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Report 707

On farm development of bedded pack dairy barns in The Netherlands

Introduction and first experiences on three farms

March 2014

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Abstract
This report is an introduction for four other reports about bedded pack barns. It describes the bedding and management of three commercial farms involved in the research. It also gives an overview of the total research, types of bedding and the learning process.

Keywords
Bedded pack barns, types of bedding, learning process, recommendations

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On farm development of bedded pack dairy barns in The Netherlands

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Preface

This report is the first of a series of five reports on the development of bedded pack barns on three commercial dairy farms in the period 2010 till mid-2013. This research is a continuation of a tentative study on the feasibility of bedded pack barns and experiments on experimental farms and is funded by the Dutch Dairy Board and Ministry of Economic Affairs. The research and the communication concerning the three commercial farms have much impact in the Netherlands and abroad. The way of thinking about sustainable housing systems has changed. During the development of the free stall barn system from the late 60's in the last century the focus was on increasing labour efficiency. The increasing interest in bedded pack barns has drawn attention to especially improving animal welfare and manure quality. The financiers also asked, in addition to these aspects, to study any negative effects on environment and milk quality.

This report is an introduction into the status of the overall bedded pack barn system research and management of the bedded pack at three bedded pack barn systems in practice. In three other reports animal welfare & milk quality, nutrient balances & manure quality and emissions from the barn are described. In the 5th report the various components are integrated and the perspective of bedded pack barn systems is explained from the points of view from the farmer, the animal, the environment and the public.

I want to thank the three dairy farmers Meindert Wiersma, Jeroen Groenewegen and Marc Havermans sincerely for sharing their experiences and for providing their farms and data for research. As pioneers in the dairy industry they are an example to many who are interested in a bedded pack barn and especially for those who have actually built one, in the Netherlands as well as abroad.

I also want to thank my colleagues Klaas Blanken for collecting data of these three farms and Hendrik Jan van Dooren, Herman de Boer, Wijbrand Ouweltjes and Judith Poelarends for their critical remarks.

Paul Galama
Project manager bedded pack barns

Samenvatting

Het onderzoek naar vrijloopstallen voor melkvee is in 2008 gestart met een voorstudie naar de haalbaarheid en experimenten met drie verschillende bodems op proefbedrijven. Dit onderzoek en de voorbeelden uit Amerika en Israël hebben pioniers geïnspireerd een vrijloopstal te bouwen. Drie pioniers zijn in de periode 2010 tot medio 2013 intensief gemonitoord qua dierenwelzijn, diergezondheid, melkkwaliteit, emissies in de stal, nutriënten balansen, mestkwaliteit en economie. De resultaten hiervan zijn beschreven in 4 deelrapporten, waarvan één rapport het totaal perspectief van vrijloopstallen schetst.

Dit rapport beschrijft de stand van zaken van het onderzoek naar vrijloopstallen en het belang van participatief onderzoek met praktijkbedrijven in combinatie met experimenten onder gecontroleerde omstandigheden. Op die manier wordt veel geleerd en versnelt het innovatieproces. De drie praktijkbedrijven Wiersma, Groenewegen en Havermans hebben hierin een belangrijke rol gespeeld. Hun vrijloopstal en het management van de bodem is beschreven in dit rapport. Hun belangrijkste motivatie voor een vrijloopstal komt voort uit de behoefte naar beter dierenwelzijn, langere levensduur vee en mest die de bodemvruchtbaarheid verbetert. Het bedrijf Wiersma kenmerkt zich door een bodem met houtsnippers waarin met een beluchtingssysteem via de onderlaag het composteringsproces extra gestimuleerd wordt. De compostering in de stal zorgt voor warmteontwikkeling waardoor er veel vocht verdampt en daardoor de toplaag droog blijft. Dit resulteert in een toplaag die gedurende het hele jaar stabiel is en na een jaar een waardevolle meststof oplevert met veel organische stof. De bedrijven Groenewegen en Havermans gebruik beide gft compost van een composteringsbedrijf als bodemmateriaal. Via absorptie van vocht blijft de toplaag droog. De ‘compost verrijkt met mest’ uit de stal levert een waardevolle meststof op. De innovatieve stal van Havermans kenmerkt zich door een foliekas als bovenbouw en een stalinrichting zonder voerpad met loopgang. Koeien worden op de vrijloopbodem gevoerd via verplaatsbare voerbakken. Alle mest komt dus op de vrijloopbodem, terwijl op bedrijf Wiersma en Groenwegen ca. de helft als drijfmest wordt opgeslagen in mestkelders onder de loopgang.

De drie melkveehouders hebben ervaring met zelf composteren in de stal en gebruik van gft compost in een stal met en zonder betonnen voerpad en loopgang. Hoewel er ieder jaar nog geleerd wordt zijn hun aanbevelingen tot nu toe:

Compostering bodem (met houtsnippers en beluchten (blazen)):
- Bij 15 m2 per koe vrijloopruimte lukt het gedurende het hele jaar een droge hygiënische toplaag te realiseren. 12 m2 per koe vrijloopruimte lijkt haalbaar, mits composteringsproces continue goed verloopt.
- Start in november, omdat dan vers materiaal beschikbaar is en de bodem gedurende de wintermaanden nog voldoende poreus is om vocht op te vangen.
- Belucht het bodemmateriaal meerdere keren per dag kort; 8x per dag gedurende 15 minuten
- In de winter niet te diep bewerken (ca. 10 cm) en in de zomer wel diep bewerken (ca. 30 cm)
- In de winter iedere maand bijstrooien

Compostbodem (met gft compost);
- 15 m2 per koe vrijloopruimte nodig om toplaag voldoende droog te houden. In een stal waar de gehele stal uit een vrijloopbodem bestaat is 30 m2 per koe nodig.
- Wees kritisch op het aangevoerde materiaal; moet voldoende droog zijn en weinig zand bevatten
- In de winter ondiep bewerken (ca. 10 cm)
- Tijdig bijstrooien, omdat als bodem te nat wordt de draagkracht sterk afneemt
- Een foliekas zorgt voor extra droging van de toplaag door veel zonlicht en ventilatie door het dak

Summary

The Dutch research on bedded pack barn systems for dairy cattle started in 2008 with a tentative study on the feasibility and experiments including three different types of bedding material on experimental farms. This research and examples from America and Israel have inspired forerunners to build a bedded pack barn. In the period 2010 till mid-2013 three pioneers were intensively monitored in terms of animal welfare, animal health, milk quality, emissions in the barn, nutrient balances, manure quality and economy. The results are described in four sub-reports, all related to this report, including one report outlining the total perspective on sustainability of bedded pack barn systems.

