage can cause quality problems in cheese. There are many types of sporeforming bacteria. In compost, amongst others, thermophilic aerobic sporeformers (TAS) occur. These bacteria contribute to the breakdown of organic compounds during the composting process. Spores of certain types of this group are extremely high heat resistant. These bacterial species are known as XTAS. In any case, the concentrations of TAS- and XTAS spores in raw milk are much lower than the concentration of bacteria determined in the quality testing of the farm tank milk.

Route of contamination (X)TAS
A too high concentration of TAS spores, and XTAS spores in particular, may lead to spoilage problems of certain sterilized dairy products. (X)TAS is transmitted via compost. For that reason the use of compost and other composted bedding materials in dairy cattle barns is a risk factor for milk quality. Composting 'clean' wood chips in the barn can also be a risk factor due to the heat development during the composting process (see Figure 10).

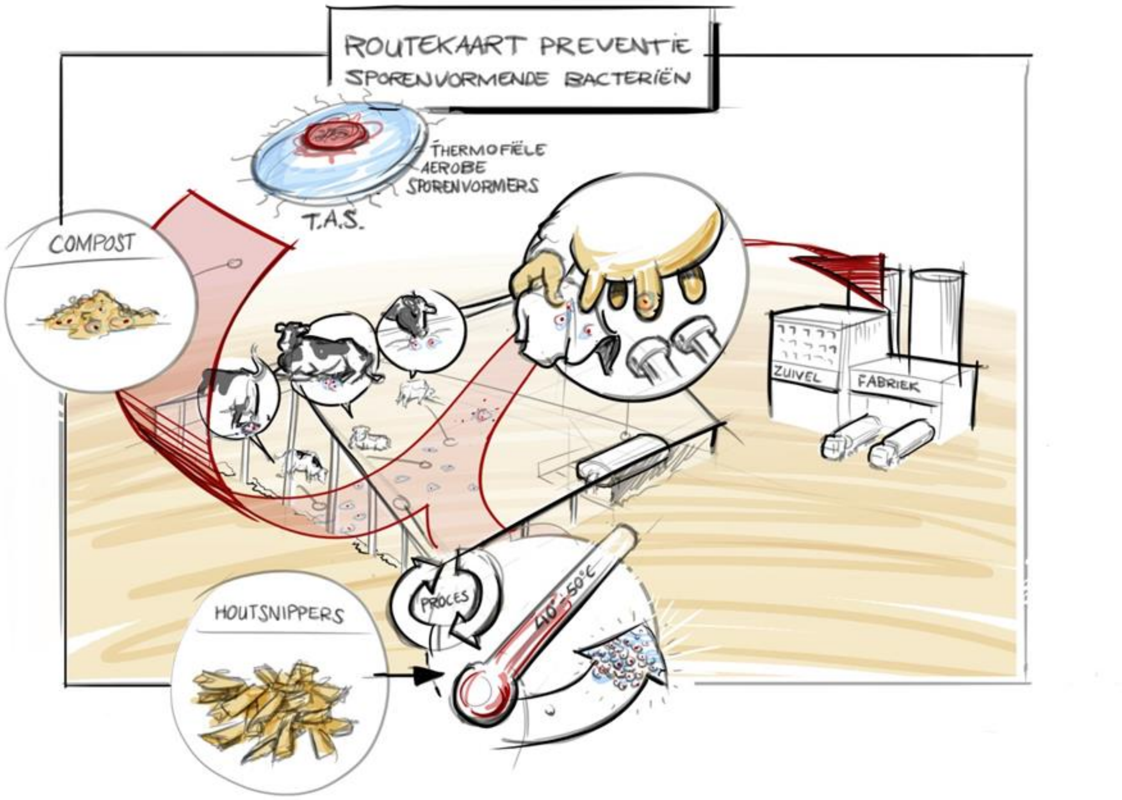

***Figure 10**. Roadmap of sporeforming bacteria (distinction between transmission of TAS via compost and possible development of TAS during composting wood chips)*

5.2 Research results

5.2.1 (X)TAS in bedded packs

In the study the concentrations of TAS- and XTAS spores were analysed in the bedding material twice (in spring and in autumn) at ten farms with bedded pack barns. In addition samples were taken in bedding materials that were fresh and unused available in stock at the farms. Finally the concentration of TAS spores in farm tank milk was analysed several times. XTAS spores in farm tank milk could not be determined since the concentration of the group is too low to be detected in milk.
Figure 11 and Figure 12 show the concentrations of XTAS- and TAS spores in the bedding of the farms. Table 7. shows the concentrations in fresh unused bedding materials. For comparison, Table 8. shows the mean concentrations of XTAS- and TAS spores in the bedding of farms with free stall barns using sawdust, straw or compost.
Compost beddings contain high concentrations TAS- and XTAS spores. The concentration of XTAS spores in compost was on average about 1000 –fold higher than in bedding materials such as straw, reed and sawdust. The high levels of TAS- and XTAS spores were already present in the compost that was provided on the farms. In the barn little or no increase was detected. The formation of these micro-organisms is probably unavoidable in the production of compost by the compost companies. The concentrations of TAS- and XTAS spores in composting wood chip beddings were on average lower than in compost bedding, but higher than in straw or sawdust beddings. At these farms with composting bedded pack in particular the concentration of XTAS spores varied much between farms. The variation was probably caused by differences in intensity of the composting process between the farms.

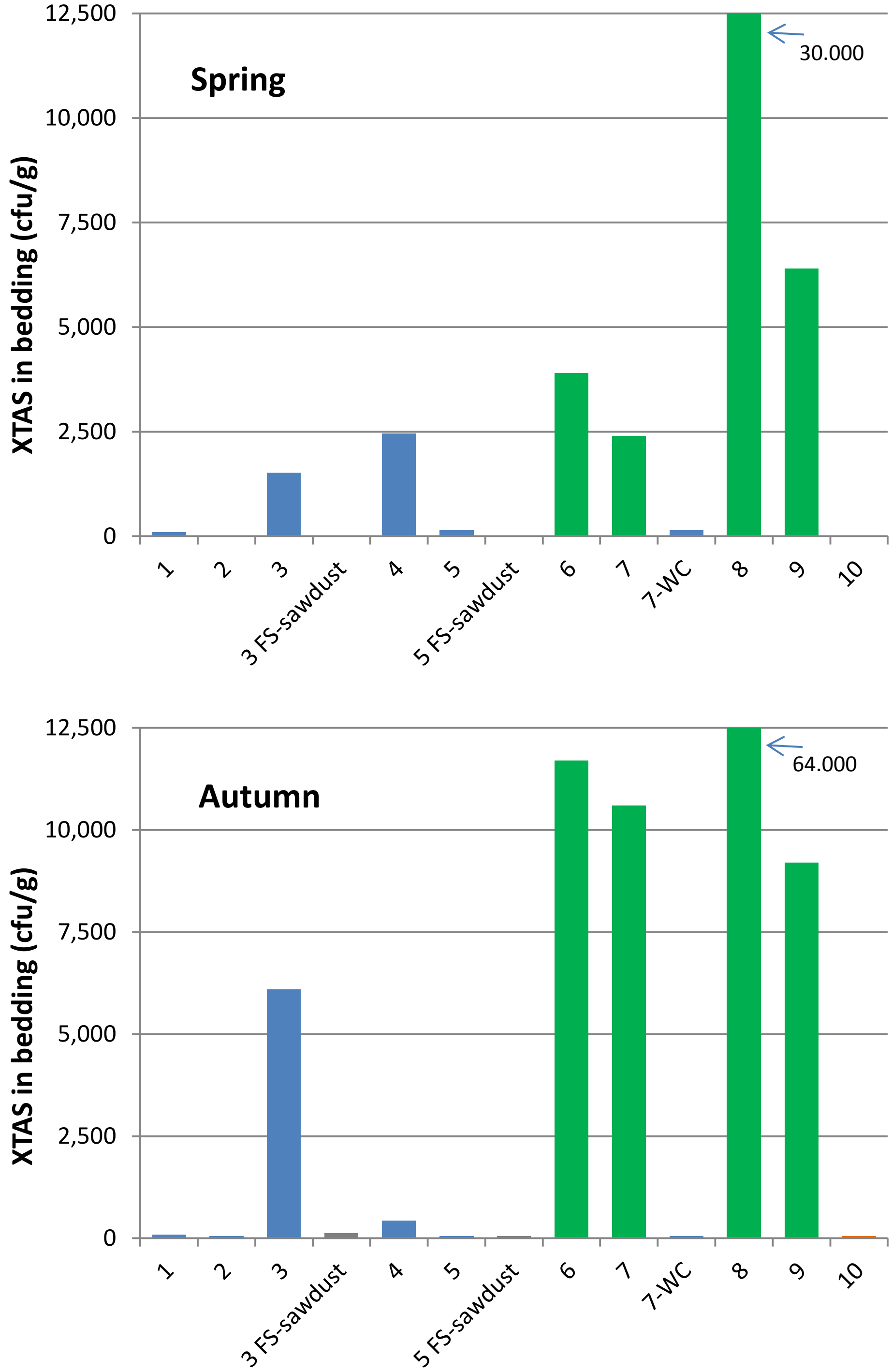

Figure 11. *The concentration of XTAS spores in the bedding of farms with composting beddings with wood chips (farm 1-5), green waste compost (farm 6-9) or straw (farm 10). Farm 3 and 5 also provided a sample to analyse from the free stall barn (FS) with sawdust and farm 7 also provided a sample from a composting bedding from a bedded pack barn with wood chips (WC). Cfu = colony forming units*

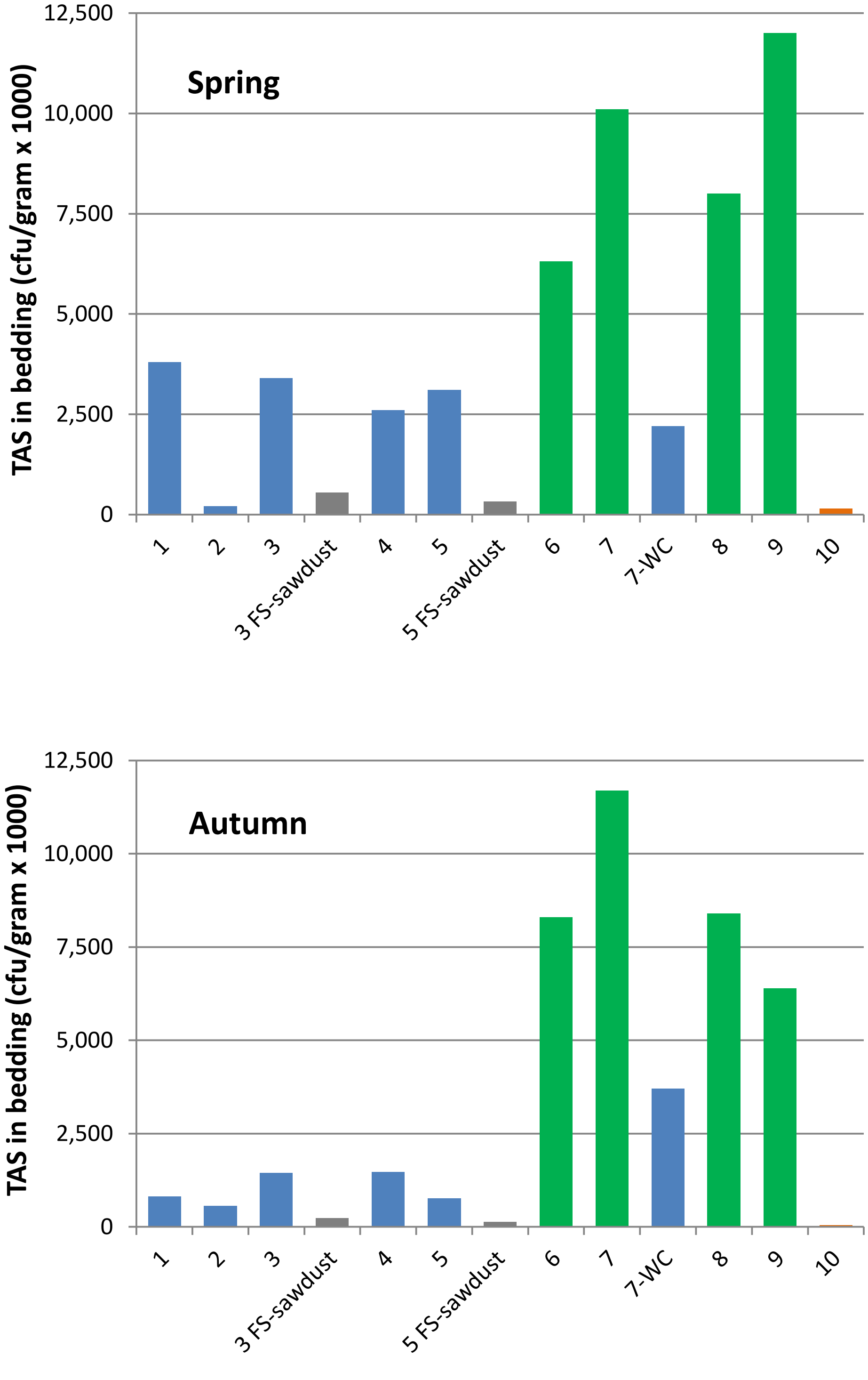

Figure 12. *The concentration of TAS spores in the bedded pack of farms with composting beddings with wood chips (farm 1-5), green waste compost (farm 6-9) or straw (farm 10). Farm 3 and 5 also provided a sample to analyse from the free stall barn (FS) with sawdust and farm 7 also provided a sample from a composting bedding from a section of a bedded pack barn with wood chips (WC). Cfu, colony forming unit*

Table 7.

Concentrations of TAS- and XTAS spores in fresh, unused compost, wood chips, straw and reed, in stock at the farms (sampled in spring or autumn).

	Farm nr	TAS (cfu/g)	XTAS (cfu/g)
Compost	Farm 7, spring	4 200 000	1 900
Compost	Farm 9, spring	12 600 000	3 400
Compost	Farm 6, spring	4 300 000	4 600
Compost	Farm 7, autumn	13 300 000	21 300
Compost	Farm 8, autumn	1 950 000	22 100
Compost	Farm 8, spring	1 665 000	25 350
Wood chips, fresh	Farm 3, autumn	<10 000	<10
Wood chips	Farm 1, autumn	10 000	<10
Wood chips	Farm 7, autumn	10 000	<10
Wood chips	Farm 2, autumn	520 000	<10
Wood chips	Farm 3, autumn	880 000	<10
Wood chips, contaminated /heated[1]	Farm 3, spring	2 900 000	<10
Wood chips, contaminated / heated[1]	Farm 2, spring	4 900 000	<10
Wood chips, warm	Farm 3, autumn	18 900 000	10
Wood chips	Farm 4, autumn	4 600 000	70
Straw	Farm 1, spring	<10 000	<10
Straw	Farm 10, autumn	10 000	<10
Straw	Farm 10, spring	545 000	15
Straw, dust	Farm 4, spring	70 000	50
Straw, cut	Farm 3, autumn	20 000	100
Reed	Farm 8, autumn	<10 000	<10
Reed	Farm 10, autumn	<10 000	<10
Reed	Farm 8, spring	900 000	40

[1] Samples contaminated by soil or other material, or heated due to air exposure.

Table 8.

Mean concentrations of TAS- and XTAS spores in saw dust and straw beddings at farms with a free stall barn.

Bedding	TAS (cfu/g)	XTAS (cfu/g)
Saw dust	16 000	<10
Straw	15 000	14

5.2.2 TAS in milk

The mean concentration TAS spores in farm tank milk of the farms is shown in Figure 13. For comparison, this figure also contains the level at farms with a free stall barn with sawdust as bedding material. The results show that the concentrations of TAS spores in farm tank milk is a reflection of the concentration in the bedding: the highest mean concentration was detected in the group of farms using compost beddings, the lowest at the farm using a straw bedding and an intermediate concentration in the group of farms using composting wood chip beddings. At most farms a variation of TAS spore concentration was observed between consecutive tank milk deliveries. This is probably due to the variability of different factors affecting microbial contamination of milk with spores, such as the heterogeneity of beddings and the inevitable variation in the hygiene of milk production.

