Scoping Study on the Potential Risks (and Benefits) of using Recycled Manure Solids as Bedding for Dairy Cattle

A. J. Bradley, K. A. Leach
Quality Milk Management Services Ltd
S. C. Archer, J. E. Breen, M. J. Green
School of Veterinary Medicine and Science, University of Nottingham
I. Ohnstad, S. Tuer
The Dairy Group

ACKNOWLEDGEMENTS

The authors are especially grateful to all the farmers who responded to the questionnaire and agreed to share information with us. We also appreciate the input from machinery manufacturers, veterinary surgeons, researchers, advisors and other colleagues who have freely contributed information and experiences.

DISCLAIMER

This report is the output of a scoping study, the aim of which was to identify and summarise the information currently available on the use of RMS as bedding for dairy cattle. It does NOT constitute a full risk assessment or "claim to be the definitive document of RMS use". Suggestions for interim guidance on use are based on current knowledge but cannot be expected to provide "fool proof advice". All users of RMS have to accept responsibility for their own decisions with respect to its use. The authors of this report cannot be held responsible for decisions made on the basis of the information contained herein.

Report prepared for DairyCo

April 2014

DairyCo

DairyCo

DairyCo

Executive Summary

This report is the output of a scoping study, the aim of which was to identify and summarise the information currently available on the use of RMS as bedding for dairy cattle. It does NOT constitute a full risk assessment or "claim to be the definitive document of RMS use". Suggestions for interim guidance on use are based on current knowledge but cannot be expected to provide "fool proof advice". All users of RMS have to accept responsibility for their own decisions with respect to its use. The authors of this report cannot be held responsible for decisions made on the basis of the information contained herein.

1. Background and aims

- Recycled manure solids (RMS) (often colloquially referred to as 'green bedding') have been used as a bedding material for dairy cows for a number of years in some jurisdictions and the practice is becoming increasingly widespread in the UK.
- There are significant uncertainties with respect to the associated risks to animal and human health from using RMS bedding. This in turn makes it difficult to establish whether the material can meet the requirements for safe use.
- The aim of the report was to review the current knowledge with respect to the use of RMS as bedding for dairy cattle and thereby increase the understanding of the use of RMS as bedding in UK conditions.

2. Sources of information

- Written sources used were peer reviewed journals, conference proceedings, articles in the popular farming press, and technical information available on-line. Experiences and opinions of researchers, advisers, machinery suppliers and farmers in countries with longer experience of RMS use were sought, as well as similar contacts in the UK where available. Online searches were carried out and collation of information available through Web searches and on-line databases of publications was undertaken.
- Information was gained from 3 manufacturers of manure separation equipment.
- The experiences of 19 farmer users of RMS bedding were collated.
- Additional information was gained from other UK industry contacts through the Nottingham Dairy Herd Health Group and BCVA as well as through DairyCo extension officers and other members of the Stakeholder group.
- International information was obtained through researchers and/or advisers in 13 countries. At least one contact responded from The Netherlands, Spain, Portugal, Denmark, Poland, Switzerland, Austria, Germany and USA.
- It is notable that there is a very limited amount of peer reviewed published information on the use of RMS as bedding, and particularly the material as currently used in the UK, i.e. physically separated solids with no further processing. Much of the available information appears in project reports and conference proceedings, and, these sources provide a combination of studies and anecdotal reports. A great deal of the experience and information is from the US and other countries where climate and farm systems differ from

those of the UK. More recent adoption in Europe has not resulted in scientific publications, although useful recent reports are available from studies in the Netherlands. Information from the UK is limited to the practical experiences of a small number of farms with a relatively short history of use.

3. Review of current technologies

- The technologies used to produce RMS bedding in the UK were identified and reviewed.
- At the time of this study, the Bauer FAN screw press separator was the equipment most commonly used to produce RMS bedding in the UK.

4. UK telephone survey of current users of RMS

- A UK telephone survey of 19 farmers using RMS found that: Only five farmers had been using the system for a year or more. The average length of time was nine months, the maximum was four years. With one exception, involving a drum composter, separated solids underwent no further processing before use as bedding. The size of the survey was limited by the small number of UK based users of the technology.
    - RMS was almost exclusively used in cubicles, both on mattresses and as deep beds.
    - The majority of farmers reported an improvement in cleanliness of cows.
    - The majority of farmers reported a benefit to the condition of hocks.
    - Reports on changes in lying time were equally split between improvement and no change.
    - With the exception of two farms, clinical mastitis incidence and somatic cell counts (SCC) were qualitatively generally considered to be equal to or lower than before the change to the use of RMS as bedding.
    - There was some qualitative opinion that mastitis or cell count problems were associated with fresh bedding material of lower dry matter content than usual.
    - The three most common reasons for using RMS were cost, cow comfort and difficulties with supply of alternative bedding materials.
    - Other benefits given were: ease of slurry storage and handling, cow cleanliness, reduced dust and ease of bedding handling.