This report describes the status of the research on bedded pack barns and the importance of participatory research with commercial farms in combination with experiments under controlled conditions. In this way a lot is learned and the innovation process accelerates. The three farmers Wiersma, Groenewegen and Havermans have played an important role. Their bedded pack barns and the management of the bedding material are described in this report. Their main motivation for a bedded pack barn system originates from the need for better animal welfare, longevity of the cows and manure quality that improves the soil fertility. The bedded pack barn of Wiersma is characterized by bedding material consisting of fresh wood chips in which the composting process is stimulated by an aeration system underneath the wood chips layer. The composting process in the pack creates heat causing evaporation of much moisture resulting in a dry top layer. This composting process ultimately results in a valuable fertilizer with a high content of minerals and organic matter. The farms of Groenewegen and Havermans both use organic waste compost from a trading company in compost materials as bedding material. By absorption of moisture the top layer remains dry. The 'compost enriched with manure' from the barn also provides a valuable fertilizer. The innovative barn of Havermans is characterized by a special superstructure of a foil greenhouse and a construction without feed alley and walking area. Cows are fed on the bedded pack by movable feeding troughs. Therefore, all the manure is excreted on the bedded pack, while at the farms of Wiersma and Groenewegen roughly half of it is stored as liquid manure in manure pits under the slatted floor and the walking area.

The three farmers have gained experience with different types of bedding material in the lying area for the cows. Although their learning is continued every year their recommendations so far are:

Composting bedded pack (with wood chips and aeration system (forced air)):

- At 15 m2 bedded pack space per cow it is possible to achieve a dry hygienic top layer throughout the year, 12 m2 bedded pack space per cow seems feasible, provided that the composting process progresses well continuously.
- Start with new bedding material preferably in November, because then fresh material is available and during the winter season the top layer is still sufficiently porous to absorb moisture.
- Aerate the bedding several times for a short period, e.g. 8 times a day for 15 minutes.
- Do not work the pack too deep in the winter season (approximately 10 cm), but work deeper in the summer season (about 30 cm).
- Litter monthly in winter.
- Per cow about 5 tonnes of material is needed in order to keep the thickness of the layer at about 50 cm.
- The temperature in the bedded pack ranges from 40 to 50 degrees Celsius.
- Remove bedding material from the barn when the C:N ratio is less than 15:1.

Bedded pack of compost (with organic waste compost);

- 15 m2 bedded pack space per cow is needed to keep the top layer sufficiently dry. In a barn provided entirely with a bedded pack 30 m2 per cow is needed.
- Be critical of the supplied bedding material, it should be sufficiently dry and contain only little sand
- In the winter season work the pack superficially (approximately 10 cm), but in the summer season about 30 cm deep. Litter the bedded pack in due time, because when the pack becomes too wet (about 35% ds) the firmness of the pack and related to this the bearing capacity of the bedded pack strongly decreases.
- A foil greenhouse provides additional drying of the top layer by sunlight and ventilation through the roof.
- Per cow approximately 8.3 tonnes of material is needed.

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1 Introduction

Free stall barns for dairy cattle have been widely used for more than 40 years, and are still the most commonly used housing system in the Netherlands. This system was developed in the 1960s, mainly to improve labour efficiency. Today the emphasis has shifted towards animal welfare. Main animal welfare and health problems relate to the need for more space per cow and softer walking surfaces (less concrete) and less steelwork in the barns (Somers et al., 2003; Haskell et al., 2006; Burow et al., 2011). The demands of the cow, the farmer, the environment and consumers have become more important. If we integrate these demands into free stall barn systems, the costs of these systems might increase. Question is, whether it is possible to develop a different housing system that especially meets the demands concerning animal welfare, emissions and milk quality.

Since 2007, a network of dairy farmers started searching for alternatives to the free stall barn that can strongly improve animal welfare, reduce environmental impact, increase manure quality and be cost-effective. During this search for alternatives the group became interested in bedded pack barns based on experiences in the USA with Compost Dairy Barns where they use wooden chips and sawdust as bedding and Israel with dried manure as bedding.

Dried manure as bedding in Israel

Bedded pack barns have no cubicles. The resting and walking areas are combined like a deep litter system with straw. This area is also manure storage together with the bedding material. This combined resting and walking area is spacious and provides a soft, permeable and/or moisture-absorbing bedded pack (Galama et al, 2008 and 2011). Farmers liked the idea of bedded pack barns, because of the possibilities to increase animal welfare, animal health, the longevity of the cows and to increase the manure quality with more organic matter and to decrease the volume of manure. The challenge is to find a bedding that can be kept dry under Dutch climate circumstances.

Following the ideas of the farmers network in 2007 and 2008 an innovation process with experiments and studies around bedded pack barns started and is still (2013) going on. The participative innovation process with researchers and farmers started at the end of 2008 with feasibility studies. From 2009 until 2010 research was done on experimental farms with three different beddings: sand, wood chips together with sawdust and a bedding of dried clay or dried peat with reed. After that in 2010 research has been started on three commercial farms: one is composting wood chips with an aerating system and two are using compost (organic waste (from households) compost or green waste compost) from a composting plant.

This search for other housing systems was supported by the Ministry of Economic Affairs with subsidies for the farmers network. In this network farmers look for new options in cooperation with scientists and experts (composting experts, architects, barn suppliers) to develop their farm sustainably (Wielinga et al., 2008 and 2010). Researchers were facilitating the process within this farmers network. This network put the subject of bedded pack barns on the research agenda of the Dutch Dairy Board (PZ). From that moment on different types of research have been done. Table 1 shows the different phases of research until now (2013).

Table1 Phases and types of research

Year	phase	type of research	report	Reference
2007 / 2008	1: oriëntation	network of interested farmers		
		international visits (Amerika, Israël)	244	Dooren et al (2009)
2008	1. Feasibility studies	labexperiments (ammonia emission different materials)	231	Smits et al (2009)
		model calculations (evaporation of water of the bedding)	230	Smits et al (2009)
		model calculations (economy)	238	Dooren et al (2009)
2009 / 2011	2. Pilots	experiments on research farms (with 20 cows)	411	Dooren et al (2011)
		(three types of bedding)	book	Galama et al (2011)
	2. In depth	experiments with different materials	608	Smits et al. (2012)
2010 / 2013	3. On farm	monitoring & evaluation on three commercial farms	5 reports	see table 2
	3. Modelling	modelling economics	in prep.	
		modelling composting process	in prep.	
2013	4. On farm	monitoring & evaluation on ten commercial farms		

In 2009 the first dairy farmer in the Netherlands invested in a bedded pack barn, from 2010 onwards more farmers built such a barn, all with different bedding material. It is estimated that around 30 dairy farmers have built a bedded pack barn until now (mid 2013). Most of the commercial farmers were interested in a bedding with a composting system where the heat in the bedding evaporates the moisture in the bedding and a bedding of compost to absorb the moisture. For that reason and based on the evaporation study research on three commercial farms started in 2010 with these types of bedding.

This report describes the different types of bedded pack barns in general and the specific bedding management of these three commercial farms. It is an introduction of the total research described in different reports (Table 2).