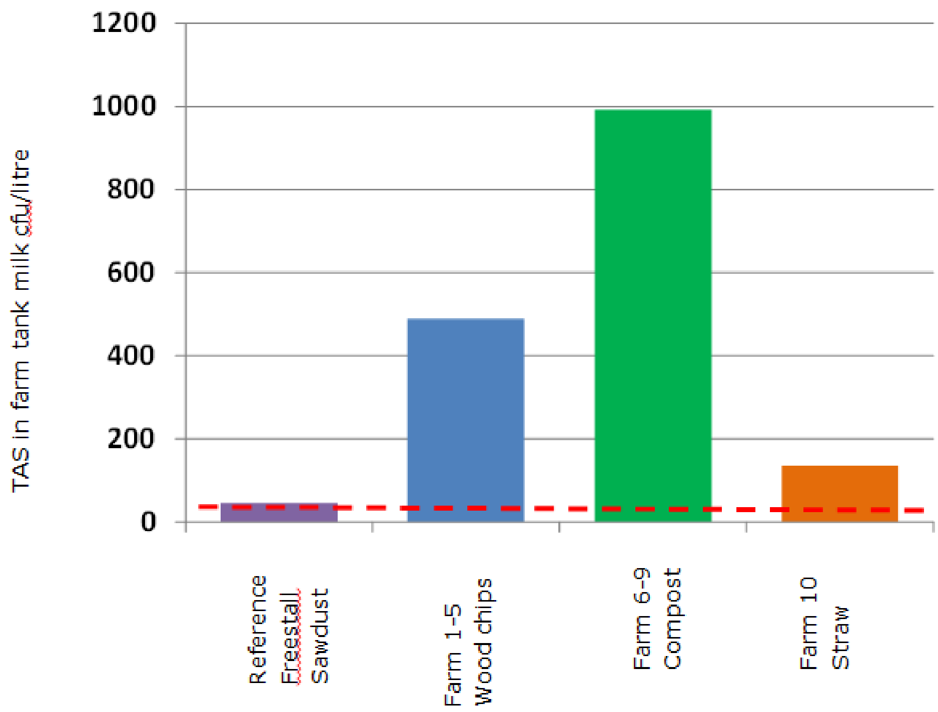

***Figure 13**. Mean concentration of TAS spores in farm tank milk of farms with composting wood chip beddings (farm 1-5), garden waste compost (farm 6-9) or straw (farm 10).The value shown is the mean value analysed in spring and autumn, after log-conversion. For comparison, the concentration in farm tank milk of a group of farms with a free stall barn with sawdust bedding is shown. The red dotted line marks the limit of determination of 40 cfu/litre*

Because of the low concentrations, the XTAS spores could not be detected in farm tank milk. However, as explained above, there is every reason to suppose the way of microbial contamination from bedding to milk is comparable and to expect the same influence of bedding type.

Good milking hygiene is not sufficient
As explained in the introduction of this paragraph it is inevitable, even with good milking hygiene, that small fractions of spores transmit from bedding to the milk. Based on the current knowledge of milking techniques it may be concluded that extra pre-treatment of the teats is insufficiently effective in compensating higher spore concentrations in farm tank milk due to higher spore concentrations in the bedding. This also applies to automatic milking systems.

5.3 Conclusion

Compost as bedding material is a risk for milk quality due to the consistently high concentration of XTAS- and TAS spores. This also applies for composting wood chips beddings, unless the composting could be organized in a way that the formation of XTAS spores is prohibited.

Statement NZO:
Partly based on the results of this study the Dutch Dairy Organization (NZO) has formulated a statement about the use of compost and composting materials as bedding materials in spring 2014, which reads as follows:
"The Dutch Dairy Organization strongly recommends not to use composting materials in dairy barns. Research has shown that beddings with composting materials may result in highly increased concentrations of sporeforming bacteria. These micro-organisms may cause spoilage problems of certain commercial sterile dairy products. In the short term there is no solution to this problem. Individual companies may decide to introduce consequences, if desired.

6 NPK balances, gaseous N loss and manure quality characteristics

6.1 Introduction

A bedded pack barn is a different dairy cow housing system compared to the commonly used free stall barn with slatted floor and has a potentially different impact on the environment. In this chapter, the results of research on some of the environmental consequences are reported.

The amount and form of N loss from a barn has an impact on the environment. A higher amount of N loss from the barn results in a lower amount of N ending up in manure to fertilize crops. This loss has to be compensated for by e.g. the purchase of N fertilizer, which involves extra costs and negatively impacts the environment. The form in which N is lost from the barn directly affects the environment. Gaseous N is mainly lost from the barn as NH_3, N_2O and N_2. Emission of NH_3 contributes to acidification and eutrophication of the environment and emission of N_2O to global warming. Emission of N_2 has no negative impacts. To minimize the environmental impact of a barn, N losses as NH_3 and N_2O, but also the level of total N loss, should be as low as possible. In the present study, the amounts of total N loss from six different bedded pack barns were calculated from their barn N balances. Measurement results of amounts of NH_3 and N_2O lost from the six bedded pack barns are reported by Van Dooren et al. (Chapter 7). In addition to N balances, also P and K balances were calculated.

On a dairy farm, gaseous N is not only lost from the barn, but also from (optional) manure storage and after application of manure to farmland. Housing systems may differ in amounts of gaseous N lost during these different stages (barn, storage, land). Low losses during one stage may result in high losses in the next stage, and vice versa. Therefore, for a correct assessment of gaseous N loss from a cow housing system, losses during all stages should be considered. In the present study, total N loss from the barn and after application of manure to farmland are calculated for both the bedded pack barns as well as for a reference free stall barn.

The use of bedding material in bedded pack barn adds to the input of nutrients on the dairy farm when compared a free stall barn and increases the amount of N and P in (composted) manure. This may have consequences for the use of (composted) manure. The composting of manure with bedding material affects manure quality characteristics, such as manure N/P and manure C/N ratio. Manure N/P ratio indicates how much kg of N can be applied per kg of P. When the N/P ratio of manure is lower, less N can be applied at the same P application level, which in turn can negatively affect yield and quality of crops. A lower N/P ratio is therefore unfavourable. The C/N ratio of manure indicates the rate at which organic N mineralises and becomes available for crop uptake. The N mineralisation rate is generally higher when C/N ratio is lower. Specific and detailed data on the rate of N mineralisation and C decomposition of bedded pack compost (relative to liquid manure and green waste compost) have previously been reported for two out of the six investigated bedded pack barns (De Boer, 2013). In the present study, the effects of composting on the N/P and C/N ratio of compost and the contribution of N and P in bedding material to N and P input in the barn are reported for six different bedded pack barns.

6.2 Materials and methods

6.2.1 Calculation of N, P and K balances

General
In this section, the type of measurements necessary for the calculation of the barn NPK balances, and the calculations themselves, are described in general. For each calculated barn balance, separate and detailed documentation is available (in Dutch). Detailed calculations of the NPK balances of barns 1 and 8, including information on the used methodology, were previously reported by De Boer (2013).
An N, P or K balance is calculated as the difference between the total N input in the barn and N fixed in the barn.
N input items for the N balance were: $N_{bedding\ material} + N_{feed\ (roughage\ +\ compound\ feed)}$.
N fixation items were: $N_{milk} + N_{liquid\ manure} + N_{compost} + N_{animals}$.
The N balance was calculated as: $N_{bedding\ material} + N_{feed\ (roughage\ +\ compound\ feed)} - N_{milk} - N_{liquid\ manure} - N_{compost} - N_{animals}$.
A description of the calculations necessary for each balance item is given below.

NPK_{bedding material}

The NPK input with bedding materials (woodchips, green waste compost and sometimes other organic materials) was calculated as the amounts of material brought into the barn during the balance period, multiplied by its NPK content. The amounts were either weighed or estimated (based on measured bedding thickness, bedding area and measured bedding material density). The NPK content of the bedding materials was determined by sampling and analysis. Sample analysis was performed by the ETE- laboratory (laboratory of the Environmental Technology Department of Wageningen University, Wageningen, the Netherlands).

$NPK_{feed\ (roughage)}$

The NPK input with roughage was calculated from the amounts of NPK fed with the daily rations to animals present in the barn, their number and the duration of the balance period. Ration composition information (type of components, amounts) was either taken from the management software or otherwise provided by the farmer. NPK contents of ration components were taken from either specific analysis results provided by the farmer or more general results provided by CVB (2011).

$NPK_{feed\ (compound\ feed)}$

The NPK input with compound feed was calculated per animal per day using the total amount of compound feed used on the farm during the balance period, or part of it, divided by the average number of animals present during that period. Based on average daily NPK intake with compound feed per animal and the daily number of animals present, NPK input for the balance period was calculated.

$NPK_{compost}$

NPK fixed in compost was calculated using the amount of compost produced during the balance period, multiplied by its NPK contents. Produced compost consisted of compost removed from the barn during the balance period and compost that accumulated in the barn during the balance period. The amount of compost present in the barn was calculated using the measured bedding thickness, the bedding area and the measured or estimated compost bulk density. The amount of compost removed during the balance period was either weighed or estimated based on changes in bedding thickness. The NPK content of the compost was determined by sampling and analysis of these samples by the ETE-laboratory.

$NPK_{liquid\ manure}$

Part of the total floor area of the investigated bedded-pack barns consisted of slatted concrete floor, which resulted in the production of liquid manure. NPK fixed in liquid manure was calculated using the amount of manure produced during the balance period, multiplied by its NPK contents. Produced liquid manure consisted of manure removed from the barn during the balance period and manure accumulated in the barn storage (below the slatted floor) during the balance period. The amount of manure present in the storage was estimated as the thickness of the manure layer multiplied by the storage area and manure density. The amount of manure removed from storage was either measured by a flow meter (when manure was applied to farmland) or estimated based on changes in thickness of the manure layer in the storage. Manure density and its NPK content was determined by manure sampling and analysis of these samples by the ETE-laboratory.

NPK_{milk}

NPK fixed in milk was calculated as the total amount of milk delivered at the milk factory during the balance period multiplied by its NPK content. N content was calculated as 15.7% of the measured protein content in milk (CBS, 2011). For P and K content, standard values of 1.0 and 1.6 g kg^{-1} milk were used (CBS, 2011).

$NPK_{animals}$

NPK fixed in born calves and (growing) pregnant heifers or young stock was calculated based on their numbers present during the balance period, duration of the balance period, live weight (calves), (estimated) increases in live weight (growing heifers), and NPK contents of body tissue during different life phases (Table 9). Net NPK fixation in adult cows was assumed to be zero.

Table 9.

Live weights (kg) and NPK contents in body tissue (g kg-1 live weight) of young stock during different life phases

Life phase	Live weight (kg)	Contents (g kg^{-1} live weight)			Amounts of NKP in animal (g)		
		N	*P*	*K*	*N*	*P*	*K*
At birth	44	29,4	8,0	2,1	1294	352	92
After one year	320	24,1	7,4	2,0	7712	2368	640
After two years	525	23,1	7,4	2,0	12128	3885	1050

Corrections on the N, P and K balances

When all balance items are accurately calculated or estimated, the P and K balances should be zero, because P and K are not lost by volatilization or leaching from a well managed bedding. A difference between input and fixed amounts of the P or K balance therefore indicates a margin of error. This difference can be used to correct the balances. In this report, a difference of the P balance was used to correct both the P and the N balance. When also a K-balance was calculated, the difference of the P balance was used to correct the P balance, the difference of the K balance to correct the K balance, and the average of both differences was used to correct the N balance. The correction was equally applied on all fixation items. For example, when the average difference of the P and K balance was 10%, all N fixation items were decreased by 10%. The assumption underlying the application of this correction is that when the amount of fixed P (and K) is overestimated, the amount of fixed N is likely also overestimated, as is the amount of N loss derived from the balance. Therefore, application of this correction likely results in a more accurate calculation of N loss. The correction could also have been applied on all balance input items, or both on input and fixation items. However, given the expected relatively high variability in the combination of measurements used to estimate NKP fixed in liquid manure and bedded pack compost, it is likely that variation was much higher for fixation items than for input items.

Corrections on calculated N loss from the barn

N loss from N input with bedding material contributes to the total N loss from the bedded pack barn. When bedding material is stored outdoors or directly applied to farmland, gaseous N is also lost to the environment. It can be argued that this loss therefore should not be attributed to the bedded pack barn. In the present study, the decision was made to correct gaseous N loss from the barn for gaseous N loss that would also have occurred during alternative use. When woodchips were used as bedding material, it was assumed that all N loss in the barn should be attributed to N excretion, because no gaseous N is lost from the composting of woodchips alone (Beck et al., 1997; Csehi, 1997). When green waste compost was used as bedding material, gaseous N loss attributed to alternative use was assumed to be 5% of total N in compost. This percentage was equal to the percentage of mineral N found in five sampled and analysed batches of input green waste compost for barn 8 (De Boer, 2013). It was assumed that with alternative use, all mineral N in green waste compost volatilises to the atmosphere. The amount of N loss from the barns with use of green waste compost (barns 8 and 9) was therefore corrected and lowered by 5% of the amount of N input with green waste compost.

6.2.2 Different ways to express gaseous N loss

In the present study, gaseous N loss from the barn is expressed in three different ways: (1) as a percentage of N excreted with urine and faeces by the cows on the barn floor; 2) as a percentage of total net N input on the barn floor (excreted N + N in bedding material); and (3) in g of N per kg of produced milk. In the Netherlands, gaseous N loss from the commonly used free stall barn is mainly from excreted N (though in many free stall barns also bedding material is used in the cubicles). For comparison purposes it is convenient to express N loss from the bedded pack barn also as a percentage of excreted N. Excreted N was calculated as: N_{feed} - N_{milk} - $N_{animals}$, using data from the corrected N balance. Gaseous N loss as a percentage of total net N input represents how much N is lost from N present on the barn floor during the balance period, not only from excreted N but also from N in bedding material. Expressing N loss in g of N per kg of produced milk gives a more balanced and complete comparison among bedded pack barns, because this method also takes into account factors that obscure comparisons based on other ways of expression. For instance, N loss expressed as a percentage of net N input on the barn floor may be at comparable level for two different barns, whereas the absolute N loss from one of the barns may be much higher than from the other, because more N is present on the floor of that barn. This difference in N loss and potential environmental impact is reflected when N loss is expressed in g of N per kg of produced milk, but not when N loss is expressed as percentage of total net N input on the barn floor. Furthermore, it makes more sense to relate N loss to produced milk, because milk production is the main objective of dairy farming. Expressing N loss per animal present makes less sense because of (large) differences between different cow categories (lactating, dry etc.), even between cows of the same category.

6.2.3 Addition of gaseous N loss after manure application to farmland

In the present study, total N loss from the barn and from farmland was calculated for all bedded pack farms, and expressed as a percentage of excreted N as well as in g N per kg of produced milk. Losses from manure/compost during storage were not considered. Storage of manure outside the barn is optional and manure is usually directly taken from the barn storage and applied to farmland. Compost storage is also optional. In addition, little information is available on N loss from compost during storage whereas the available information indicates very low losses (De Boer, 2013). Gaseous N loss after application of bedded pack compost to farmland was previously estimated at 0.3% of applied total N in the form of NH_3 and -0.3% of applied total N in the form of N_2O (De Boer, 2013). This indicates that total gaseous N loss after application of bedded pack compost to farmland is negligible. For a reference free stall barn with slatted floor and year round housing, gaseous N loss in the barn is 8.9% of N excretion and gaseous N loss (NH_3 + N_2O) after shallow injection of liquid manure into grassland/farmland is 8.7% of N excretion (or 9.6% of total N applied) (Appendix I, Velthof et al. (2009). It should be noted that all bedded pack barns in the present study produced both bedded pack compost as well as liquid manure; the N loss percentages after application of bedded pack compost or liquid manure were therefore applied to the respective amounts of N fixed in bedded pack compost and liquid manure (Table 14).

6.2.4 Contribution of N and P in bedding material to N and P in manure

The use of bedding material in bedded pack barn adds to the input of nutrients on the dairy farm when compared a free stall barn and increases the amount of N and P in (composted) manure. This may have consequences for the use of (composted) manure. It is therefore important to know the contribution of N and P in bedding material to total N and P input on the farm. Therefore, N and P input with bedding material is expressed as a percentage of total N and P input on the barn floor (bedding material + urine and faeces).

6.2.5 N/P and C/N ratio of bedded pack compost compared to liquid manure

N/P and C/N ratio for barns 1, 3, 4 and 5 were calculated for the compost that was discharged from the barn during the balance period (barn 3, 4 and 5) or at the end of the balance period (barn 1). For barn 8, the N/P ratio was the average of all batches of compost discharged from the barn during the balance period, and the C/N ratio was the average of two different samplings during the balance period. For barn 9, the ratios were calculated from the composition of the compost present in the barn at the end of the two-year balance period. For all barns, N/P and C/N ratios of liquid manure were the averages of all samples taken during the balance period.

6.3 Results

6.3.1 Characteristics of the bedded pack barns

An overview of some relevant characteristics of the six bedded pack barns is given in Table 10. The barns varied considerably in several characteristics. For instance, the bedding area per cow varied between 10 and 25 m^2, and bedding area as percentage of the total floor area varied between 55 and 86%. There were also large differences in N intake with feed and milk production level.

Table 10.