Table ES1 overleaf illustrates the benefits mentioned by farmers

Table ES1: Benefits identified by users in answer to an open question

Benefit	Number of farmers mentioning
Cost savings	10
Ease of slurry storage and handling	9
Cow comfort or increased lying times	8
Cow cleanliness	8
Availability, making it easy to use bedding liberally	7
Reduced dust in buildings	7
Udder cleanliness	4
More effective utilisation of slurry	4
Cow welfare - reduced hock lesions	3
Bedding easy to handle	1
Not "buying in bugs" in bedding	1

5. Review of Key Pathogens

- Initially, a “long list” of pathogens likely to be found in cattle faeces was collated
- Pathogens perceived, or known, to be likely to have a high load in cattle slurry were then identified (notifiable diseases were also included).
- Based on the findings of a literature review, existing knowledge, experience and consultation, a subset of pathogens was derived that were *either* likely to have high load in slurry, *or* unlikely to have a high load, but likely to be of major significance if present
- The rationale for selecting pathogens as ‘important’, or excluding them, was partly on the basis of risk, considered in terms of both likely presence in slurry and exposure route. Note; this exercise did not in itself constitute a formal or complete risk assessment
- A final list of key pathogens was compiled, with an assessment of likely load in slurry, transmission route and consequences for animal and human health
- Antimicrobial resistance was considered but the understanding of the persistence of genetic material encoding antimicrobial resistance and resistant organisms in the environment and more specifically the impact of the use of RMS is currently limited. The potential impact of antimicrobial resistance should be borne in mind when considering the effects of incorporating faeces and urine from animals under treatment, and milking machine washings (which will contain disinfectants), in slurry that is to be used for separation to provide bedding materials. This lack of understanding and current knowledge suggest a cautious approach would be prudent.

DairyCo

6. Effects of treatment and processing of RMS on microbial population

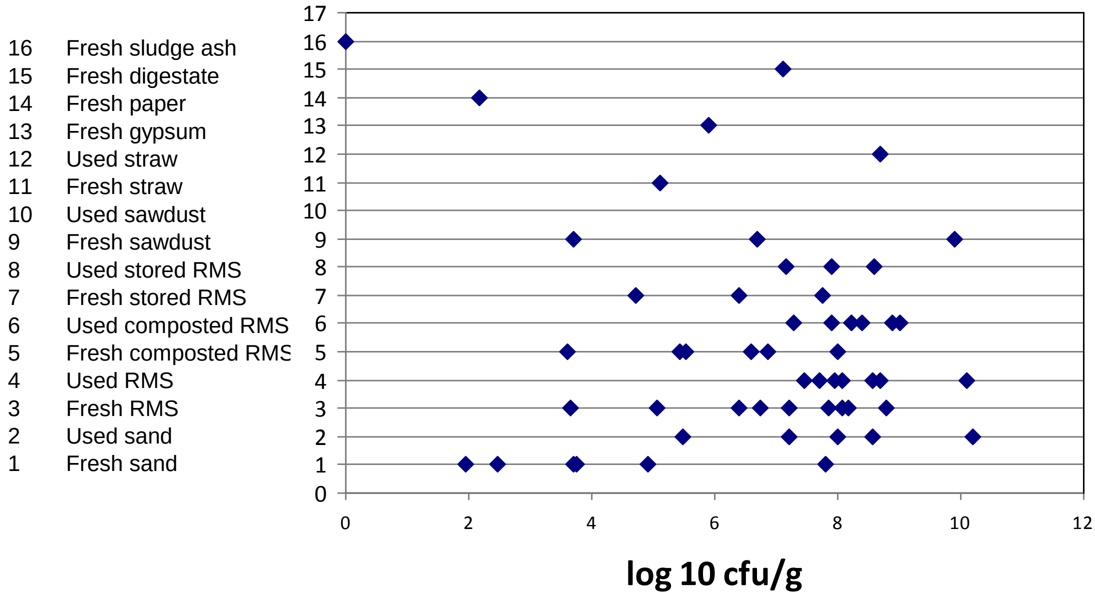
- A variety of treatments of RMS were considered in terms of their influences on pathogen load but although evidence was identified, it was limited and it is difficult to draw definitive conclusions.
- Separation is unlikely to alter the microbial load greatly from fresh slurry, though there is little published information to substantiate this comment. Composting and digestion have the potential to reduce the pathogen load if performed in optimum conditions. However, pathogens are not completely eradicated. Knowledge of processing indicates that temperature is likely to be critical and that composting can be difficult to control.