Table 2 Five reports about research on three commercial bedded pack barns

Rapport	Titel	Auteurs
707	Introduction and first experiences on three farms	Galama
708	Animal welfare and milk quality	Ouweltjes
709	Nutrient balances and fertilizer value of bedding material	Boer, de
710	Gaseous emissions from housing	Dooren, van
711	Overall sustainability: status and outlook	Galama et al

The research described in these five reports was financed by the Dutch Dairy Board (PZ) and the Dutch Ministry of Economic Affairs.
Chapter two of this report describes the interaction between different types of research in relation to the innovation process. Chapter three describes the different types of bedding in general and chapter 4 the management of the bedding on three commercial farms in more detail. Chapter 5 reflects on the innovation process and chapter 6 gives conclusions and recommendations based on experiences about the management of three bedded pack barns.

2 Interaction between different types of research

Table 1 in the introduction shows the different types of research projects. There is a strong interaction between these projects which stimulates the innovation process. The innovation process started in 2007 with a network of farmers who got inspired by international visits to the USA (Proceedings, congress June 2007, Minnesota) and Israel. In 2008, the network managed to get bedded pack barns on the research agenda of the Dutch Dairy Board and the Ministry of Economic Affairs, Agriculture and Innovation. As a result, several studies and experiments related to the new housing system were started. The learning process with farmers, stakeholders and scientists about the bedded pack barns started and is still continuing. The lessons of this process are described by using the DEED model (in general by Giller et al. (2008) and for bedded pack barns by Galama et al. (2011)). DEED stands for 'describe', 'explain, 'explore' and 'design'.

Figure 1 shows the interaction between different types of research which lead to a continuous process of learning and re-designing of the barn and the management of the bedding.
The most important drives of the farmers for bedded pack barns are improved animal welfare, longevity of the cows, better manure quality and economy. To achieve these aims different barn designs and types of bedding are described and discussed with experts. All the small experiments on lab scale, modelling studies, research on experimental and commercial farms that followed contribute to the process that explains the influence on sustainable aspects, that explores new ideas and results in new designs of the barn and management of the bedding. The sustainability aspects relate to the drivers but also to possible conflicts with environment or milk quality.

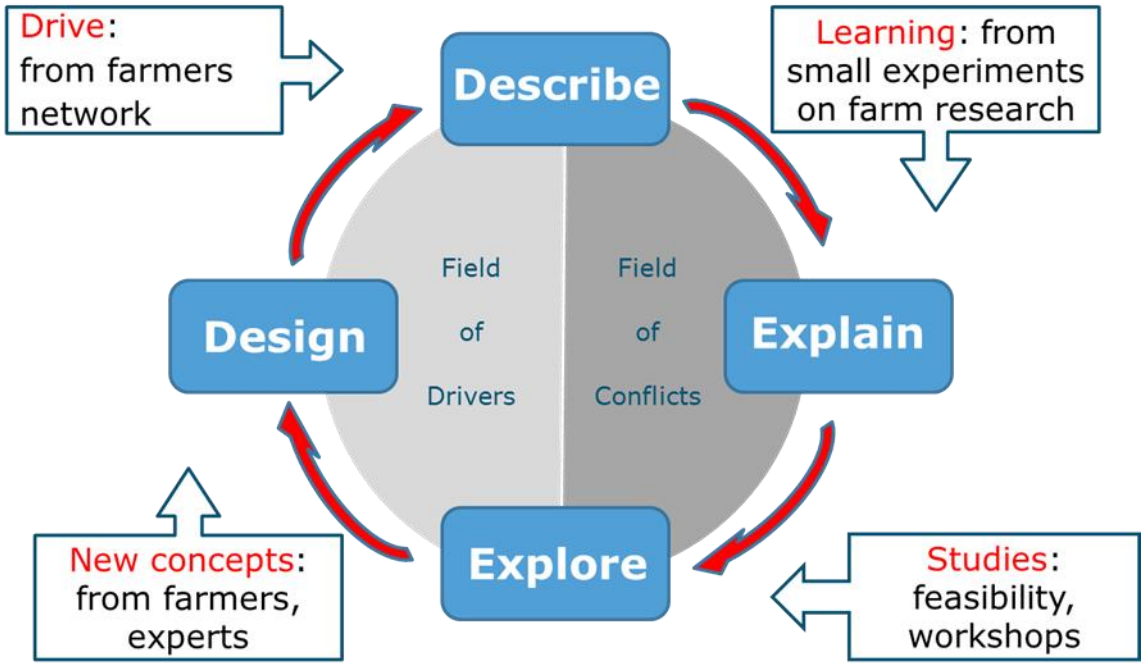

Figure 1 Innovation process of participative research around bedded pack barns

The farmers in the farmers network came up with ideas for different types of bedded pack barns (describe). In 2008, a feasibility study was done on the prospects of bedded pack barns in the Netherlands (explore). This was a study on evaporation of water in the Dutch climate compared to North America and Israel, a lab experiment to measure the ammonia emission of different materials and an economic study. Based on these studies three new designs are made with farmers and experts (design). To keep the top layer dry, three experimental farms of Wageningen UR Livestock

Research have tested three different bedding materials (explain):

- Sand pack to drain moisture and separate faeces and urine.
- Composting bedded pack to evaporate moisture by heat development in the pack and fixate the nitrogen.
- Compost bedded pack and bedded pack of dried clay or peat with reed to absorb moisture by large amounts of dry material and fixate of nitrogen.

Also two small experiments (2011 and 2012/2013) were done with different materials to characterise the materials for use of composting and to study the influence of materials and aerating on the ammonia emission (explain).

Since 2009 commercial farmers invested in bedding with compost from a compost plant and composting wooden chips. In this report we describe the experiences of the three commercial farms that keep the bedding dry by composting (one farm) or by absorbing moisture with compost bedding (two farms). The compost is waste from households that is composted on a compost plant. The focus of the research is on environmental issues, because more space per cow can conflict with emissions. But also the contaminants in the bedding and the milk can be a risk for the quality of the milk and mastitis. Therefore also in depth research is done on this aspect.

The process of learning from studies, small experiments on lab scale and monitoring and evaluation on commercial farms together with discussions with farmers and experts in workshops is still going on. This leads to continuous new ideas for bedding material, management of the bedding and farm designs.



Several workshops and discussions with dairy farmers and experts are organised, leading to new questions and ideas

3 Types of bedding materials and bedded pack barns in general

The deep litter barn with straw is a well-known system and is also a type of bedded pack barn. The disadvantages are the costs of providing straw and little evaporation of moisture. The current development of bedded pack barn systems focuses on different types of bedding material that are distinguished in the way of eliminating / absorbing moisture in the top layer and reducing nitrogen losses (see Table 3).