Characteristic	Barn code					
	1 WC	3 WC	4 WC	5 WC	8 GWC	9 GWC
Bedding material	WC[1)]	WC	WC	WC	GWC[2)]	GWC
Bedding area (m^2)	1138	705	1500	618	982	224
Slatted floor area (m^2)	557	236	370[3)]	99	809	123
N intake (g N lactating cow^{-1} day^{-1})	729	549	590	592	661	379
Milk production (kg cow^{-1} year^{-1})[4)]	11369	9064	9262	8292	7045	7154
Milk protein content (%)	3.38	3.65	3.46	3.72	3.48	3.64
Lactating cows (#)	45.4	46.8	96.3	62.6	86.1	8.8
Dry cows (#)	8.1	8.0	0[5)]	0	10.8	0.2
Heifers (#)	3.5	0[5)]	0[5)]	0[5)]	10.4	0
Young stock (#)[6)]	0[5)]	0[5)]	0[5)]	0[5)]	22.0	0
Bedding composting temperature (ºC)	30-60	30-60	30-60	30-60	20-30	20-30
Mechanical ventilation	Blowing	Suction	Suction	None	None	None
Length balance period (days)	306	165	193	148	271	427
Starting date balance period	15-01-11	17-09-12	25-10-12	18-09-12	15-03-12	11-01-12
Ending date balance period	17-11-11	01-03-13	06-05-13	13-02-13	11-12-12	13-03-13

[1)] Woodchips; [2)] Green waste compost; [3)] Asphalt floor, manure removed by scraper; [4)] Including dry period; [5)] Not housed in the bedded pack barn; [6)] Between 1 and 2 years of age

6.3.2 N, P and K balances

The initially calculated N, P and K balances (before any corrections) are given in Table 11, Table 12 and Table 13. N and P balances could be calculated for all six barns; K balances only for barns 1, 3 and 4. Uncorrected N loss varied between 6 and 30% of total N input in the barn (feed + bedding material).

Table 11.

N balances of six different bedded pack barns.

Balance item	Barn code					
	1 WC	3 WC	4 WC	5 WC	8 GWC	9 GWC
Input with bedding material	889	2154	5683	525	5543	2322
Input with roughage	6739	2383	4773	2767	13111	817
Input with compound feed	4315	2046	6191	2721	5076	623
Fixed in compost	3461	3304	5857	1850	8744	1685
Fixed in liquid manure	4146	1528	3487	1490	7256	537
Fixed in milk	2703	1284	2877	1228	2763	429
Fixed in animal tissue	61	70	91	41	224	0
Total input	11943	6583	16647	6012	23730	3762
Total fixed	10371	6186	12312	4609	18988	2651
Loss (kg)	1571	397	4336	1403	4743	1111
Loss (% of input)	13	6	26	23	20	30

Table 12.

P balances of six different bedded pack barns.

Balance item	Barn code					
	1 WC	3 WC	4 WC	5 WC	8 GWC	9 GWC
Input with bedding material	94	272	855	54	1000	477
Input with roughage	915	372	781	366	1733	121
Input with compound feed	746	305	738	458	549	109
Fixed in compost	638	547	1079	426	2076	440
Fixed in liquid manure	589	261	522	291	1090	98
Fixed in milk	510	225	530	210	507	75
Fixed in animal tissue	17	19	25	11	68	0
Total input	1755	949	2374	878	3282	708
Total fixed	1755	1051	2155	939	3740	614
Loss (kg)	0[1)]	-102	219	-61	-458	93
Loss (% of input)	0	-11	9	-7	-14	13

[1)] is exactly 0 because of the used calculation method; see de Boer (2013)

Table 13.

K balances of six different bedded pack barns.

Balance item	Barn code					
	1 WC	3 WC	4 WC	5 WC[1)]	8 GWC[1)]	9 GWC[1)]
Input with bedding material	385	1341	3660	304		
Input with roughage	7747	2942	5275	2455		
Input with compound feed	1966	664	1780			
Fixed in compost	4271	3662	5817	1879		1652
Fixed in liquid manure	5002	1720	3031	1305		804
Fixed in milk	816	359	848	337		121
Fixed in animal tissue	10	5	6	3		0
Total input	10098	4947	10715			
Total fixed	10098	5746	9703			
Loss (kg)	0[2)]	-799	1012			
Loss (% of input)	0	-16	9			

[1)] K balance not calculated because of missing data

[2)] Is exactly 0 because of the used calculation method; see de Boer (2013)

The difference of the P balances varied between -14 and +13% and the difference of the (three) K balances between -16 and +9%. When the N balances were corrected for this differences, corrected N loss varied between 13 and 29% of total N input in the barn (feed + bedding material) (Table 14). The corrected N, P and K balances are given in Table 14, Table 15 and Table 16.

Table 14.

N balances of six different bedded pack barns, corrected for the average difference of their P and K balances.

Balance item	Barn code					
	1 WC	3 WC	4 WC	5 WC	8 GWC	9 GWC
Input with bedding material	889	2154	5683	525	5543	2322
Input with roughage	6739	2383	4773	2767	13111	817
Input with compound feed	4315	2046	6191	2721	5076	623
Fixed in compost	3461	2913	6460	1730	7673	1942
Fixed in liquid manure	4146	1347	3846	1393	6357	618
Fixed in milk	2703	1132	3173	1149	2424	495
Fixed in animal tissue	61	62	100	39	197	0
Total input	11943	6583	16647	6012	23730	3762
Total fixed	10371	5453	13579	4311	16651	3055
Correction for alternative use of input bedding material (kg)	0	0	0	0	-266	-111
Loss (kg)	1571	1131	3068	1701	6813	596
Loss (% of input)	13	17	18	28	29	16

Table 15.

P balances of six different bedded pack barns, corrected for the observed difference.

Balance item	Barn code					
	1 WC	3 WC	4 WC	5 WC	8 GWC	9 GWC
Input with bedding material	94	272	855	54	1000	477
Input with roughage	915	372	781	366	1733	121
Input with compound feed	746	305	738	458	549	109
Fixed in compost	638	494	1188	398	1822	507
Fixed in liquid manure	589	235	576	272	956	113
Fixed in milk	510	203	584	197	445	87
Fixed in animal tissue	17	17	27	11	59	0
Total input	1755	949	2374	878	3282	708
Total fixed	1755	949	2374	878	3282	708
Loss (kg)	0	0	0	0	0	0
Loss (% of input)	0	0	0	0	0	0

Table 16.

K balances of six different bedded pack barns, corrected for the observed difference.

Balance item	Barn code					
	1 WC	3 WC	4 WC	5 WC[1)]	8 GWC[1)]	9 GWC[1)]
Input with bedding material	385	1341	3660			
Input with roughage	7747	2942	5275			
Input with compound feed	1966	664	1780			
Fixed in compost	4271	3152	6424			
Fixed in liquid manure	5002	1481	3347			
Fixed in milk	816	309	936			
Fixed in animal tissue	10	4	7			
Total input	10098	4947	10715			
Total fixed	10098	4947	10715			
Loss (kg)	0	0	0			
Loss (% of input)	0	0	0			

[1)] Corrected K balance not calculated because of missing data

6.3.3 Contribution of bedding material to net N and P input on the barn floor

The contribution of N input with bedding material to total net N input on the barn floor (N in bedding material + N excreted with urine and faeces) varied considerably between the bedded pack barns (Figure 14). As a result of the use of bedding material, the increase in net N input varied between 11% (barn 1) and 246% (barn 9). Within the group of barns with woodchips as bedding material, the contribution of bedding material was much lower for barns 1 and 5 compared to barns 3 and 4. This is explained by a larger initial input of woodchips, that were composted at lower rate and remained longer in the barn, for barns 3 and 4 compared to barns 1 and 5. Within the group of barns with green waste compost as bedding material, the contribution of bedding material was much higher for barn 9 than for barn 8. Barn 9 started the balance period with a relatively large input of green waste compost and no compost was removed during the balance period. The starting amount of green waste compost for barn 8 was much lower and compost was brought into the barn and discharged from the barn on a regular basis during the balance period.

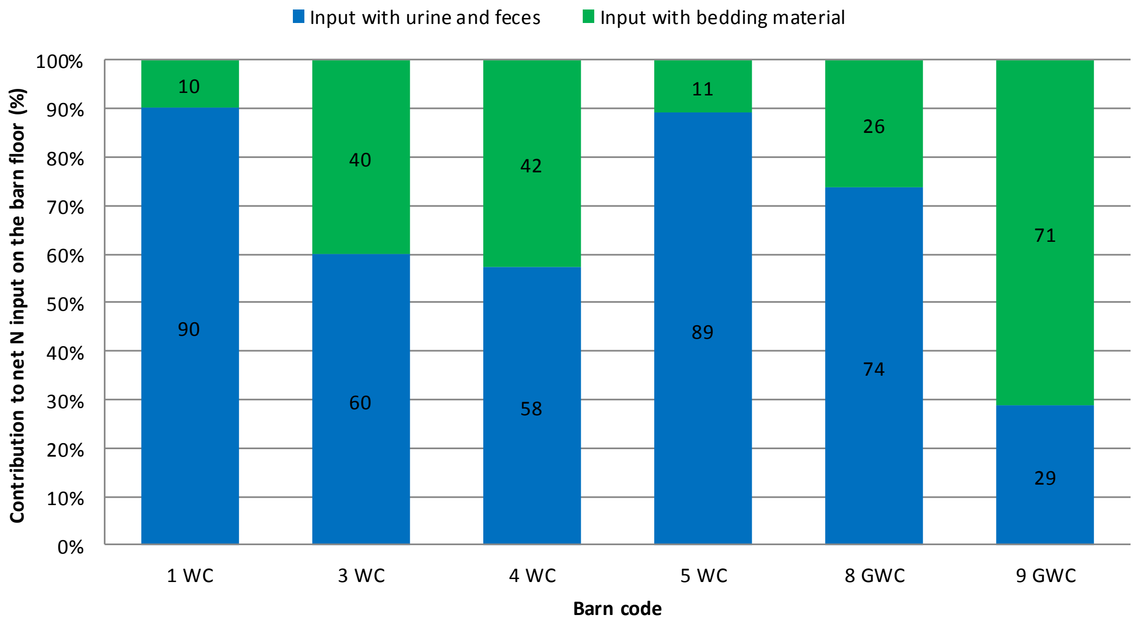

Figure 14. *Contribution (%) of excretion with urine and faeces and bedding material to total net N input on the barn floor, for bedded-back barns with woodchips (WC) or green waste compost (GWC) as bedding material*

Differences between bedded pack barns in contribution of bedding material to net P input on the barn floor were largely similar to differences in contribution of bedding material to net N input (Figure 14). As a result of the use of bedding material, the increase in net P input varied between 8 (barn 1) and 334% (barn 9).

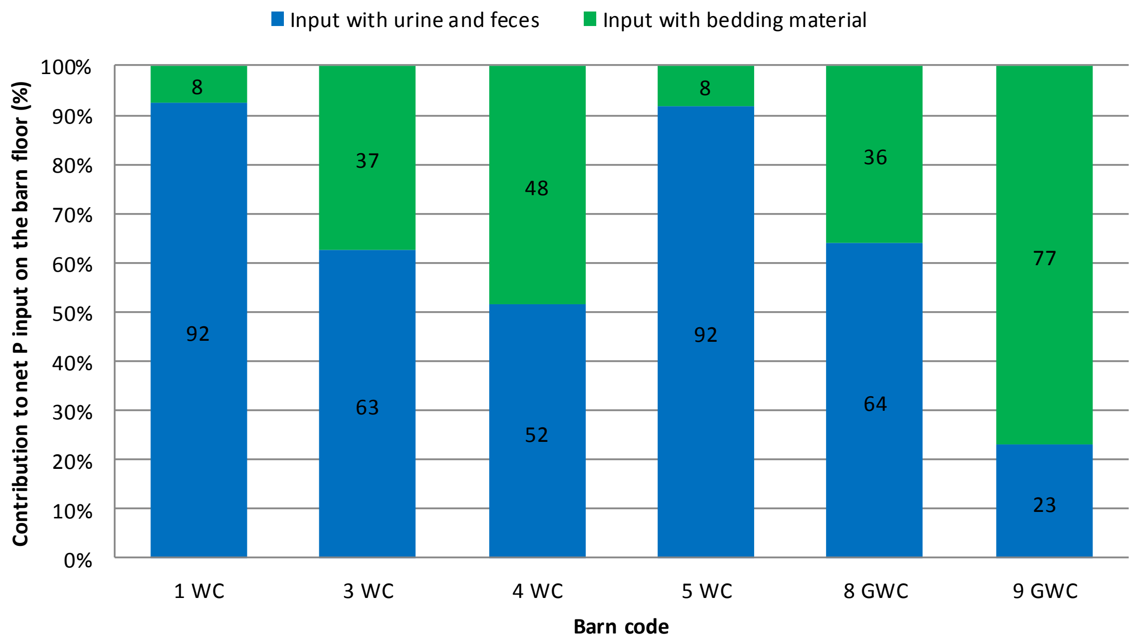

Figure 15. *Contribution (%) of excretion with urine and faeces and bedding material to total net P input on the barn floor, for bedded-back barns with woodchips (WC) or green waste compost (GWC) as bedding material*

6.3.4 Gaseous N loss from the barn expressed in different ways

N loss, expressed as a percentage of net N input on the barn floor, was lowest for the barn with woodchips as bedding material and mechanical ventilation by air blowing (barn 1) (Figure 16). The two bedded pack barns with woodchips as bedding material and mechanical ventilation by air suction (barns 3 and 4) had a higher N loss than barn 1, and were comparable to each other. N loss from the barn with woodchips as bedding material but without mechanical ventilation (barn 5) was much higher compared to N loss from the other barns with woodchips, and comparable to the barn with regular input of green waste compost (barn 8). N loss from the barn with a large input of green waste compost at the start of the balance period (barn 9) was comparable to N loss from the barns with woodchips as bedding material and mechanical ventilation by air suction.

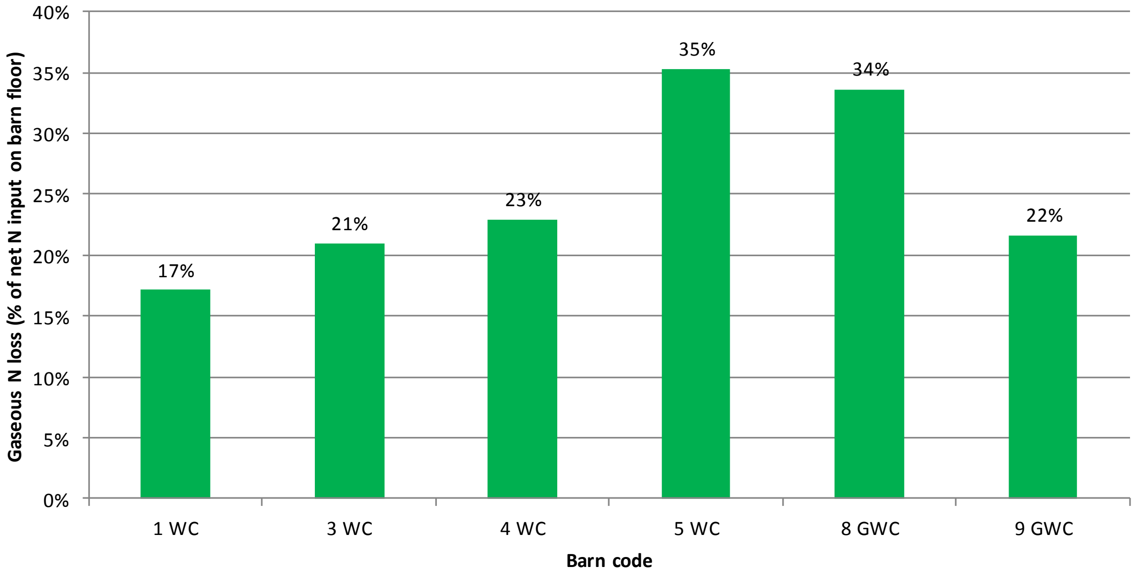

***Figure 16**. Gaseous N loss from six different bedded pack barns, with woodchips (WC) or green waste compost (GWC) as bedding material, expressed as % of net N input on the barn floor*

Expressed as a percentage of N excretion with urine and faeces on the barn floor, N loss was also the lowest for barn 1 (Figure 17). N loss was clearly higher for both barns with woodchips as bedding material and mechanical ventilation by air suction (barns 3 and 4) and the barn with woodchips as bedding material but without mechanical ventilation (barn 5). N loss from the barn with regular input of green waste compost (barn 8) was a little higher compared to barns 3 and 4, but N loss from the barn with a high starting input of green waste compost (barn 9) was considerably higher compared to the other barns. Gaseous N loss from all bedded pack barns was considerably higher when compared to the gaseous N loss of 8.9% of N excretion from a reference free stall barn with slatted concrete floor and year round confined housing in the Netherlands (Appendix IVelthof et al., 2009).