7. Review of pathogen numbers in bedding

- Bacterial counts appear to vary greatly both within and between different bedding materials, and the ability to compare studies is limited because of differences in the methods or units used to express results.
- Total bacterial counts in fresh RMS of the order of 10^4 and 10^8 cfu/g fresh bedding have been reported. Fresh sawdust shows a similar range and even “fresh” sand, claimed to be inert, can provide some samples with very high load. With use, there is a trend for all products to move towards or beyond the higher end of the range for fresh material.

Figure ES1 illustrates the range of total bacterial counts for a number of bedding materials using some examples from the literature and samples submitted to QMMS laboratory before the start of the study.

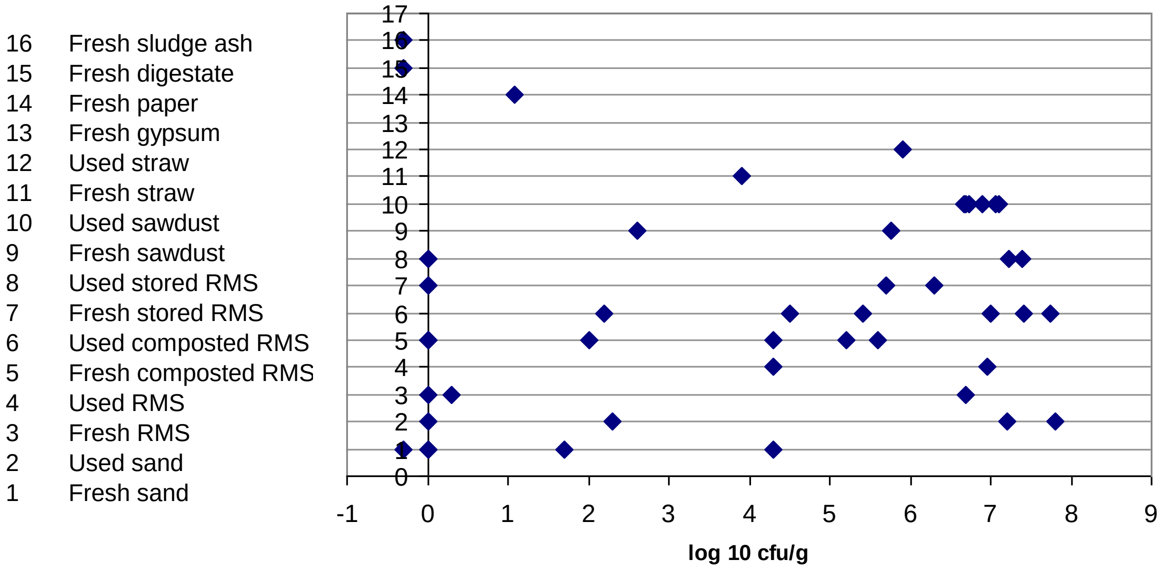
Figure ES1: Total bacterial counts in different bedding materials



- Coliforms are very variable in all bedding materials, in some samples falling below the level of detection, but can frequently be found at levels at or above 10^6 cfu/g for both used and unused sawdust, and RMS of all types. *Klebsiella* spp counts are extremely variable within bedding types, but have been reported at least once at relatively high levels (10^4 cfu/g or more) in all materials both before and after use, apart from sand. *E. coli* has been reported in most materials. Used RMS, whether or not composted or stored, demonstrated some of the highest levels (10^6 cfu/g or more). Counts from fresh and used sawdust are also high.

Figure ES2 illustrates the range of total coliform counts for a number of bedding materials, using some examples from the literature and samples submitted to QMMS laboratory before the start of the study.

Figure ES2: Total Coliform counts in different bedding materials



- *Staphylococcus* spp are much less frequently detected in bedding materials. However, in some cases high levels can be found, particularly in fresh RMS, but also in used sand.
- *Streptococcus* spp are also undetected in some materials, including samples of unused separated, stored and composted RMS, but may also often be found at above 10^6 cfu/g in each of these materials both before and after use.
- The only individual organisms to have been specifically enumerated in any reports on RMS are *E. coli*, *Klebsiella* spp, *S. aureus*, *Mycobacterium avium paratuberculosis* (MAP) and *Salmonella* spp.