Table 3 Classification types of bedded pack / bedding material in bedded pack barns

No.	Type of bedded pack	Bedding materials	Moisture	Nitrogen
1	Composting process: a. additional aeration by forced air b. additional aeration by sucking air c. no additional aeration	Wood chips, fresh compost, solid fraction of manure, combinations	Evaporation by heat production in the bedded pack	Fixation
2	Absorption	Organic waste compost, Green compost, Dried dredgings Straw	Absorption	Conversion / fixation
3	Drainage	Sand Synthetic floors	Drainage	Separation of faeces and urine

In the composting process much moisture evaporates and nitrogen is fixated by the bedding material. The composting process can be stimulated by additional aeration by forced air (blown from underneath the pack) or sucking of air (opposite of blowing). The nitrogen is also fixated in moisture absorbing types of bedding material containing for example compost materials from a composting plant. In draining bedding materials urine is collected through the bottom layer and the faeces is removed from the top layer. Using sand as bedding material the separation is more difficult than using a synthetic floor, because some of the manure and the urine will mix with the sand layer. On a synthetic floor the separation of urine and faeces is easier. Different types of synthetic floors are being developed.

Examples of three bedding types: Composting wood chips, dried dredgings and sand

The different types of bedded packs and bedding materials determine on one hand the drying of the top layer and on the other hand how N-emissions can be limited, but also determine the type of manure. The farmers' choice for a new barn will therefore be more and more determined by the type of desired manure, namely slurry or separated faeces and urine or 'compost enriched with manure'.

In the year 2013 about 30 bedded pack barns are in operation in the Netherlands, most of them using composting of wood chips in combination with some form of aeration (moisture evaporation) or use of compost materials from a composting plant (moisture absorption).

4 Types of bedding material and bedded pack barns of the three commercial farms

The three farms participating in the research are Wiersma, Groenewegen and Havermans. Their main driver to choose for a bedded pack barn system is to improve animal welfare, particularly by less claw problems and more comfort for cows when lying down and getting up. Thus they also aim at more longevity of the dairy cattle. But also the manure quality is important. Jeroen Groenewegen started a dairy farm on what was previously a crop farm and therefore appreciates manure containing much organic compounds.

Farm Wiersma is inspired by the development of bedded pack barns in Minnesota (USA) where wood chips and sawdust are composted in the barn. To manage the composting process better and because sawdust is very expensive that farm has chosen for additional aeration of bedding material consisting of wood chips only. The farms Groenewegen and Havermans are inspired by the design of the first bedded pack barn in the Netherlands since 2009 by farm Peeters. That farm was inspired by participation in the study trip to Israel in 2008 where the cows are housed on dried manure. However, dried manure as bedding material in the Netherlands does not appear to keep the top layer dry enough. A bedded pack with absorbing compost material may do so. Farm Peeters has implemented a bedded pack with compost material in one half of the barn without walking area along the feed alley and cubicles on the other side of the feed alley. In 2010 this farm stopped using this bedding material, since it needed too many m2 per cow.

Farm Peeters was the first bedded pack barn in the Netherlands with compost material

Farms Groenewegen and Havermans have chosen such a compost bedded pack because of the lower price for the bedding material and according to them the management is easier than the composting process with wood chips.

The three farms Wiersma, Groenewegen and Havermans are chosen for the study because these are the first pioneers and therefore have the most experience. The farms differ in bedding material, management of the bedded pack and type of bedded pack barn system (Table 4). In the following sections the three farms are described.

Table 4 Type of bedded pack barn system of the three commercial farms (situation in 2011)

	Wiersma	Groenewegen	Havermans
Type of bedded pack	composting	compost	compost
Experience since	Dec-09	Aug-10	Jun-10
Bedding material	Wood chips	Organic waste compost	Organic waste compost
Thickness bedding material	35-50 cm	25-35 cm	50-70 cm
Bottom layer	Concrete elements	Concrete	foil and sand layer
	with aeration tubes		
Working the bedded pack	Cultivator	Tine cultivator	Cultivator with aeration
Costs bedding material	€ 35 - € 45 / ton	€ 8- € 14 / ton	€ 8- € 14 / ton
Amount of bedding material	300 ton / year	800 ton / year	2500 ton/ year
Number of cows	60	96	160
production per cow per year	11000	9000	8000
m2 per cow lying area	15	10,8	23,5
m2 per cow slatted floor	8,3	6,3	0
total m2 per cow	24,3 *)	17,1 *)	23,5 **)
*) exclusive feed alley			
**) the barn is enlarged eventually resulting in 27 á 28 m2 per cow (entire barn)			

The bottom layer, the cultivation of the bedded pack and the number of m2 per cow are quite different between the farms. In the following sections the differences are illustrated. Also the production per cow is quite different between the farms. At Groenewegen the production per cow was 9400 per year in 2011, in 2012 it decreased to just over 8000 due to ration modification.

The practical experiences of these entrepreneurs regarding keeping the top layer dry are explained. The results of management of the bedded pack for animal welfare, hygiene of the cows, emissions, milk quality, manure quality and economy are discussed in the other four sub-reports (see introduction). The description of farm Wiersma also gives details about the composting process, because this is crucial in providing adequate evaporation of moisture. The absorption capacity of the bedded pack on the farms Groenewegen and Havermans is determined by m2 per cow, thickness of the layer, the material (ds% and absorption capacity) and the frequency of adding bedding material.

The description of the bedded pack barn system of the three farms is indicated for the period 2011 and 2012. In this period the farmers also experimented with different bedding materials and method of working the bedded pack themselves. Because the management of the bedded pack is a developmental process this can change every year. The description of the management per bedded pack barn system, therefore, is not a fixed item, it may be adjusted continuously by progressive insights.

4.1 Composting bedded pack Wiersma

Wiersma strives for a herd with longevity and a high production per cow. The bedding material should provide adequate hygiene for the livestock and the bedding material supplemented with the manure of cows should result in a good fertilizer without any risk for mastitis and milk quality. Therefore, he assertively chooses bedding material that he can compost himself. Much moisture evaporates by the heat generation in the bedded pack and there is less risk of bacteria development that can cause mastitis. By controlling the composting process properly, the bedded pack in the entire barn is of equal quality and hygienic for the cows.

Farm Wiersma with composting bedded pack

Barn with aeration system

The bedded pack barn system of Wiersma is operative since December 2009. The bedded pack consists of a 50 cm deep litter with wood chips. These wood chips and the manure that the cows add daily are composted with an aeration system. By the heat generation during composting much moisture evaporates causing the top layer to remain dry. The top layer is milled each day in order to mix the manure with the bedding material and to keep the pack airy. This is basically the composting bedded pack system on the farm Wiersma. The barn, the aeration system and the adjustments in bedded pack management are explained in this chapter.

The barn is open at three sides and is 39.5 meters wide and 66.5 meters in length. The bedding area in the bedded pack barn is 22x51.5 meters in size and 50 cm deep. The 60 dry and lactating animals have approximately 15 m2 lying area per cow available. The barn is built for 100 cows, when fully occupied it results in approximately 11 m2 per cow. The question is whether the top layer remains sufficiently dry at this occupation rate. The access to the bedded pack from the walking area along the feeding rack is organized by multiple gates that are alternately opened or closed. This enables daily adjustments in load on the bedded pack along the edge of the slatted floor.