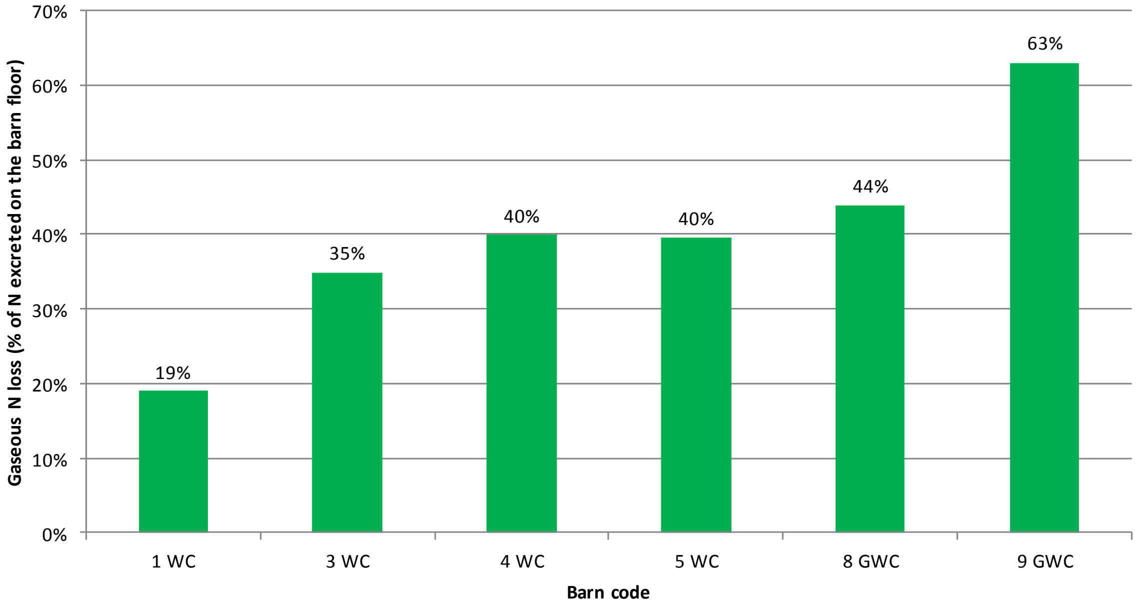

***Figure 17**.* *Gaseous N loss from six different bedded pack barns, with woodchips (WC) or green waste compost (GWC) as bedding material, expressed as % of N excreted with urine and faeces on the barn floor*

Expressed in g N per kg milk, the lowest N loss was realized for the bedded pack barns with woodchips as bedding material and mechanical ventilation (barns 1, 3 and 4) (Figure 18). The barn with mechanical ventilation by air blowing (barn 1) had a lower gaseous N loss than the barns with mechanical ventilation by air suction (barns 3 and 4). The barns with green waste compost as bedding material and the barn with woodchips as bedding material but without mechanical ventilation had the highest gaseous N loss per kg of produced milk (barns 5, 8 and 9).

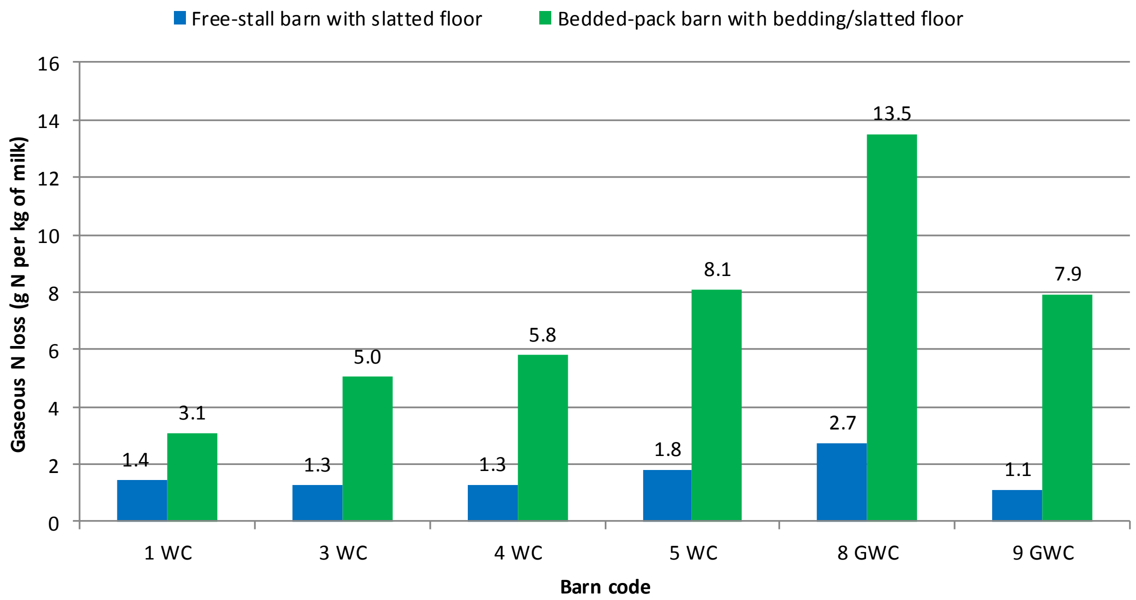

***Figure 18**.* *Gaseous N loss from six different bedded pack barns with woodchips (WC) or green waste compost (GWC) as bedding material, and after simulation of N excretion in a reference free stall barn with slatted floor. N loss expressed in g N per kg of produced milk*

When it was assumed that N in urine and faeces was not excreted in the bedded pack barn, but in a reference free stall barn in the Netherlands (with gaseous N loss of 8.9% of N excretion), simulated N loss was considerably lower (Figure 18).

6.3.5 Gaseous N loss including N loss after manure application to farmland

When gaseous N loss after application of liquid manure and bedded pack compost to farmland is added to N loss from the barn, the difference in gaseous N loss between bedded pack barns and simulated free stall barns decreases (Figure 19). However, total gaseous N loss is in general still much higher for the bedded pack barns. The difference in N loss between the two barn types is smallest for barn 1 and largest for barn 9.

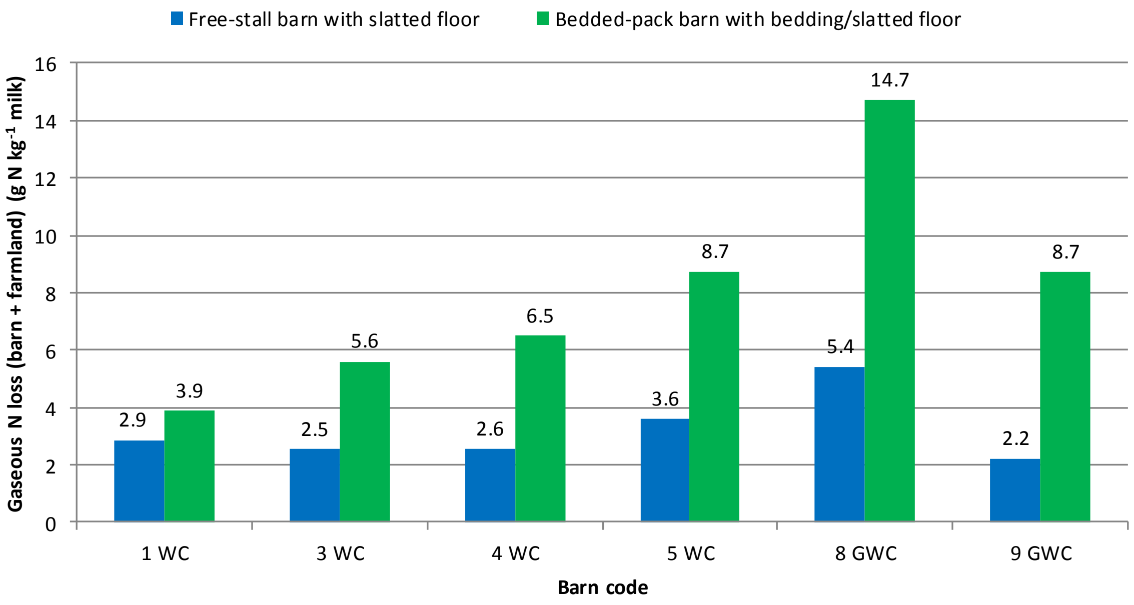

Figure 19. *Total gaseous N loss (from the barn and after application of compost and liquid manure to farmland) for six different bedded pack barns with woodchips (WC) or green waste compost (GWC) as bedding material, and after simulation of N excretion in a reference free stall barn with slatted floor. N loss expressed in g of N per kg of produced milk*

6.3.6 Differences in N/P and C/N ratio between bedded pack compost and liquid manure

On all farms, the N/P ratio of the bedded pack compost was lower than the N/P ratio of the liquid manure (Figure 20). This means that less N can be applied with bedded pack compost than with liquid manure, at the same P application level. The lower N/P ratio is largely caused by a higher N loss from bedded pack compost relative to liquid manure; the barns with the highest N losses in g per kg of milk (Figure 18) had the lowest N/P ratio in bedded pack compost (barn 5, 8 and 9).

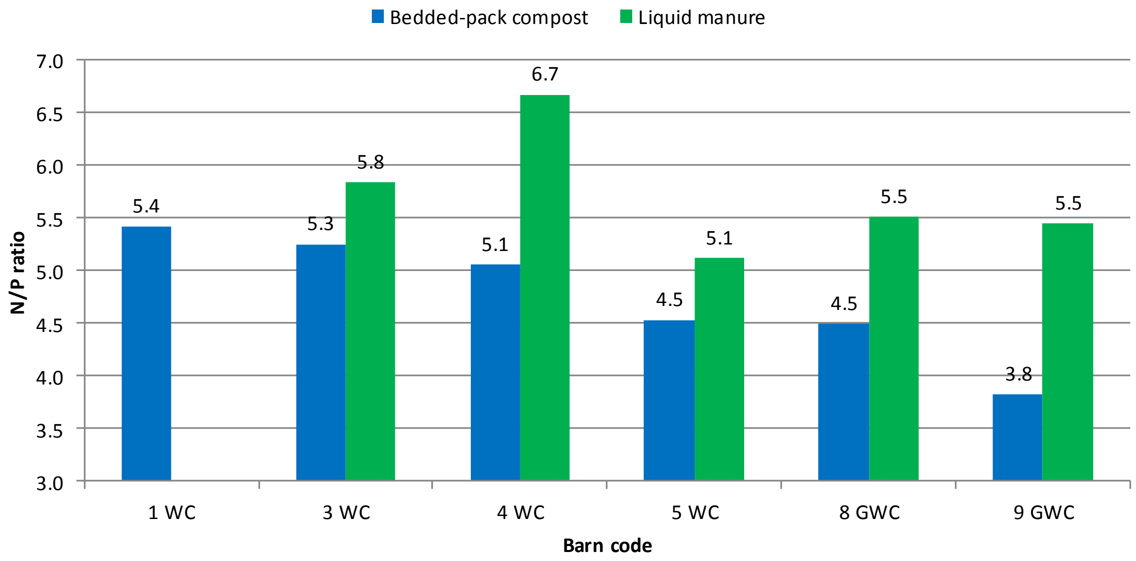

Figure 20*.* *N/P ratio of produced bedded pack compost and liquid manure on six different farms with woodchips (WC) or green waste compost (GWC) as bedding material*

The C/N ratio of most bedded pack composts was relatively high and (much) higher than for liquid manure from the same barn (Figure 21). The barn with the lowest N loss (barn 1) also had the lowest C/N ratio in compost; C/N ratio of other barns with woodchips as bedding material were much higher (barn 3, 4 and 5). An explanation for this is that the (coarse) woodchips in these barns were only partly decomposed, because of less intensive composting/cultivation. C/N ratio of barns with green waste compost as bedding material was on average lower than C/N ratio of barns with woodchips as bedding material.

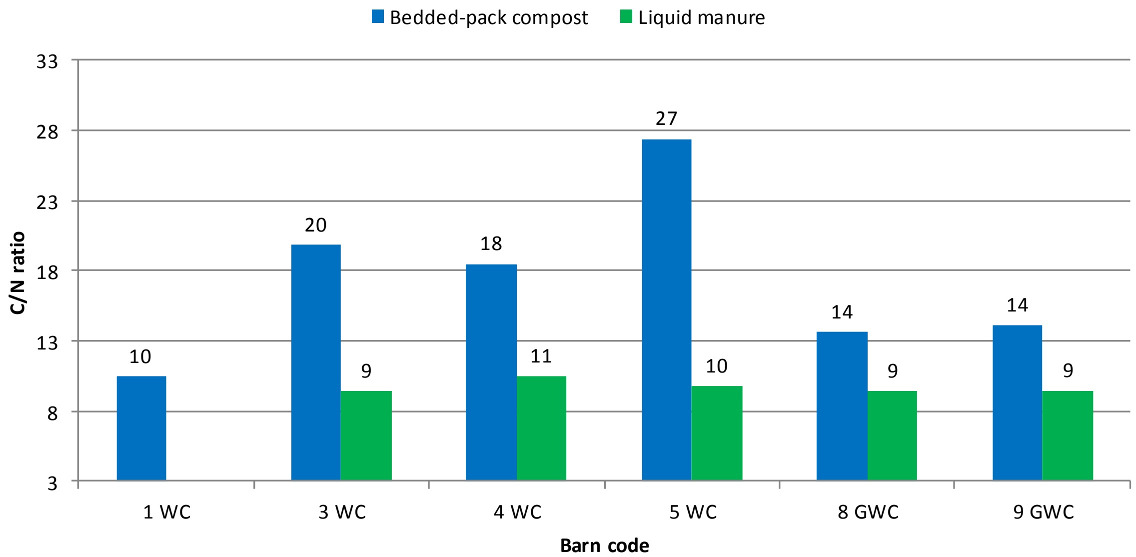

Figure 21*.* *C/N ratio of bedded pack compost and liquid manure on six different farms with woodchips (WC) or green waste compost (GWC) as bedding material*

Based on the level of C/N ratio, the indication is that N mineralisation will be highest for bedded pack compost from barn 1, followed by barns 8 and 9, barns 3 and 4 and finally barn 5. C/N ratio of liquid manure was lower than C/N ratio of bedded pack composts.

6.4 Discussion

6.4.1 Potential to reduce N loss from the bedded pack barn

The calculated N losses from the bedded pack barns are relatively high when compared to the reference free stall barn. However, the development of bedded pack barns in the Netherlands is still in the early stages, and this should give ample room for improvement of bedding management and reduction of N loss from the barn.

6.4.2 Differences in feed N conversion efficiency between barns can affect differences in N loss

When N excretion of the bedded pack barns was simulated to have taken place in a reference free stall barn, simulated gaseous N loss from the barns varied between 1.1 and 2.7 g of N per kg of milk. Because a fixed percentage of gaseous N loss of 8.9% of N excretion was used for all barns, the variation in calculated N loss indicates large differences in feed N conversion efficiency between the farms. In other words, on some farms much more N was fed and excreted per kg of produced milk than on other farms. For instance, farm 8 had a much higher amount of N excretion per kg of milk than farm 9, and thus also a higher gaseous N loss per kg of milk in the free stall barn simulation. This observation suggests that differences in gaseous N loss between different types of bedded-back barns are obscured by differences in feed N conversion efficiency, and that some bedded pack barns had a relatively high gaseous N loss because their feed N conversion efficiency was lower compared to other barns. However, this observation does not affect the conclusion that N loss from bedded pack barns is at the moment much higher than N loss from the free stall barn, because simulated N loss for the free stall barn was based on the same amount of N excretion and milk production as for the bedded pack barn. For some farmers with a bedded pack barn, N loss from the barn can be reduced considerably when feed N conversion efficiency is increased. Additionally, this will also reduce feeding costs.

6.4.3 Measured N loss for bedded pack barns versus calculated loss for the free stall barn

The used percentage of gaseous N loss from N excreted in a reference free stall barn is based on calculations/estimations of Velthof et al. (2009) (p. 77) and a total NH_3-N emission of 11.0 kg NH_3 cow^{-1} $year^{-1}$ (free stall barn with slatted concrete floor and year round housing in the Netherlands). However, recent emission measurements suggest that NH_3 emission from the free stall barns in the Netherlands has increased, due to increased barn ventilation and more floor area per cow (Ogink, 2012). It is therefore proposed by Ogink (2012) that the emission norm should be increased, from 11.0 to 13.5 kg NH_3 cow^{-1} $year^{-1}$. In that case, gaseous N loss for the reference free stall barn should also be increased, from 8.9% to roughly 10.6%. As a result, differences in N loss between bedded pack barns and the free stall barn become smaller. When the higher percentage of N loss is used for the simulation that N excretion of barn 1 takes place in a reference free stall barn, N loss from the barn per kg of milk increases from 1.44 to 1.73 g, and N loss after application of liquid manure to farmland decreases from 1.41 to 1.39 g (decreases because more N is lost in the barn and therefore less N is available to be lost during and after manure application). Total gaseous N loss (barn + farmland) then increases from 2.9 to 3.1 g of N per kg of milk. This is still lower than the total N loss of 3.9 g per kg of milk for the bedded pack barn with the lowest N loss (barn 1).

6.4.4 Consequences of differences in N/P and C/N ratio between bedded pack compost and liquid manure for crop fertilisation

The lower N/P ratio of bedded pack compost compared to liquid manure is largely caused by a higher gaseous N loss in the barn. A lower N/P ratio means that less N can be applied to farmland when compared to liquid manure, at the same level of P application. Combined with the lower short-term N mineralisation rate of N in bedded pack compost relative to liquid manure (paragraph 6.3.6; De Boer, 2013), this means that the amount of N that mineralises and becomes available for crop uptake is in the short term even smaller. In the longer term, when the same amount of N is applied, the amount of annually mineralised, plant-available N from bedded pack compost will increase relative to liquid manure, due to a larger accumulation of organic N in soil. However, when the higher N loss from the bedded pack barn is not compensated for by additional application of N from manure, fertilizer or biological N fixation, N available for plant uptake will also decrease in the long term and crop yields will decrease. It therefore appears that bedded pack compost is less suitable as an organic N fertilizer for crops in the short term, and is more suitable for improvement of soil quality on the long term.