Between the 13 cm thick, 2 meters long and wide concrete slabs, which are at the bottom of the barn, perforated polyethylene tubes with a diameter of 20 cm are positioned. The tops of the tubes are situated 2 cm underneath the concrete slabs. In the back of the barn the tubes are closed and in the front they are connected to each other and to a ventilator that aerates the bedded pack through the holes in the tubes. The first months after becoming operative in December 2009 no aeration was applied. Only in February 2010, when use of the aeration system was started, the composting process developed well reaching about 55 degrees Celsius. The wood chips provide an airy pack but firm enough to ensure sufficient bearing capacity of the bedded pack for the animals. Due to the composting process bedding material is degraded. The pack becomes less airy and the volume decreases. Bedding material is added during the year (approximately every 3 months) to keep progress in the composting process and to maintain a sufficiently firm and thick bedded pack. After almost a year the composting process in the pack is more or less finished. This is shown by the compactness of the bedding material and by the C:N ratio. In November, the material is removed and a new pack is started. In that period, new fresh wood chips are available.

The aeration system at farm Wiersma: perforated tubes between the concrete slabs are connected to the aeration system outside the barn

The development of the temperature in the pack and the oxygen level in the pack is shown in three figures in Appendix 1.

Adjustments management bedded pack
In the first year, aeration was applied for an hour per day. In agreement with composting experts it is decided to adjust this in four times a day during 15 minutes, aiming at a reduction in emissions. This adjustment is implemented late 2010.
During cold winter months also adjustment of the system is necessary, to prevent heat loss from the pack. The most important, according to Wiersma, is to prevent too much heat escaping from the pack during frost. "You have to temper the airflow, because that withdraws all the heat." And heat is important for the evaporation of the moisture from the pack. In January 2012 there was a very cold period. The eastern side of the barn is then covered with silage and straw packets to protect the bedded pack from the intense cold eastern wind. The bedded pack was only 30 cm thick at the time, the minimum, and to prevent this thin layer to cool down too quickly a 15 cm of wood chips was added. Although it were frozen wood chips, the composting process continued well.

Straw- and silage packets on the outside of the barn during a very cold winter period

Besides this the pack was less aerated: only 15 minutes once a day (around noon, the 'hottest' of the day) instead of 4 times a day for 15 minutes. This adjustment prevented too much cold air entering the bottom in the pack.
Following the coldest night of February 3 to February 4, 2012, the pack was less milled, instead of every day, to once every two days. It showed good results, because the pack was still at a good temperature despite a small decrease, and the composting process was well maintained. At a depth of 40 cm a temperature of 45 °Celsius was measured compared to 55 °Celsius in the previous year (2011) (see Table 5).

Table 5 Temperatures composting bedded pack Wiersma (in °Celsius)

Measuring depth	February 7, 2012	March 23, 2011	October 24, 2011*
0-3 cm	10.9	14.7	24.7
20 cm	45.4	57.7	34.6
40 cm	44.6	54.8	39.4

* In October 2011 the measurement took place just before the removal of the pack. The composting process was already reducing and in November the pack was removed and a new composting bedded pack was created. This is applied in autumn every year.

The top layer of the pack was somewhat frozen, as well as the manure that was excreted on it, but when the cows were lying, the lying area became warm. Walking on the bedded pack, according to Wiersma, was for the animals much more enjoyable than on the frozen manure on the slatted floor.

Frozen manure on the slatted floor

4.2 Compost bedded pack Groenewegen

The choice for a bedded pack barn system by Groenewegen is on one hand motivated by better animal welfare, but also because the compost pack provides a fertilizer that results in a good soil improver on the crop land of the farm. The compost enriched with manure increases the level of organic matter in the soil.

Pictures of compost material spread out on the land in spring

The cows are milked in an automatic milking system and are housed in two groups of 48 cows: a heifer group and a group of older cows. The older cows have 12.9 m2 bedded pack space and 6.8 m2 slatted floor, the heifers have 8.8 m2 bedded pack space and 6.3 m2 slatted floor. The bedding area is not a deep litter. The thickness of the pack is small on the side of the slatted floor and it increases towards the sides of the barn. The surface is made of concrete. Approximately every 3 months new compost is added to keep the top layer sufficiently dry. In the winter compost was supplied every three weeks.

In 2010 they started with green compost, but this did not work well. This compost gets wet too quickly which reduces the bearing capacity of the pack. Therefore, the green compost was replaced by

organic waste compost. This compost will absorb more moisture if it does not contain too much sand.. Although the pack sometimes is too wet the udders of the cows remain clean. When the top layer is too dry udders become dirty. The bearing capacity is greatly reduced if the pack is too wet. The critical limit appears to be about 35% ds. The pack is worked once a day with a rotary harrow. Groenewegen has experienced that sufficient ventilation and regular addition of dry material is important to avoid problems.

The compost bedded pack barn on farm Groenewegen

The development of the temperature in the pack and the oxygen level is shown in Appendix 2.

4.3 Compost bedded pack Havermans

Havermans aims for an integrated sustainable bedded pack barn system. Good animal welfare and healthy animals are important for the community but also saves a lot of labour, because of less problem cows. In one part of the bedded pack barn the calves also stay some weeks with their mother after calving. This is easily fitted into a bedded pack barn. The bedding material, together with the manure, should result in a valuable fertilizer product.

The barn of Havermans is innovative in several aspects. The superstructure is a foil greenhouse that can be used to regulate the climate in the barn. The ridge can be opened at several places. During warm weather, shade cloths in the barn can provide about one third of the surface with shadow. It has been shown that cows prefer lying in the shade only above approximately 27 degrees Celsius. In the winter season during snowfall the roof will not open, although 20 cm of snow does not cause difficulties for the foil greenhouse.

Compost bedded pack barn of Havermans with superstructure of foil greenhouse

In the basement no manure pits are present and no foundation is created. There is no separate feed alley of concrete with a feeding fence and a walking area adjacent to the feed alley, as usual in dairy housing systems. The 160 Montbéliarde cows are fed roughage via movable feeding troughs located in the bedded pack and concentrates in the automatic milking system. The troughs are moved daily to prevent overloading of the pack surrounding the troughs. The surface of the bedded pack area comprises a foil covered with sand and a layer of compost with coarse wood chips. On top of these layers a layer of compost is applied for the cows to walk on. Only the top layer is replaced. The total thickness of the pack is 50 to 70 cm.

The bedding material first consisted of green compost, but it did not absorb enough moisture. Therefore, they changed to organic waste compost. An important experience is that the amount of sand (ash fraction) must be low, because sand reduces the absorption capacity intensely. Initially, the pack was worked once a day with a digging machine, but in 2011 they switched to a rotary harrow with roller. The idea is that the bearing capacity of the pack is best retained by working the pack not deeper than 5 to 7 cm. From late 2012 Havermans uses a combination of milling with spading attachment that provides aeration.

Movable feeding troughs in the pack

All manure from the cows is excreted on the bedded pack. This requires more m2 bedded pack per cow, but spares a walking area with solid floor or manure pit along a central feeding alley. So there is no slurry. All manure is 'compost enriched with manure’. The total surface area per cow of the entire barn seems to equal other bedded pack barn systems, since a separate feed alley with walking area is absent. In 2011 the total barn surface was 24.3 m2 per cow. In 2012 the barn is extended, enlarging the area to approximately 30 m2 per cow at present. In time, the herd will increase to about 200 cows with an area of 27 to 28 m2 per cow. It is experienced that having more m2 per cow the pack remains drier and therefore the bearing capacity of the pack is better maintained.

The development of the temperature in the pack and the oxygen level is displayed in Appendix 3.

5 Reflection

Learning from bottom-up by innovating with pioneers
The development of bedded pack barn systems in the Netherlands started in 2007 with a quest by farmers and researchers for barns for dairy cattle to improve animal welfare, longevity and ensure good manure quality. At the time, this process is facilitated by the research program " Networks in livestock" of the Ministry of Economic Affairs. The role of the researcher was to facilitate the process as a free actor (Wielinga, et al, 2009 and 2010), inserting knowledge and inspiring the entrepreneurs. The entrepreneurs in the network chose for development of a system without cubicles, similar to deep litter housing with straw. Inspired by experiences in the USA and Israel the bedded pack barn system is created. The network has placed the questions about bedded pack barn systems on the research agenda of the Dutch Dairy Board. From 2008 on tentative studies and experiments were started up and from 2009 on the first pioneers built a new barn. Since then there has been much experimentation by these pioneers and a lot of experience knowledge is exchanged through seminars and workshops with farmers and experts. This bottom-up process is important to achieve integrated solutions for sustainability problems. A top-down approach driven by a future vision alone is not sufficient (Elzen et al, 2012). The aim is to connect these two approaches so that system innovations actually are anchored in practice (Elzen et al, 2012).

The research described in five sub-reports (see introduction) is performed on three commercial farms. These farms are pioneers in the developmental process of bedded pack barn systems. Since the farms are constantly working on improving management of the bedded pack, the experimental conditions change regularly. These changes concern bedding material, m2 per cow, method of working the pack, amount of aeration and extra ventilation. In addition, the farms differ in animal management, resulting in, amongst other things, differences in productions per cow. The research on the various aspects of sustainability such as animal welfare and environment is therefore indicative and process orientated. The impact of these three farms, however, has been comprehensive for both Dutch farmers and international farmers. Much has been learned from the research and practical experiences of these farmers and the entrepreneurs who have participated in discussions in the network bedded pack barn systems since 2007. This also applies to discussions with interested farmers, consultants, architects, composting experts and policy makers in seminars and workshops. This knowledge is actually embedded in several commercial farms, in total there are about 30 bedded pack barns now in the Netherlands (in 2013). Twelve farms form a network group that exchanges experiences regularly. Also at some international farms bedded pack barns are built, namely in Denmark, Germany, Austria and Italy. Much interest is also shown from Slovenia and England. Furthermore, knowledge is still exchanged with researchers from the USA, dairy farmers and an architect from Israel.



All workshops and seminars got a lot of participants that wanted to learn more about the bedded pack barns

The iterative learning cycle of "Describe, Explain, Explore and Design (DEED)"
Learning from the pioneers in practice continues constantly, because barn design, type of bedding material and management of the bedded pack are adjusted each time based on progressive insights. Besides the predominantly development-oriented research at these commercial farms also additional experiments under controlled conditions have been carried out. This mixture of participatory research, supported by small-scale experiments, facilitates the innovation process. This innovation process of bedded pack barn systems is described on the basis of the DEED cycle (Galama et al 2012). The measurements and studies in the research focus on analysing (Explain) the sustainability aspects and whether there is trade off, for example more space per cow resulting in higher emissions. New explorations (Explore) aim at solving bottlenecks that may lead to new designs (Design). These designs may be developed by farmers and barn constructors themselves with inspiration from the research. The present 30 bedded pack barn systems in the Netherlands are very divers. That means that “there are many flowers flourishing” and much is learned. In the end, types of bedded pack barn systems will fade out, if they are detrimental to one or more sustainability aspects. Which ones will disappear or are successful is often hard to tell in advance (Design), because unexpected results or experiences may come out. Therefore, a top-down design is insufficient in the sustainability process of the dairy industry, but a top down design can help to make big system changes originating from an inspiring vision and shifts in thinking (Bos et al, 2009). Designing and redesigning must be adjusted to practical experiences (bottom-up) supported by experiments under controlled conditions on a laboratory scale or practical farm scale. Since many sustainability aspects such as animal welfare, health and emissions are influenced by many factors, many farms and experiments are needed to explore and recognize the most promising bedded pack barn system and bedding material(s).

6 Conclusions and recommendations

Bedded pack barn systems in general
Until mid-2013, approximately 30 bedded pack barns were built in the Netherlands. Many select a bedded pack with composting e.g. wood chips or using organic waste compost supplied by a composting plant. The composting process is implemented both with or without additional aeration by blowing or extraction. It is important to make a well-informed choice for type of bedding material in relation to keeping the top layer dry, required manure type and availability of the bedding material. There are three ways of keeping it dry, namely moisture absorption, moisture drainage or moisture evaporation.

Experiences at the bedded pack barns of the three commercial farms
The conclusions and recommendations are based on experiences of the three commercial farms in collaboration with researchers. It should be interpreted as progress status, because the most appropriate management of the bedded pack may still be modified.

Composting bedded pack in general
In a composting bedded pack moisture evaporation is pursued. This means that it is necessary to have knowledge of the composting process. Directives are:
- C:N ratio of bedding material at the beginning (at least 30:1)
- C:N ratio at the end when the pack is used as fertiliser on the land (maximum of 15:1)
- Sufficient porosity
- Equal treatment of total bedded pack

Composting wood chips with an aeration system, as applied by Wiersma, ensures a stable dry top layer, but requires skills regarding aeration, ventilation and working the bedded pack with anticipation of weather conditions. That means less aeration under cold conditions and working the pack to avoid cooling down of the pack. Also add bedding material in time, because the pack is compacting due to the composting process.

Composting bedded pack specifically
- Make sure you keep the bedded pack airy by forcing air through an aeration system in the bottom layer of the pack, by milling once a day and by offering at least 12 m2 per cow lying area
- Aerate the bedding several times for a short period, e.g. 8 times a day for 15 minutes.
- If the pack temperature rises too much (more than 55 degrees Celsius) than cool down the pack by using the aeration system (forced air)
- Aeration tubes must not be made of PVC, since this material deforms at high temperatures in the pack
- A passive air layer underneath the entire bedding can also provide the bedded pack with additional air
- Make sure that in the winter season the bedded pack is sufficiently thick, about 60 cm, since the bedding material may cool down quickly otherwise. In summer approximately 40 cm as a minimum is sufficient. The composting process will make the pack more compact, which means that adding bedding material throughout the year is required.
- Do not work the pack too deep in the winter season (approximately 10 cm), but work deeper in the summer season (about 30 cm). Milling is well accepted, because it works the manure into the top layer well and it makes coarse wood chips smaller. This facilitates the composting process
- Add bedding material more frequently (e.g. monthly) in the winter season
- Start in autumn (approximately November) with new, fresh bedding material, preferably soft wood chips
- Use the compost on your land immediately in autumn (within the manure legislation of application standards and condition of use (period of the year to apply manure on the field))
- Change the entry to the bedded pack area from the walking area (slatted floor) along the feed alley frequently. This can be done by having a fence which can be opened and closed at different locations.