6.5 Conclusions

- The use of bedding material increased net N input on the bedded pack barn floor by 11 to 246% and P input by 8 to 334% if compared with a reference free stall barn without the use of bedding material

- Gaseous N loss from the bedded pack barns varied between 17 and 35% when expressed as percentage of net N input on the barn floor (excreted N + N in bedding material), between 19 and 63% when expressed as percentage of N excretion, and between 3.1 and 13.5 g N when expressed per kg of produced milk

- N loss per kg of milk was lowest for the barns with woodchips as bedding material and mechanical ventilation. N loss of the barn with mechanical ventilation by air blowing was lower than N loss of the two barns with mechanical ventilation by air suction

- N loss per kg of milk was highest for the two barns with the use of green waste compost as bedding material and the barn with woodchips as bedding material but without mechanical ventilation

- When N excretion was simulated to have taken place in a reference free stall barn with slatted concrete floor instead of in the bedded pack barn, N loss per kg of milk was considerably higher for the bedded pack barn compared to the simulated free stall barn. N loss from the bedded pack barns varied between 3.1 and 13.5 g N per kg of milk, whereas N loss simulated for a free stall barn varied between 1.1 and 2.7 g N per kg of milk

- Gaseous N loss after application of bedded pack compost to farmland is much lower than N loss after application of liquid manure. When N loss after application to farmland is included, total N loss (barn + farmland) for the simulated free stall barn varied between 2.2 and 5.4 g N per kg of milk, and total N loss for the bedded pack barns varied between 3.9 and 14.7 g N per kg of milk. N loss including N loss from farmland was therefore also higher for the bedded pack barn when compared to the simulated free stall barn

- The difference between total N loss from the bedded pack barn and the simulated free stall barn was lowest for barn 1, with a total N loss of 3.9 and 2.9 g N per kg of milk, respectively

- N/P ratio of bedded pack compost was on all farms lower than N/P ratio of liquid manure. This means that less N can be applied to farmland with bedded pack compost when compared to liquid manure, at the same P application rate

- C/N ratio of bedded pack compost was on all farms higher than C/N ratio of liquid manure. This indicates that N from bedded pack compost mineralises at lower rate than N from liquid manure

- The combination of a higher C/N ratio and lower N/P ratio of bedded pack compost relative to liquid manure means that in the short term considerably less N is available from bedded pack compost compared to liquid manure. Bedded pack compost is therefore less suitable as an organic fertilizer for crops in the short term, and is more suitable for improvement of soil quality on the long term.

- When the higher N loss from the bedded pack barn is not compensated for by additional supply of N from manure, synthetic fertilizer or biological N fixation, N available for plant uptake will also decrease in the long term, resulting in a decrease in crop yields

7 Gaseous emissions

7.1 Introduction

One of the aspects of the environmental impact of bedded back barns is the gaseous emissions of C- and N-compounds. These can emit in different forms depending on the processes that take place and circumstances that occur. Most important gasses with environmental impact are ammonia (NH_3) that leads to acidification and eutrophication and nitrous oxide (N_2O), carbon dioxide (CO_2) and methane (CH_4) that are greenhouse gasses. Also N_2 might emit but has no negative impact on the environment and only represents a loss of valuable nitrogen.
Gaseous emissions of bedded pack barns have not been measured extensively before. However, emissions of deep litter systems for cows and pigs and other type of litter based systems for dairy and beef cows have been researched. Also emissions during composting are reported frequently. The combination of composting processes with a constant input of faeces and urine from the cows walking and lying in these bedded pack barns and a frequent tillage of the upper layer sometimes combined with an aeration system probably influence the nutrient losses through gaseous emissions and make an assessment of these type of barns necessary. Losses have been quantified by making balances over a long period for a selection of farms described in this report. This was reported in chapter 6. In this chapter the direct measurements of gaseous emission of fore mentioned components is described.

Bedded pack barns in the Netherlands can be divided in two groups. One group uses organic material, mostly compost, as bedding material. Urine is absorbed in that material and faeces is mixed by daily tillage of the top layer with a cultivator or similar device. The other group also uses organic material but with the aim to start a composting process in the bedding. This process should produce enough heat to keep the top layer of the bedding dry. Wood chips are the most used material and urine is partly absorbed and partly evaporated. Faeces is also mixed with the litter but the tillage of the top layer also has the aim to aerate that layer and stimulate the composting processes. In most cases a tractor driven device is used which has a more intensive effect. The rotating devices used have in most cases a more intense effects. Some farmers installed an additional aeration system at the bottom of the bedded pack. Some use this to blow outside air upwards through the bedding material, others use it as a suction system to create a downwards airflow through the bedding and concentrate the air at a single emission point. Temperatures in these composting bedded pack barns can rise to more than 60^{o}C.

7.1.1 Scope

Emission measurements have been part of the project from the beginning. After the laboratory experiments in the first phase of the project, emissions were measured using a flux chamber at three research farms in 2009 each with a different bedding material (Dooren *et al.*, 2012). In the next, third stage of the project the scope was extended to four farms. However one of these farms stopped with the compost bedding system soon after. The other three (1, 7 and 8, see table 17) continued and in 2010, 2011 and the first half of 2012 a series of flux chamber measurements took place. At farm 1 and 8 additional measurements at barn level were done. In the next fourth phase the measurements again were extended with seven extra farms. In this phase the measuring equipment and methods slightly changed. Measurements at two of the three remaining farms from the third stage (7 and 8) continued. Emission measurements on barn level were done on an extra farm from the fourth phase of the project. Figure 22 gives a summary of the measurements. All measurements in the fourth phase (indicated in yellow) are reported here. There is one exception for farm 1: as in other chapters of this report also data from other years are presented, therefore the emission results based on measurements in 2011 (reported in Galama *et al.*, 2013) will be also be included here. The numbers indicate the number of measurement days in a particular year on a particular farm.

	Phase	1	2	3	3	3/4	4	Total
	Year	2008	2009	2010	2011	2012	2013	
	Farm							
Flux Chamber	1			3	3	1		7
	2						2	2
	3						2	2
	4						4	4
	5					1	1	2
	6						2	2
	7				3	1	2	6
	8				2	1	1	4
	9						2	2
	10						2	2
Barn	1					2		2
	8					1	1	2
	9						2	2

Figure 22. *Summary of emission measurement in third and fourth phase of the project and number of measurement days per farm*

7.1.2 Aim

Aim of the research described in this chapter was to measure the gaseous emissions of different types of bedded pack barns and compare these with each other and with known emissions from a reference type of barn.

7.2 Material and methods

To measure the gaseous emissions two methods have been used: flux chamber measurements and barn measurements. Flux chamber measurements were used to compare different bedded pack barns with each other and with a known reference (a concrete slatted floor). The barn measurements were used to get insight in the absolute emission level.

7.2.1 Farms

Detailed description of the farms is given in chapter 2. The farms are not referred to with names but with numbers. Table 17 gives a summary of the most important characteristics related to gaseous emissions.

Table 17
Summary of important farm characteristics

Farm number	Lying area		Walking area	
	Material	(m^2/cow)	Material	(m^2/cow)
1	Wood chips (WC)	12,5	Concrete slats	5,0
2	Wood chips (WC)	15,0	Concrete slats	4,0
3	Wood chips (WC)	15,0	Concrete slats	4,0
4	Wood chips (WC)	16,0	Solid asphalt	3,0
5	Wood chips (WC)	8,5	Concrete slats	1,5
6	Compost (C)	18,0	Concrete slats	4,0
7	Compost (C)	22,0	None	0,0
8	Compost (C)	9,5	Concrete slats	7,0
9	Compost (C)	22,0	Concrete slats	4,0
10	Straw (S)	10,0	Concrete slats	3,0

7.2.2 Flux chamber measurements

The flux chamber used had a square measuring area of 1,21 m^2 and a cross section height of 0,4 m resulting in a cross section area of 0,44 m^2. On both sides of the flux chamber a triangle shaped duct was mounted to guide the air over the measuring area. Air was coming in and going out through a round flexible tube with a diameter of 0,35 m (VP-super, Panflex, Ede). A ventilator (Fancom FMS 35) with ventilation control unit (Fancom FCTA) was used to pull the air through the flux chamber and over the measuring area. The ventilator had a maximum capacity of 3.000 m^3/h. Ventilation was set at a constant value of 30% of the maximum capacity resulting in an average air velocity across the emitting surface of 0,57 m/s.

The flux chamber was used as an open flux chamber to measure ammonia fluxes. The ventilator created a constant air flow through the flux chamber. Incoming air was taken from above the bedding at a distance of around 5 meter from the flux chamber. The exhaust point of the outgoing air was also around 5 meter away at the other side of the flux chamber. Ventilation rate was measured using a fan wheel anemometer placed before the ventilator in the outgoing air flow. Both incoming and outgoing air were sampled using a PE sampling line. Concentration of ammonia in incoming and outgoing air was measured using two photo-acoustic multi gas monitors (Innova 1312). Concentrations were measured during 30 minutes. During the last 15 minutes the concentration of ammonia of both incoming and outgoing air was also measured by leading an air sample with a restricted flow of around 1000 ml/min through two glass impingers placed in serial and both put in 100 ml 0.5M sulphuric acid solution. The ammonia emission (E) in mg/m^2/h from the measuring area (A) is calculated by multiplying the difference of average ammonia concentration in the last 15 minutes between ingoing (C_{in}) and outgoing air (C_{out}) with the ventilation rate (ϕ) as in formula (1):

$$E = \frac{\phi * (C_{out} - C_{in})}{A} \tag{1}$$

The flux chamber was used as a closed flux chamber to measure fluxes of methane, nitrous oxide and carbon dioxide. To close the flux chamber both ends of the flexible tubes were connected. The ventilator created a constant air flow through the flux chamber. Two photo-acoustic multi gas monitors (Innova 1312) were used to measure the concentration of N_2O, CO_2 and CH_4 using filters UA0985, UA983 and UA0987 respectively. As the filter used to measure the N_2O is also sensitive for CO_2, influencing the N_2O reading for one photo-acoustic multi gas monitor the CO_2 was filtered from the sampled air using soda lime in granular form. Emission is calculated using the method described by Mosquera et al. (2010a):

$$E = \frac{V * (C_1 - C_0)^2}{A * t * (2C_1 - C_2 - C_0)} * \ln\left(\frac{C_1 - C_0}{C_2 - C_1}\right) \tag{2}$$

With V [m^3] the volume of the box and tubes, A [m^2] the measuring area and C_0 gas concentration at t=0, that is the moment the flux chamber is placed on the emitting surface, C_1 gas concentration at t and C_2 the gas concentration at 2*t. Gas concentration were measured every 2 minutes (t=2 min).

Besides the emission per m^2 from available bedding the results are also presented related to the emission from a reference floor and as emission per cow for the complete housing system related to the reference housing system.
The reference floor is defined as a concrete slatted floor with slurry storage in a pit underneath the floor which is the most common floor system in Dutch housing for dairy cattle. An average emission based on flux chamber measurements has earlier been reported by Dooren et al. (2012) and was based on several measurements. This average emission of 1200 mg NH_3/m^2/hour is used as reference for the current measured emissions from the different bedding materials.
The most common housing system for dairy cattle in the Netherlands is the system with cubicles combined with a concrete slatted floor with pits for slurry storage. Based on the average emission from the concrete slatted floor (1200 mg NH_3/m^2/h) and assuming that the emitting area is 4 m^2 per cow the calculated emission per cow of this system can be compared with the emission per cow from

the compost bedded pack system. Only farm 4 used a solid floor with another material instead of a concrete slatted floor. This floor was separately measured using the flux chamber.
Comparison with the official emission factor published in the Regeling ammoniak en veehouderij (Rav) is not possible as flux chamber measurements are not suitable to base an emission factor for a housing system on. Measurement methods differ and circumstances during the flux chamber measurement are static and not representative for the dynamic circumstances that occur in the barn over a longer time.

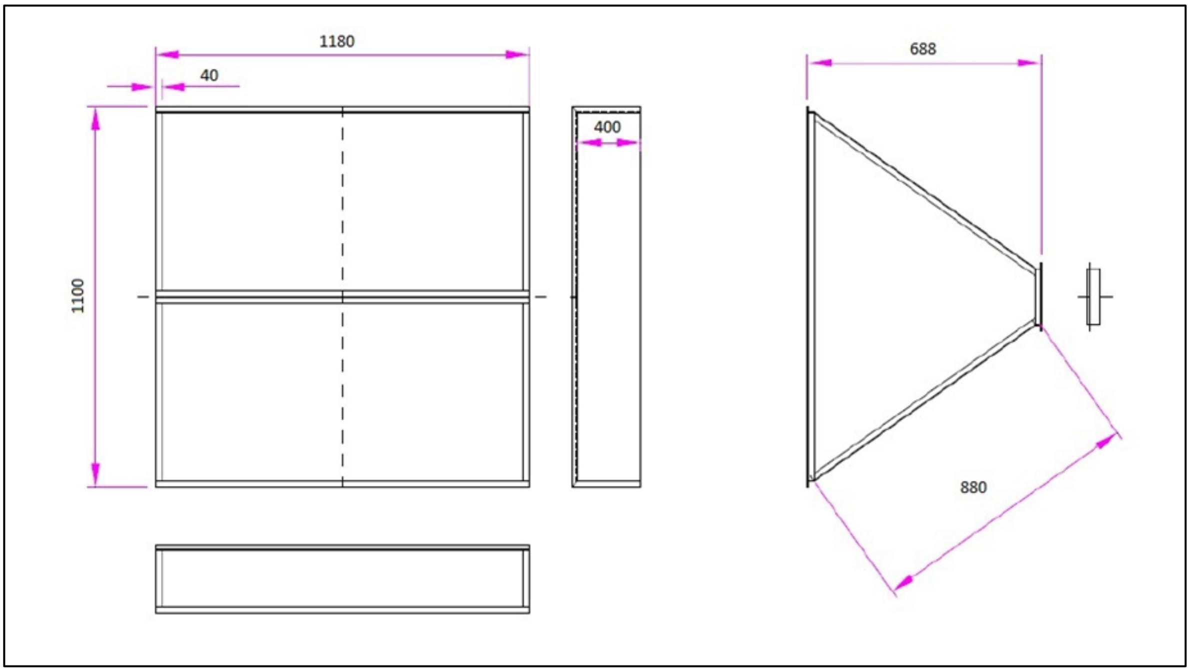

Figure 23*. Top view of flux chamber (dimensions in mm)*

7.2.3 Barn measurements

To get insight in the absolute emission levels of three of the bedded pack barns the emission were also measured on barn level. For two barns (farm 1 and 8) emission were measured using SF_6 and naturally produced CO_2 as tracer gas. For the third barn (farm 9) only CO_2 was used as a tracer. Besides emissions of ammonia the emissions of greenhouse gasses (N_2O and CH_4), particle matter (PM 2,5 and PM 10) and odour were measured at farm 1 and 8.

The tracer gas SF_6 was injected at a constant and known rate through 20-30 points evenly divided over two injection lines, one at the air inlet just above the bedding and on in the middle of the barn at a height of around 2 meters above the feeding rack. Air flow of each injection point was restricted to guarantee an even distribution of the tracer gas over the whole length of the barn.
Concentration of SF_6 in outgoing air was measured at 20-30 points divided over two sampling lines, one at the ridge and one at the sidewall acting as an outlet. Concentrations in the incoming air were measured using a same type sampling line with 5 sampling points outside the barn at the sidewall acting as air let. Airflow of each sampling point was restricted to guarantee an even distribution of the sampled air over the whole length of the barn. Concentrations were determined using a gas chromatograph (Compact GC, Interscience).

Concentration of CO_2 and NH_3 were continuously measured over the whole length of the barn at the sidewall acting as an air outlet using an open path laser for each gas (GasFinderFC, Boreal Laser Inc.) and semi-continuously through sampling lines in the ridge and the sidewall acting as an air inlet using two photo-acoustic multi gas monitors (Innova 1312).

Concentration of NH_3 was also measured using five 24 hours samples at two points in both the ridge and the sidewall acting as an air outlet (at 1/3 and 2/3/ of the length of the barn) and at one point at the sidewall acting as an air inlet (halfway the length of the barn) by leading an air sample of around

1000 ml/min through two glass impingers placed in serial and both put in 100 ml 0.5M sulphuric acid solution.

Concentration of N_2O, CH_4, CO_2 and SF_6 was (also) measured in five 24 hour samples using the lung method described by Mosquera et al. (2002). Samples were taken at the same points as 24 hour ammonia samples and were analysed in the lab on fore mentioned gasses using a GC (GC8000, Interscience).

Particle matter was measured using the gravimetric method described by Ogink et al. (2011) at two points in both the ridge and sidewall acting as an air outlet (at 1/3 and 2/3 of the length of the barn) and at one point at the sidewall acting as an air inlet (halfway the length of the barn).

Odour was measured at one point halfway the length of the barn in both the ridge and the sidewall acting as an air outlet taking a 2 hour sample with the lung method and analysed in the lab using the olfactory method.

Table 18
Overview of methods and locations of gas, particle matter and odour concentrations on farms 1 and 8

	Inlet side wall	Outlet ridge	Outlet side wall
Ammonia	Sampling line (Innova)	Sampling line (Innova)	Laser
	Impingers at 1/2	Impingers at 1/3 and 2/3	Impingers at 1/3 and 2/3
CO2	Sampling line (Innova)	Sampling line (Innova)	Laser
	Lung method at 1/2	Lung method at 1/3 and 2/3	Lung method at 1/3 and 2/3
CH4/N2O	Lung method at 1/2	Lung method at 1/3 and 2/3	Lung method at 1/3 and 2/3
SF6	Sampling line (GC)	Sampling line (GC)	Sampling line (GC)
	Lung method at 1/2	Lung method at 1/3 and 2/3	Lung method at 1/3 and 2/3
PM2,5 and PM10	Gravimetric at 1/2	Gravimetric at 1/3 and 2/3	Gravimetric at 1/3 and 2/3
Odour		Lung method at 1/2	Lung method at 1/2

At the third farm (9) only CO_2 has been used as a tracer to calculate the ventilation rate. This method uses the measured CO_2 concentration of in and out going air together with the calculated and measured CO_2 production in de barn. The CO_2 production from the animals is calculated using the CIGR rules (CIGR, 2002 and Pedersen et al., 2008). As the possible CO_2 production in the compost bedding can be considerable, its contribution to the total CO_2 production cannot be ignored. Therefore the CO_2 production of the bedding is measured using the closed flux chamber method described in paragraph 7.2.2. This gives a CO_2 production per m^2 of bedding area that can be calculated to a production per cow. The CO_2 concentration in the flux chamber was measured every 5 minutes for at least 15 minutes using a photo-acoustic multi gas monitor (Innova 1312). The average CO_2 emission from the bedding was based on at least 20 measurements on the day after the barn measurement took place using formula (2) and converted to an emission per animal using the available bedding area per cow from table 17. By multiplying the CO_2 production per animal with the number of animals present in the barn the ventilation rate (m^3 per day) can be calculated as:

$$\phi = \frac{CO_2\text{−}production}{[CO_{2,in}]-[CO_{2,out}]} \tag{3}$$

The ammonia emission is calculated from the ventilation rate and the differences in ammonia concentration inside and outside the barn as:

$$E = \phi * ([NH_{3,in}] - [NH_{3,out}]) \tag{4}$$

7.2.4 Ambient circumstances and bedding temperature

Both during flux chamber and barn measurement the ambient inside barn temperature and relative humidity was recorded using Rotronic T en RH sensors (ROTRONIC Instrument Corp., Huntington, VS) with a precision of ± 1,0 °C en ± 2% respectively.
In most cases the bedding temperature around the flux chamber was measured five times at three depths: 0 cm, 20 cm and 40 cm.

7.3 Results

7.3.1 General

The flux chamber measurements took place on 9 farms during 19 days between November 2012 and November 2013. In total 99 spots were measured. Data from farm 1 were collected earlier on 4 days between March 2011 and July 2012 on 16 spots. Nine measurement days were in spring, four were in summer, nine were in autumn and one was in winter.
The barn measurements took place on 3 farms (1, 8 and 9) during 6 days between July 2012 and November 2013.

7.3.2 Ambient circumstances

The average temperature and relative humidity during the measurements was 15,9 °C and 80% respectively. The annual temperature pattern is clear from Figure 24. In month 1, 2, 8 and 12 no measurements took place. The average temperature during measurements on compost beddings was 16,4 °C en and wood chips bedding was 16,0 °C.

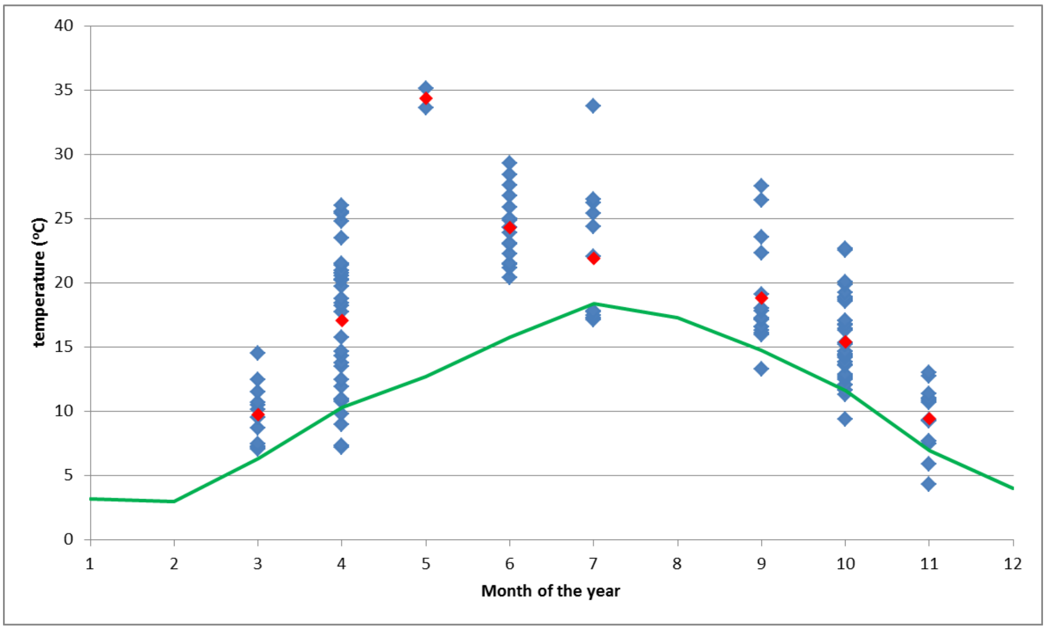

Figure 24. *Temperature per measurement against month of the year. Blue: temperature of measurement. Red: average temperature over all the measurements that month. Green: average outside temperature at De Bilt between 2010 and 2014 in that month (source: KNMI)*

7.3.3 Flux chamber measurements

7.3.3.1 Ammonia

The emissions in mg NH_3 per m^2 per hour from are presented in table 19.

Table 19

Results of NH_3 emission from the bedding in mg/m^2/h.

Farm	n[1]	NH_3 emission (Innova)	SE[2]	NH_3 emission (Impingers)	SE
1	16	190,4	42,9	154,2	83,8
2	9	177,6	26,6	163,8	38,4
3	9	216,2	33,1	207,6	39,7
4	16	358,4	76,9	346,5	65,7
5	7	246,7	18,1	59,6	28,0
6	10	512,9	88,1	356,2	105,7
7	10	593,6	151,1	837,8	152,7
8	5	70,5	23,1	319,1	80,1
9	10	119,2	38,3	123,2	63,2
10	9	503,3	121,2	1305,4	374,3

[1] Number of measurements; [2] standard error

To include the amount of space per cow into the results the emission of ammonia from the bedding was calculated using the innova and impinger data and the amount of available space from table 17.

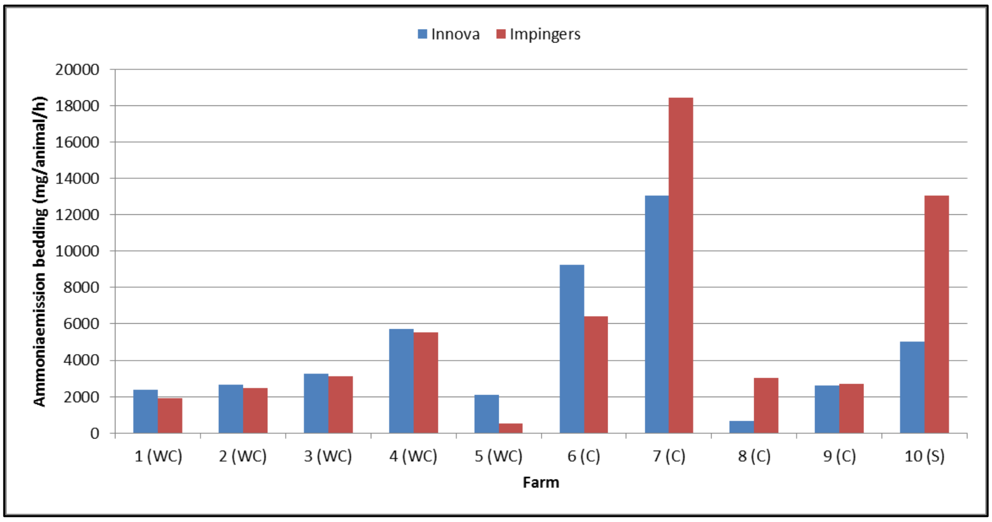

Figure 25. *Ammonia emission per animal per hour from the bedding based on flux chamber measurements*

To compare the emission from the bedded pack barns with the reference cubicle system with concrete slatted floor the results in table 19 are calculated to emission per *animal* using the available lying area per animal from table 17. This emission is added to the emission per animal from the concrete slatted walking floor (when available) using the 1200 mg NH_3 per m^2 per hour measured in another project before and again the available walking area from table 17. Farm 4 has instead of the concrete slatted floor a solid floor with a measured emission of 473 mg NH^3 per m^2 per hour. The comparison of the emission per animal from the bedded pack barn with the emission from the reference system both based on flux chamber measurements is given in Figure 26.

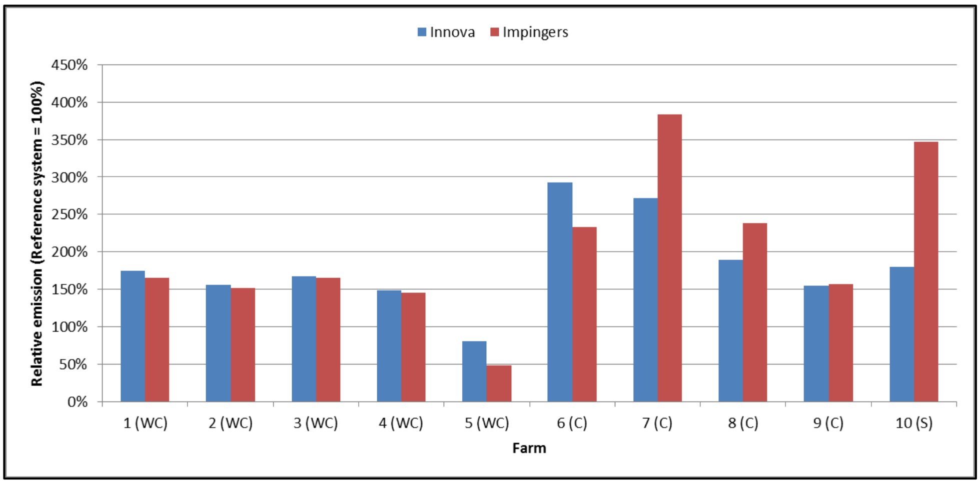

***Figure 26**. Relative emission per animal from bedded pack barns based on flux chamber measurements and compared to the reference system (cubicle system with concrete slatted floor=100%)*

7.3.3.2 Greenhouse gasses

The results of the N_2O and CH_4 emission are presented in table 20 and table 21 respectively.

Table 20
Results of N_2O emission from the bedding in mg per m^2 per hour.

Farm	n	N_2O emission [mg/m²/h]	SE
1	13	7,3	1,9
2	4	8,3	3,6
3	6	25,4	9,2
4	7	23,6	5,9
5	2	29,6	28,1
6	7	27,5	7,0
7	1	1,4	-
8	5	22,1	7,2
9	8	5,2	1,9
10	7	41,1	18,7

Table 21
Results of CH_4 emission from the bedding in mg per m^2 per hour.

Farm	n	CH_4 emission [mg/m²/h]	SE
1	13	82,1	32,5
2	4	37,7	13,9
3	4	242,8	66,3
4	6	162,3	78,2
5	5	147,3	55,4
6	2	6,1	4,3
7	4	161,0	56,5
8	5	1795,9	472,8
9	2	34,8	32,9
10	7	237,6	61,9

7.3.4 Barn measurements

The ammonia emission measured on barn level on three farms (1, 8 and 9) is presented in Figure 27. As described in paragraph 7.2.3 the ventilation rate of farm 1 and 8 has been measured using SF_6 as a tracer gas. For farm 9 CO_2 produced by animals and bedding has been used as a tracer gas.

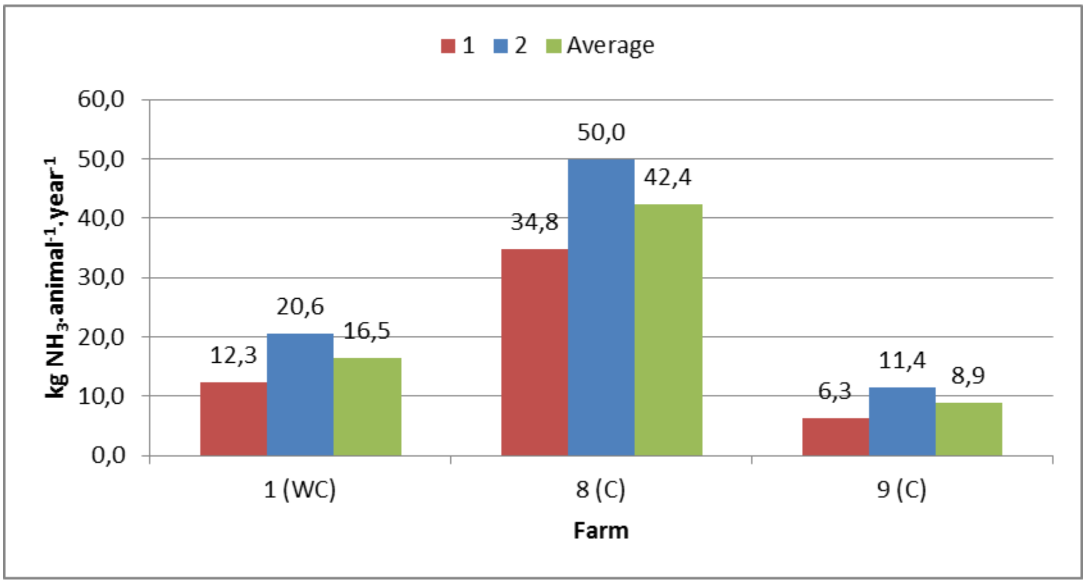

Figure 27. *The absolute ammonia emission based on barn level measurement of farm 1, 8 and 9. Emission calculated with SF_6 (farm 1 and 8) and CO_2 (farm 9) as tracers*

Table 22 and Table 23 give the results of other emissions of nitrous oxide, particle matter and odour.

Table 22
Results of NH_3, and N_2O emission per animal per year.

Farm	NH_3 [kg/animal/y]	SE	N_2O [kg/animal/y]	SE
1	16,5	4,2	2,7	0,8
8	42,4	7,6	2,6	2,2
9	8,9	2,6		

Table 23
Results of odour, PM2.5 and PM10 emission for farm 1 and 8.

Farm	Odour [OU/s/animal]	SE	PM2.5 [g/animal/y]	SE	PM10 [g/animal/y]	SE
1	360	334	-158	122,8	123	29
8	399	64	-373	-	181	105,4

7.3.5 Bedding temperature

At every flux chamber measurement the bedding temperature was measured at three depts. The average temperature per farm (1-10) for the three depths is given in Figure 28.

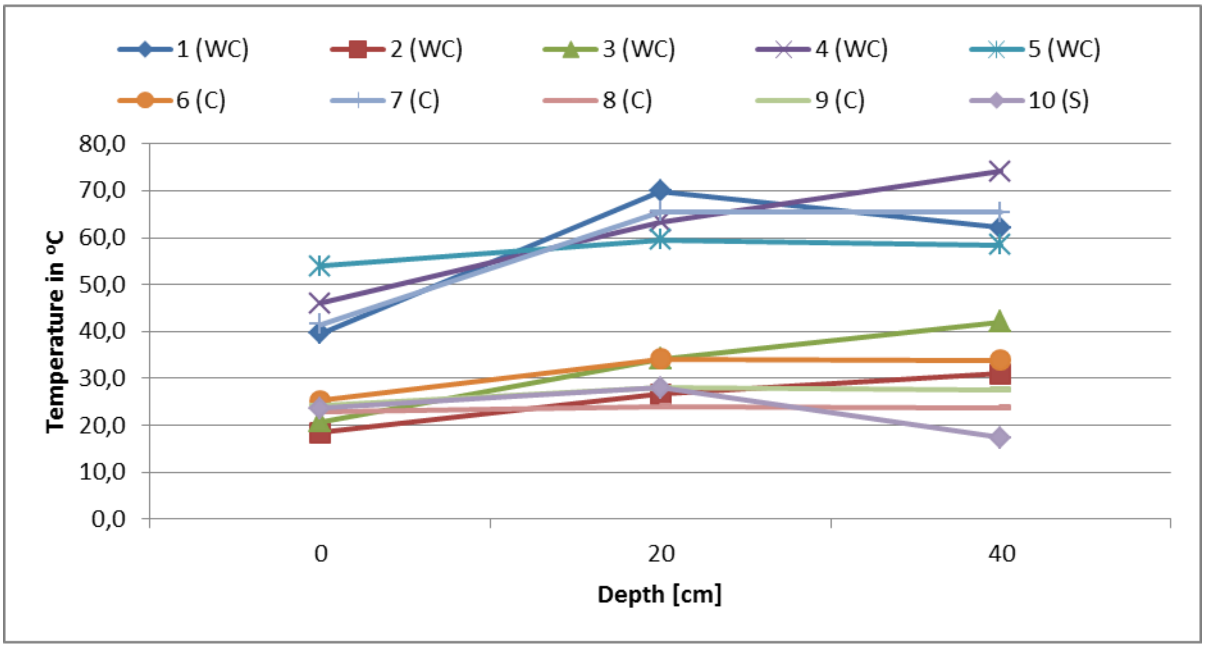

Figure 28. Bedding temperature at three depths for each farm (1-10).