Compost bedded pack in general
In a compost bedded pack moisture absorption is pursued. When using organic waste compost, like Groenewegen and Havermans do, there will be some composting after applying it to the pack. Keeping a bedded pack that consists of compost dry, requires skills aimed at preventing the bedding material to become wet, otherwise the bearing capacity of the pack reduces. That means adding enough bedding material at time and not working the pack too deep to retain capacity. For a good moisture absorption many m2 per cow and / or a thick bedded pack are required.

Compost bedded pack specifically
• Use clean compost, that means containing only little sand (low ash fraction)
• Use fine, dry organic matter. Besides compost this can be straw or reed chopped into small particles
• In summer working the pack to about 40 cm deep is possible, potentially using a spading machine. Then it is important to loosen the bedded pack
• In the winter season work the pack superficially to approximately 10 cm deep
• In the winter season often apply a thin layer, for example by working the bedded pack with a power harrow in front of the tractor and at the rear a spreader for littering bedding material
• Applying a foil greenhouse provides additional drying, because more sunlight enters the barn and by additional ventilation through the ridge

General directive m2 per cow
The experiences of the network group of 12 farmers with different types of bedded pack barn systems is that 15 m2 per cow lying area is needed to keep the bedding material sufficiently dry. This applies to a barn with half bedding material and half slatted floor. For a barn consisting entirely of a bedded pack a directive of 30 m2 per cow applies. At a well composting bedded pack 12 m2 per cow seems to be feasible (but in barns with bedded pack and slatted floor (or solid floor).

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Appendices

Appendix 1 Bedded pack temperature and oxygen level at farm Wiersma

The development of the bedded pack temperature is shown in **figure 1**. The development of the oxygen level in the bedded pack in 2011 is shown in **figure 2.**

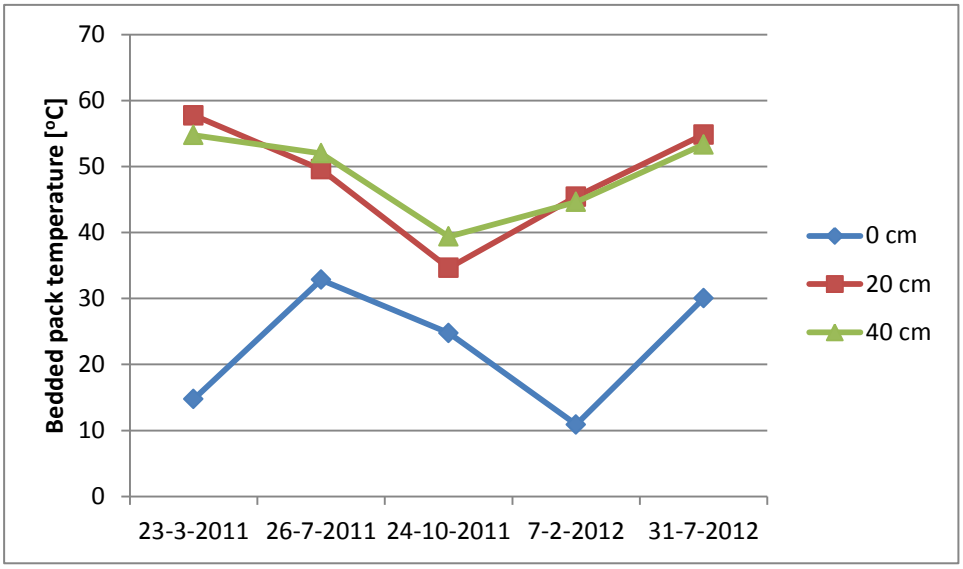

Figure 1 Development bedded pack temperature during measurements in 2011, 2012 en 2013

The temperature in the top layer of the bedded pack almost equals the environmental temperature. The temperatures at 20 and 40 cm deep are almost identical. The development of temperature in these layers is probably more influenced by the stadium of composting activity. The longer the bedded pack has been used, the more the composting process slows down. The temperature is a result of that activity. The measurement in February 2012 was done in a relatively new bedded pack.

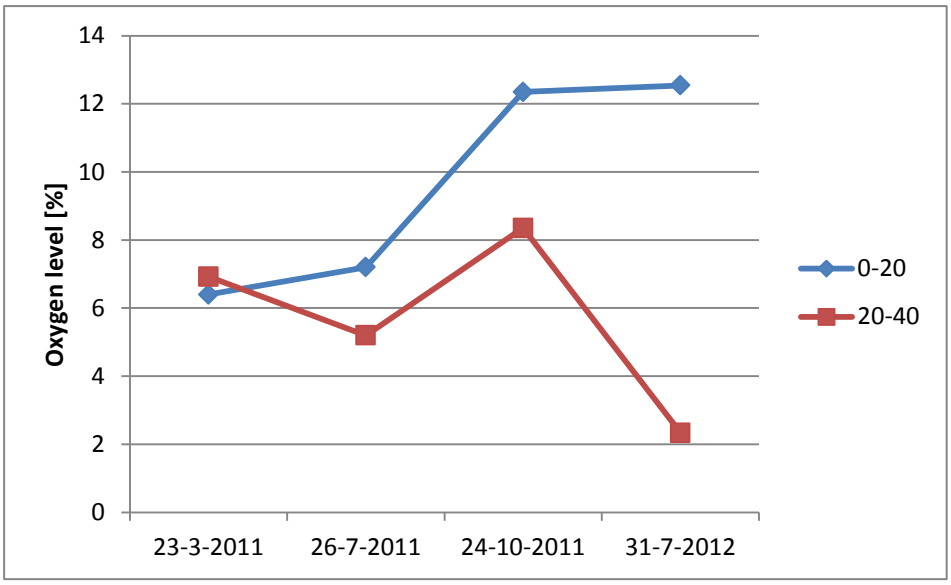

Figure 2 Development of oxygen level in bedded pack in 2011

The oxygen level in the upper 20 cm is strongly influenced by cultivation of the top layer. The oxygen level in the bottom layer is on the long term influenced by particle size. The longer the bedded pack has been used, the smaller the particles are and the smaller the air space between the particles. On the short term the oxygen level in the bottom layer is also influenced by the aeration of the pack. During the measurement in March 2011 the oxygen level in the upper layer is almost the same as in the bottom layer between 20-40cm deep. The bedded pack is quite fresh at that time and therefore the porosity in the bottom layer is still good. The top layer is worked on. Probably that is the reason that the oxygen level in this layer during the following measurement is dropped while it is slightly increased in the upper layer. The oxygen levels are sufficiently high.

Appendix 2 Bedded pack temperature at farm Groenewegen

The development of the bedded pack temperature is shown in **figure 3.**

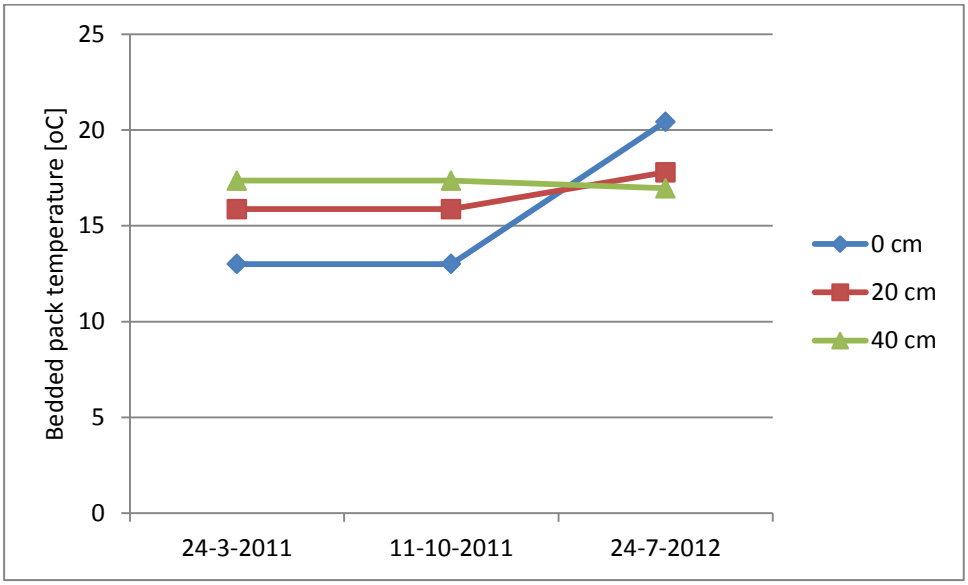

Figure 3 Development bedded pack temperature during measurements in 2011 and 2012

There is not much variation in temperature to be seen. The temperature mostly follows the environmental temperature. In the deeper layers there is a slightly higher temperature to be seen that reflects some composting activity at that level. However, in this bedded pack composting was not pursued and therefore not stimulated. The top layer of this pack is worked on and this will probably cause the temperature of the top layer to follow the environmental temperature. That may be the reason that, during the measurement in July 2012, the temperature of the top layer is higher than the other layers.
Oxygen level was not measured in this pack, because composting process is not the goal here.

Appendix 3 Bedded pack temperature at farm Havermans

The development of the bedded pack temperature is shown in **figure** 4.

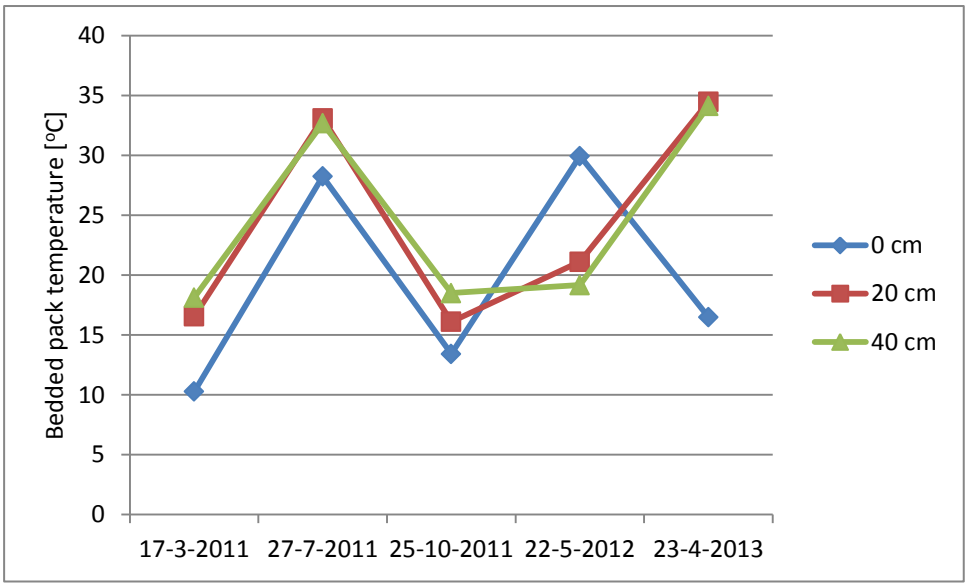

Figure 4 Development bedded pack temperature during measurements in 2011, 2012 and 2013

During the measurements in 2011 and 2012, composting was not pursued. The bedded pack temperature seems to follow the environmental temperature.

However, the results of 2013 are different. In that year Havermans started a composting process in one part of the bedded pack. That seems to result in higher temperatures in the lower parts at these places. At other places, the temperature of the different layers is still comparable. The top layer is probably still following the lower environmental temperatures at that moment (figure 5).

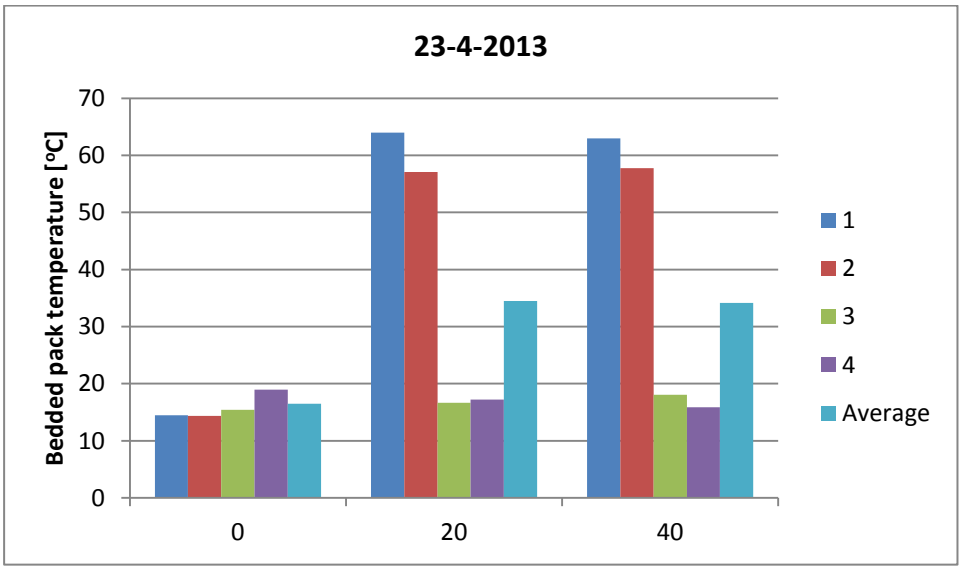

Figure 5 Variation in bedded pack temperature during measurement in April 2013

Oxygen level was not measured in this pack, because composting process was not the initial goal here.

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