The temperatures per depth fall apart in two groups: a group with a bedding temperature at 40 cm depth between 58 and 74 °C (average 65 °C) and a group with a bedding temperature at 40 cm depth between 17 and 42 °C (average 29 °C). Three of the five wood chips farms and 1 of the compost farms fall in the upper group.

7.4 Discussion

7.4.1 Ambient circumstances

The flux chamber measurements took place at temperatures between 4,3 and 35,1 °C reflecting all seasonal variation that can occur. The average temperature in month 5 (May) is higher than could be expected. Average of that months is based on measurement in May 2012 on farm 7. Outside temperature that month was higher than the average between 2010 and 2014 for that month (21,4 instead of 12,7 °C) and foil greenhouse roof led to high inside barn temperatures.

7.4.2 Flux chamber measurements

Innova versus impingers
The photo-acoustic multi gas monitors are known to be less accurate at low concentrations. Typical ammonia concentrations measured during flux chamber measurements are below 5 ppm.
A t-test showed that emissions per m^2 based on Innova measurement and impinger measurements are not significantly different ($p=0,36$).

Effect of bedding material
Averaged per type of bedding material (see table 24) the emission per m^2 from the wood chip bedding is lower than the emission from the compost bedding. Both differ significantly from the emission per m^2 of the reference (1200 mg NH_3 per m^2 per h). Straw, although based on only one farm, has the highest emission. Due to the lower space per cow, the emission per cow from the total bedding however is not significantly higher for straw.

Table 24
Ammonia emission from the bedding per type of bedding material based on innova measurements

Bedding material	Number of farms	Bedding area [m^2/cow]	NH_3 emission [$mg/m^2/h$]	SE	NH3 emission [mg/animal/h]	SE
Wood chips	5	13,4	237,9^a	32,4	3224^a	655,7
Compost	4	17,9	324,1^a	133,7	6396^a	2879,3
Straw	1	10	503,3^b		5033^a	
Total	10	14,9	298,9	57,6	4674	1206,6

^{a,b} The averages in a column with a different superscript letter differ significantly (P=0,05)

The relative emission based on flux chamber measurements per bedding material is given in Figure 29.

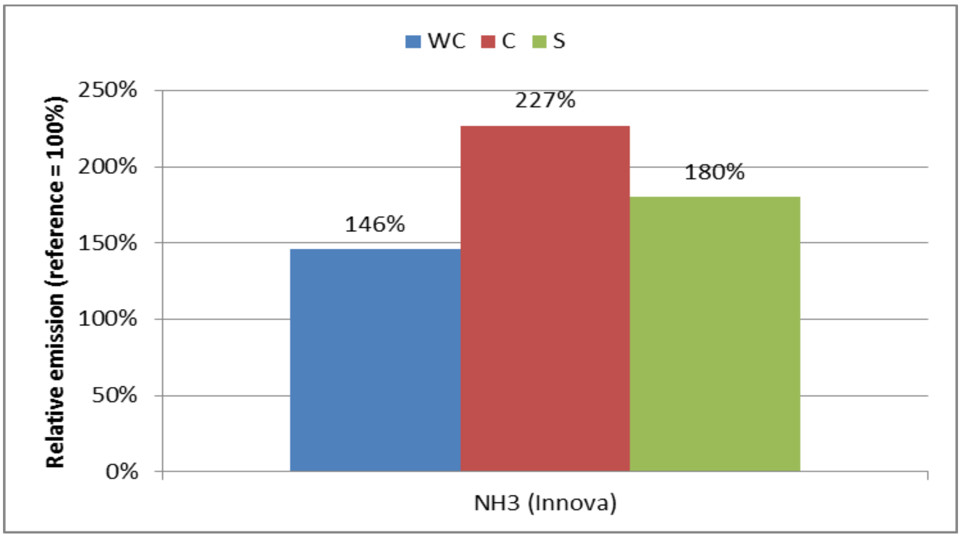

Figure 29. *Relative emission from bedded pack barns with different bedding material based on flux chamber measurements and compared to the reference system (cubicle system with concrete slatted floor=100%). WC=wooden chips, C=compost, S=straw*

The relative ammonia emission of wood chips does not differ significantly from the emission of the reference system (=100%). The relative emission of compost is significantly higher (p=0,03) than the emission from the reference system.

The emissions per m^2 of bedding did not differ significantly between compost and wood chips and were both significantly lower than the emission per m^2 from the reference system. The relative emissions of all materials were higher than the reference. This means that both the number of m^2 per cow and the emission from the (concrete) walking area play an important role in the total emission from the barn (based on flux chamber measurements). To reduce ammonia emissions from a bedded pack barn one can therefor either try to influence the emission from the bedding or from the (concrete) walking area. One option is to use a solid floor with a lower emission per m^2 as is used on farm 4. In Figure 30 the effect on total relative emission is shown. The average emission reduction as a results of this other floor is 29%.

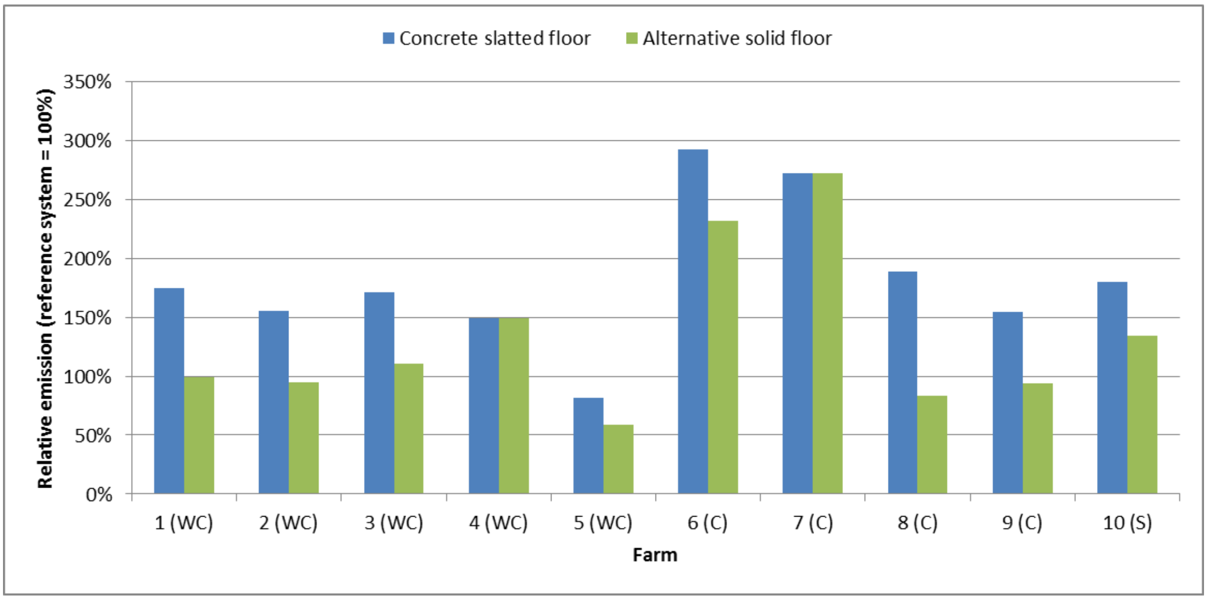

***Figure 30**.* *Relative emission from bedded pack barns based on flux chamber measurements and compared to the reference system (cubicle system with concrete slatted floor)*

Nitrous oxide (N_2O) emissions

Nitrous oxide is a strong greenhouse gas (298 times stronger than CO_2). It can be formed during biological processes in the bedding especially when both aerobic and anaerobic circumstances are available. Ammonia is transformed to nitrogen gas (N_2) in two processes called nitrification and denitrification. N_2O is an intermediate product and can emit. Temperature, pH and oxygen availability play an important role. The emission of nitrous oxide (laughing gas) from a cubicle system with concrete slatted floor and pits for slurry storage has not been measured before using a flux chamber. Mosquera and Hol (2012) calculated emission factors for this reference system. This emission factor is 0,23 kg N_2O per animal per year. Compared with this factor the relative emission from the different farms is given in Figure 31. All farms produced more N_2O than the reference system up to almost 19 times more. Averaged over bedding material straw had an almost two times higher emission compared to both compost and wood chips (Figure 32).

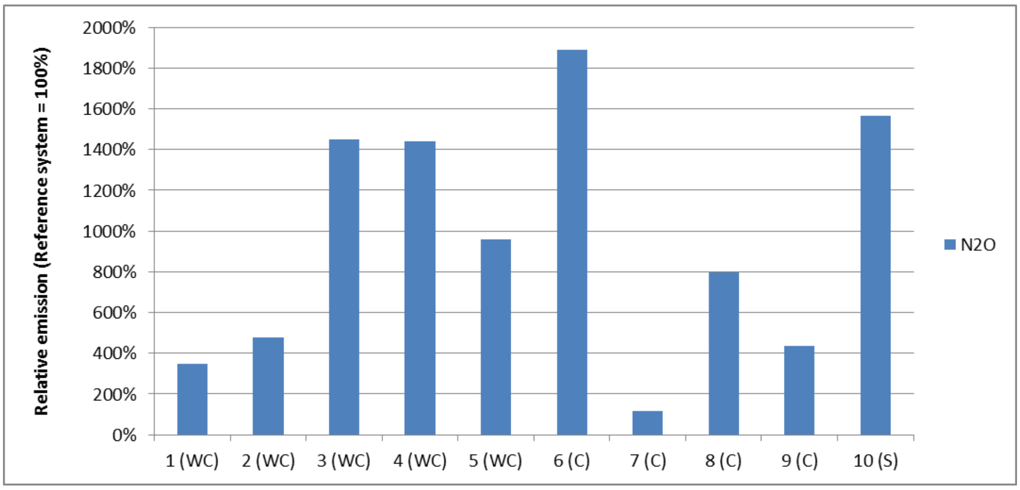

***Figure 31**.* *Relative emission of N_2O from bedded pack barns with different bedding material based on flux chamber measurements and compared to the reference system (cubicle system with concrete slatted floor=100%). WC=wood chips, C=compost, S=straw*

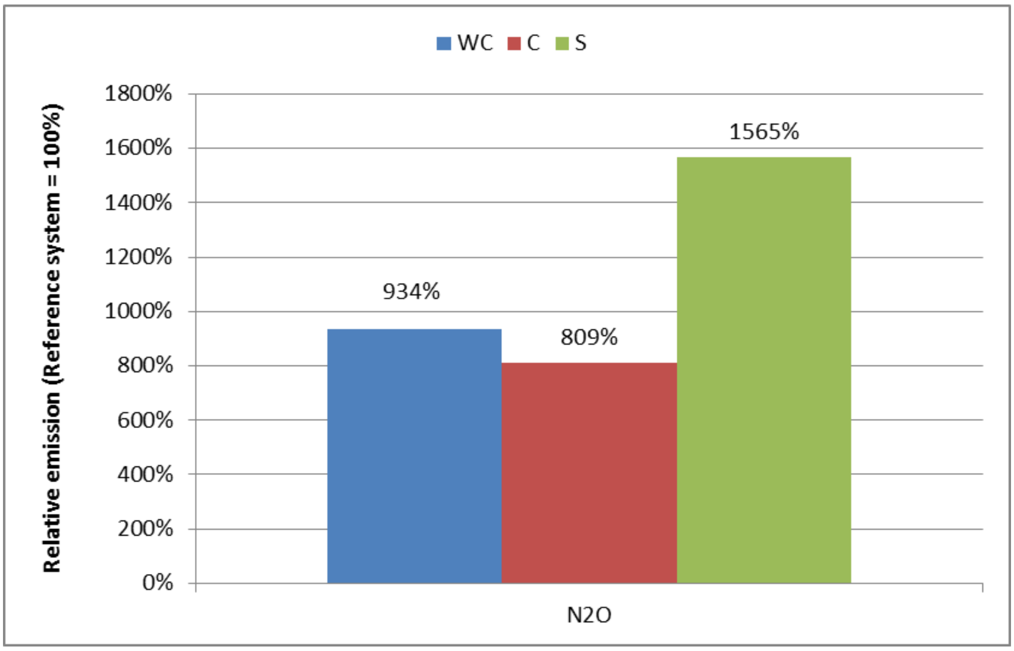

Figure 32. *Relative emission of N_2O from bedded pack barns with different bedding material based on flux chamber measurements. WC=wood chips, C=compost, S=straw*

Methane (CH_4) emissions
Methane is a strong greenhouse gas (25 times stronger than CO_2). It can be formed during biological processes in the bedding under anaerobic circumstances. It is produced in several steps from volatile solid available in the bedding or slurry. Intermediate products are volatile fatty acids, and they can be formed and emitted during the complex process. Temperature, pH and oxygen availability play an important role. However, a more important source of methane are the enteric processes in the rumen of cattle. Roughly 75% of the total methane emission from a dairy barn comes from the rumen. The emission of methane from a cubicle system with concrete slatted floor and pits for slurry storage has not been measured before using a flux chamber. Mosquera and Hol (2012) calculated emission factors for this reference system. This emission factor is 141,7 kg CH_4 per animal per year. Compared with this factor the relative emission from the different farms is given in Figure 33. All farms produced less CH_4 than the reference except for farm 8 that produced around 5 times more than the other farms. Averaged over bedding material compost had a three times higher emission the both compost and straw (Figure 34). These results only reflect the emission from the bedding. In all cases the methane from the enteric fermentation should be added to get a comparable emission factor per animal per year!

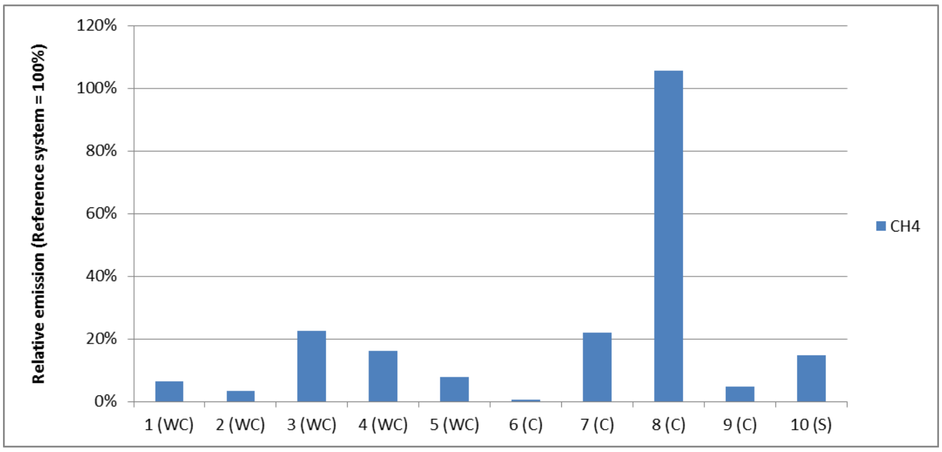

Figure 33. *Relative emission of CH_4 from bedded pack barns with different bedding material based on flux chamber measurements and compared to the reference system (cubicle system with concrete slatted floor=100%). WC=wood chips, C=compost, S=straw*

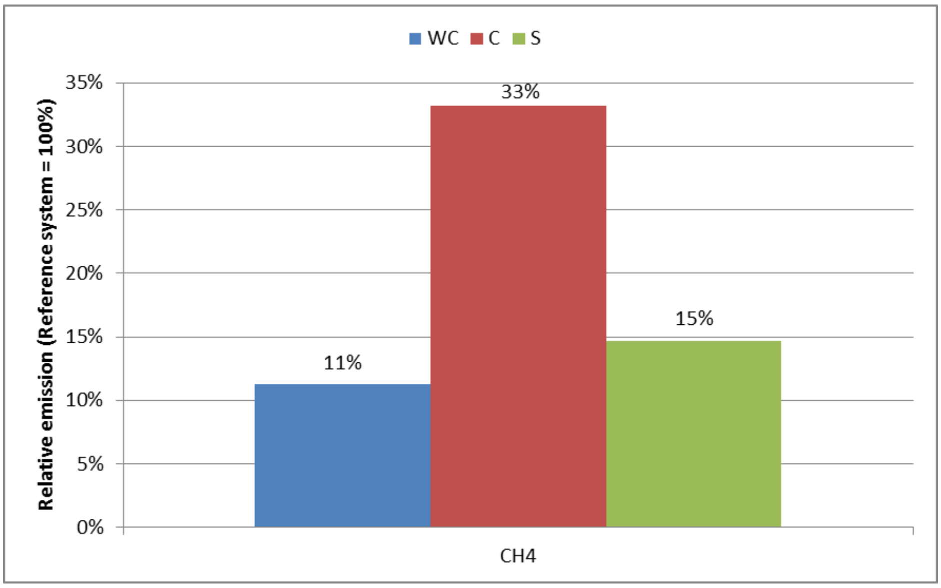

***Figure 34**.* Relative emission of CH_4 *from bedded pack barns with different bedding material based on flux chamber measurements. WC=wood chips, C=compost, S=straw*

7.4.3 Barn measurements

Ammonia emissions

The barn measurements of ammonia emission from wood chips at farm 1 and compost at farm 8 are similar with the flux chamber measurements. The ammonia emission from compost is higher than from wood chips. Both are higher than the emission level of the reference barn (11 kg NH_3 per animal place per year). The ammonia emission of farm 9 with compost is considerably lower than the ammonia emission of farm 8 with compost and even lower than the ammonia emission of farm 1 with wood chips. A possible reason for this lower ammonia emission at farm 9 is the fact that it were low producing cows with an average milk urea on days of measurement of 15 mg per 100 mg milk.

The measurements at farm 9 were based on the use of carbon dioxide as tracer. The contribution of the bedding to the total CO_2 production is considerable (9,2 and 5,3 g CO_2 per m^2 per hour). Expressed as production per cow it was 1,1 and 0,5 m^3 CO_2 per hour that is 32% and 21% of the total CO_2 production from cows and bedding during that measurement. This production was measured one day after the emission measurement of the barn. When the CO_2 production from the bedding of farm 1 and 8 measured during the flux chamber measurements are used the total production was 3,0 and 2,8 m^3 CO_2 per hour for farm 1 and 8 respectively. Related to the total CO_2 production of cows and bedding this is 13% for farm 1 and 10% for farm 8. These measurement of the CO_2 production from the bedding had however no close relation in time with the emission measurements on barn level and are based on five to six places as the results of the dedicated CO_2 measurements are based on 23 measurements. The estimation of the CO_2 production from the bedding is therefore more accurate at farm 9 than at farm 1 and 8. When ammonia emission of farm 1 and 8 is calculated based on CO_2 as a tracer gas and CO_2 production measured during the flux chamber measurements is included the emission of both farm 1 and 8 are lower than those based on SF_6 as a tracer.

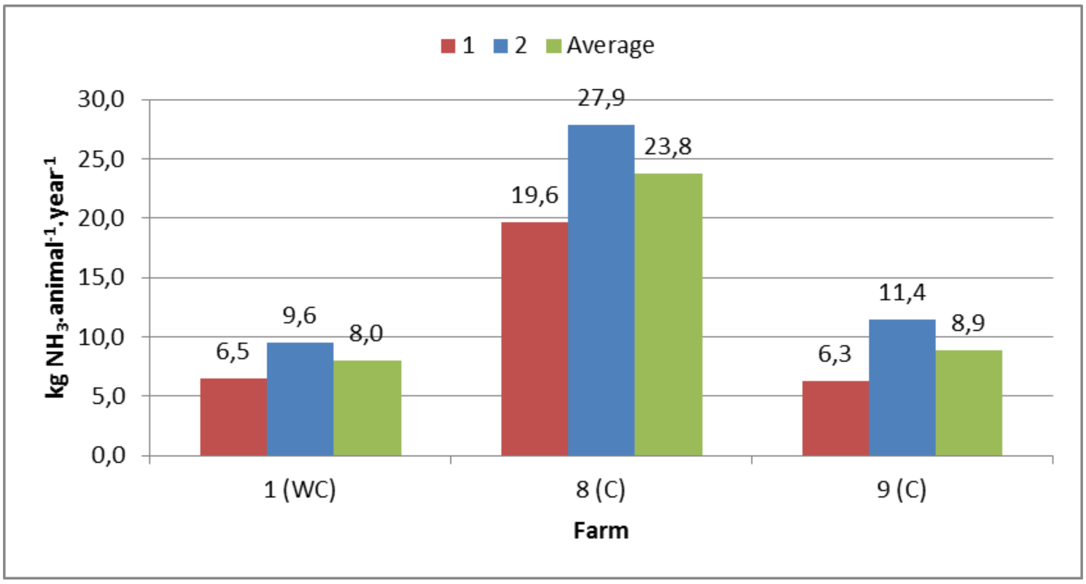

***Figure 35**.* *The absolute ammonia emission based on barn level measurements of farm 1, 8 and 9. Emissions calculated with CO_2 as a tracers*

Odour and particle matter emissions

There is no emission factor available for odour and PM2.5 for the reference system. The emission factor for PM10 is 148 g PM10 per animal per year. The measured emissions are just below (farm 1) or just above (farm 8) this emission factor. The average of both farms is 152 g PM10 per animal per year with a standard error of 47,7 gram. Based on these results there is no reason to assume that the emission of PM from compost or wood chips differ from each other significantly and are higher than the emission from the reference system. The negative emission of PM2.5 is probably caused by measuring inaccuracy. The concentration ranges from 0,0003 to 0,013 mg per m^3.

Mosquera et al. (2010b) report an odour emission of 165,5 OU_E per second for a reference housing system based on slurry storage underneath a concrete slatted floor. Emissions from farm 1 and 8 are higher and also the average odour emission is higher (380 OU_E per second per animal). However odour concentrations (OU_E per m^3) are low ranging from 30-135 and high emissions are mainly caused by high ventilation rates. It is likely that, although higher than the reference system, the use of compost and wood chips as bedding material will cause no problems.

Greenhouse gas emissions

Mosquera et al. (2010b) reports an emission of methane emission of 141,7 kg CH_4 per animal place per year (zero grazing) and a nitrous oxide (N_2O) emission of 225,1 g N_2O per animal place per year. Measured methane emission for both compost (farm 8) and wood chips (farm 1) were considerably lower than what would be expected from enteric fermentation only (around 125 kg CH_4 per animal per year). Unless large amounts of methane are oxidized, including part of the enteric produced methane, which is not very likely, the measured values should be considered as failures and are therefore not reported.

The emission of nitrous oxide is 11 to 12 times higher than from the reference system and does not differ much between farm 8 (compost) and farm 1 (wood chips) although the variation between the measurements was higher at farm 8. This is not surprising as the emission of nitrous oxide is related to nitrification and denitrification processes that take place in both aerobic and anaerobic circumstances. Due to more porous bedding compared to liquid storage of slurry, the aeration at farm 1 and the frequent tillage of the bedding in both farm 1 and farm 8 it is likely that nitrification and denitrification can occur in the bedding although maybe not always and throughout the whole bedding constantly (see Figure 36).

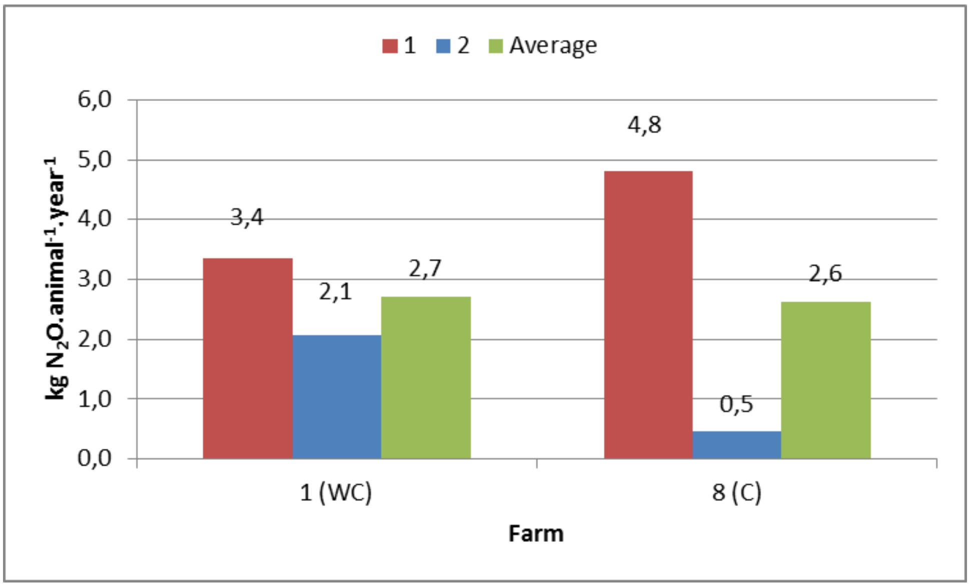

***Figure 36**. The absolute nitrous oxide emission based on barn level measurements of farm 1, 8 using SF_6 as tracer*

Nitrogen loss

Emission of ammonia and nitrous oxide can both be expressed as loss of nitrogen. Based on the two emission measurements on both farms Table 25 summarizes the nitrogen loss through emission of ammonia and nitrous oxide and compares these figures with the losses from a reference system.

Table 25

Results of NH3-N and N_2O-N emission of farm 1 and farm 8.

Farm	NH_3-N [kg N /animal/y]	% of total per farm	N_2O-N [kg N /animal/y]	% of total per farm	Total-N [kg N /animal/y]	% of reference system
1	13,6	89%	1,7	11%	15,3	166%
8	34,9	95%	1,7	5%	36,6	397%
Ref.	9,1	98%	0,1	2%	9,2	100%

The total loss of nitrogen for both compost and wood chips is higher than in the reference system and the loss of nitrogen from compost is more than twice as high as the nitrogen loss from the wood chips. The relative loss of nitrogen through nitrous oxide emission is higher for the wooden chips farm. This could be explained by the nature of the bedding where composting is a deliberate purpose to evaporate the moisture from urine and manure. The changes of nitrous oxide production and emission are more favourable than in the compost bedding.
These results are comparable to the results of the nitrogen balances in chapter 6 of this report.
It should be emphasised that the emission results are only based on two measurements per farm. However, the conclusions in the chapter about nitrogen balances are based on a long period in which nitrogen flows are monitored.

7.4.4 Bedding temperature

Averaged per bedding type (**Figure 37**) there are clear differences. The depth of 0 cm (surface) is highly influenced by the ambient temperature in the barn. No clear differences can be seen on that depth. But at the depth of 20 and 40 cm the temperature in the compost and straw bedding is clearly lower than in the (composting) wood chips bedding.

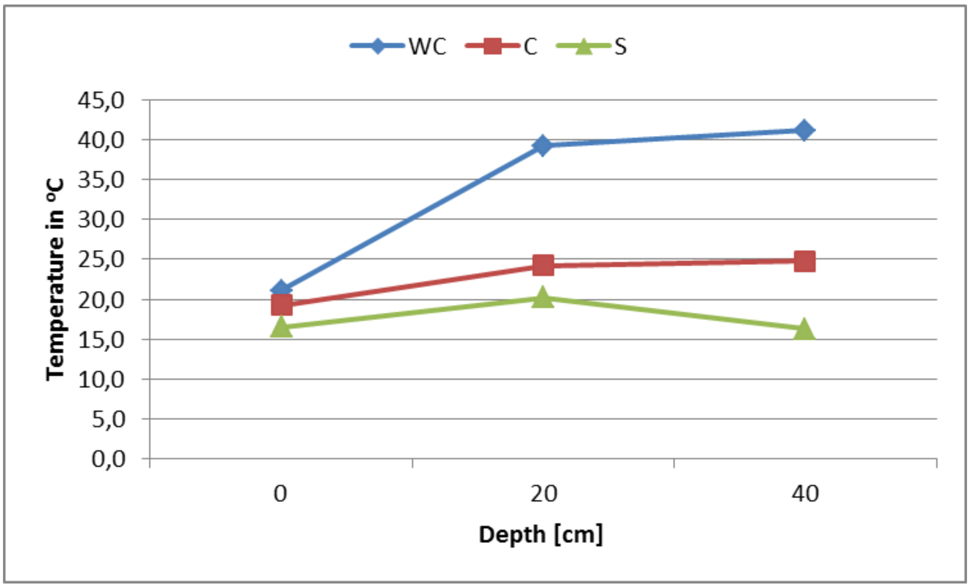

Figure 37. *Bedding temperature at three depths for bedding materials wood chips (WC), compost (C) and straw (S).*

These results reflect the aim of the farmers using wood chips: the production of heat through composting. The compost used in the other farm was already composted and did have less carbon available for heat production.

7.5 Conclusions

7.5.1 Flux chamber measurements

- The ammonia emission per m^2 area available for cows based on flux chamber measurements from a wood chips bedding was 238 mg NH_3 per m^2 per h and for a compost bedding 324 mg NH_3 per m^2 per h but did not differ significantly. The emission from a straw bedding was 503 mg NH_3 per m^2 per h and was significantly higher than the other two.
- For all three materials the emission per m^2 per h is lower than the emission of ammonia from a reference system.
- The higher available area per cow leads to a higher emission per cow from farms using wood chips, compost and straw. The emissions were 146%, 227% and 189% respectively compared to the reference system (=100%).
- Nitrous oxide emissions were 8 to 16 times higher than the reference system.
- Methane emissions were on the other hand considerably lower than what could be expected from the reference system.

7.5.2 Barn measurements

- Average ammonia emission from the farm using wood chips as bedding material (farm 1) was 16,5 kg NH_3 per animal per year with SF_6 used as a tracer gas.
- Average emission emissions from the farms using compost as bedding material was 8,9 (farm 9) and42,4 (farm 8) kg NH_3 per animal per year using CO_2 and SF_6 as a tracer gas respectively.
- Emissions of nitrous oxide from farm 1 (wood chips) and farm 8 (compost) were 2,7 and 2,6 kg N_2O per animal per year, more then 10 times higher than emission from the reference system (0,23 kg N_2O per animal per year).
- The loss of nitrogen through emission of ammonia and nitrous oxide was more than two times higher for farm 8 (compost) compared to farm 1 (wood chips) and ranged from 166% to 397% of the emission from the reference system for farm 1 and 8 respectively.

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Appendix 1

Gaseous N losses from a reference free stall and after liquid manure application.

Gaseous N losses from the reference free stall barn and after application of liquid manure to farmland are derived from data provided by Velthof et al. (2009) and Velthof and Mosquera (2011), and related to a reference N excretion level in the barn. For a free stall barn with concrete slatted floor and year round housing (no grazing), a total N excretion of 131 kg N cow^{-1} year^{-1} was used (p. 77, Velthof et al., 2009). Total gaseous NH_3-N loss related to that excretion level is 11.6 kg N cow^{-1} year^{-1} (p.77, Velthof et al. 2009), or 8.9% of excreted N.

The amounts of gaseous N lost after manure application are not directly given by Velthof et al. (2009), but can be derived from their data. For liquid cattle manure, the standard NH_3 emission factor used in the Netherlands is 19% of applied NH_4-N after shallow injection into grassland (Velthof et al., 2009). With an average total N and NH_4-N content in liquid cattle manure in the Netherlands of 4.1 and 2.0 kg Mg^{-1}, respectively (Adviesbasis bemesting, 2014), this means that 9.3% of applied total N volatilises as NH_3. The percentage of N_2O-N lost after shallow injection of liquid manure into grassland was estimated at 0.3% of total N (Velthof and Mosquera, 2011). This gives a total gaseous N loss (as NH_3 and N_2O) after manure application of 9.6% of applied N. This percentage is a little underestimated, because also some N will be lost as NO_x and N_2. However, these amounts are not known. Applied N is initially excreted N minus total gaseous N lost from the barn, and amounts to (131-10-1.6) = 119.4 kg N cow^{-1} year^{-1}. Thus, (119.4 x 0.096) = 11.4 kg NH_3-N, or 8.7%, is lost from initially excreted N. An overview of the used data is given in Table 26.

Table 26

N excretion level in the barn and gaseous N losses from the barn and after application of liquid manure to grassland, for a reference free stall barn in the Netherlands, expressed in kg N per cow per year (data from Velthof et al., 2009)

	Winter period	Grazing period	Total
N excretion	69.3	61.7	131
NH_3-N lost in barn	4.60	5.40	10.0
Other gaseous N lost in barn[1)]	0.85	0.78	1.60
Total gaseous N loss in barn	5.45	6.18	11.6
N-NH_3 lost after manure application	5.92	5.15	11.1
N_2O-N lost after manure application	0.17	0.15	0.32
Total gaseous N loss after manure application	6.09	5.30	11.4

[1)] Amounts are slightly different from amounts reported by Velthof et al. (2009), because in this table the amounts are calculated by subtraction of amounts of NH_3-N lost in the barn from total gaseous N lost in the barn

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