DairyCo

8. Review of possible impacts of using RMS bedding

- Impact on cow comfort and welfare: In general it can be expected that there will be benefits for cow comfort with use of RMS, whether on mats or in deep beds, compared to the situation with mattresses and sawdust. There may be little difference between the situations with deep bedded sand and deep bedded RMS.
- Impact on animal health: Consideration was made of the pathways and risks associated with the use of RMS as bedding. The main risks to animal health that may *alter* as a result of a switch to the use of RMS as bedding are considered to be:
    - Infectious diseases transmitted by pathogens present and persisting in the recycled bedding;
    - Effects of inhalation of bedding particulates – lower exposure since less dust is reported;
    - Exposure to a higher level of ammonia and ammonium compounds – although published reports of emissions differ.

The likely routes of infection are:

- Intramammary - via the streak canal
- Contact with skin (particularly digital dermatitis)
- Respiratory - pathogens carried on dust particles
- Ingestion - the oral route
- Reproductive – via the reproductive tract and navel

The only disease of which the consequences have been studied in any detail is mastitis. There are anecdotal reports of serious outbreaks of clinical mastitis associated with RMS bedding use (including outbreaks specifically attributed to *Klebsiella* spp and *Pseudomonas* spp). However, these are outnumbered by reports of successful use. Of two attempts to investigate the long term influence on somatic cell count in the US, one suggested a slight increase in SCC, but numbers were small and methods not particularly robust so we do not claim to have found supporting evidence for this. However, it should be remembered when making comparisons between countries that the US national tolerance for SCC is much higher than in the EU, at 700,000 cells/ml, compared with 400,000 cells/ml for the EU. It has been concluded that excellent cow preparation at milking time, sanitation of milking equipment, cow hygiene, adequate dry cow housing and bedding/stall management appear to be critical in maintaining a low SCC while successfully using manure solids for bedding.

Although MAP in RMS has been specifically quantified in a few studies, it was not isolated from RMS in all farms where the disease was known to be present. This is probably as a result of a combination of test sensitivity, intermittent shedding and treatment of RMS. No studies have been found that have related RMS use to clinical incidence or prevalence of Johne's disease, or any infectious disease other than mastitis.

- Impact on Human Health: There are no reports of the impact of RMS on human health.
    - In the light of current knowledge, the likely impact to farm workers, as long as routine hygiene precautions are taken, might be beneficial in comparison with sawdust or chopped straw, because of the reported reduction in dust.

  - There is little information available on the possible transfer of pathogens from bedding to milk. In the absence of this, it would be prudent to recommend that milk from RMS herds is pasteurised before consumption.

- Impact on Food Quality: The main risk identified is of coliforms, bacterial spores, yeasts and fungi in the milk, increasing the risk of food spoilage, particularly for artisan cheeses. However, recent results from the Netherlands demonstrated increased levels of spores in milk were only associated with composted materials as bedding, and not “fresh” RMS.

9. Assessment of housing effects

- Information was gathered from the survey of UK users and reports from other countries on the structural and infrastructural aspects of different types of housing in which RMS is being used.
- It should be remembered that many of the published reports are from countries with warmer and drier climatic conditions than the UK
- There is some evidence from a laboratory study of potential negative impacts of gaseous ammonia when using RMS while preliminary measurements from barns in Denmark indicate that the increased emission compared with straw bedding is likely to be of little practical significance.
- The consensus from UK farmers is that dust levels are low with RMS
- Factors affecting general hazards and risks associated with bedding materials in dairy cow housing include; ambient temperature, bed management, microbial competition, humidity and frequency of bedding. There are specific aspects of RMS use which are particularly affected by all of these, due to a large extent to the capacity of the material to absorb and release large amounts of moisture.

10. Risk mitigation when using RMS

Critical control points are considered to be:

- Source of material
  There are likely to be additional risks associated with the use of material not originating from the premises on which it is being processed and used. For this reason RMS should only be generated on the unit on which it is to be used and only from product originating from that unit - *ie* manure should not be moved between units either before or after processing.

- Control of material entering the pool for separation
  Manure should only be recycled as bedding to the species from which it was originally produced. Manure from different species should not be introduced as this increases the risk of introducing different pathogens; care should be taken to make sure that ‘runoff’ from manure sources from other species, such as from a midden, does not reach the pool for separation. It is suggested as a further disease control precaution that slurry from adult cattle should not be used to produce bedding for youngstock under 12 months, and vice versa, due to differences in shedding of, and susceptibility to, pathogens.

DairyCo

Additional consideration should also be given to certain notifiable diseases. In the case of notifiable exotic disease additional controls over the use of RMS as bedding may be implemented. Consideration should be given as to whether the use of RMS should be suspended in herds experiencing a TB breakdown.

The introduction of other material should also be minimised – waste milk carries the risk of recycling mastitis pathogens onto the bedding and the inclusion of milking machine wash water carries a similar risk as well as potentially introducing disinfectants into the slurry pool which may have adverse effects with respect to the development and perpetuation of antimicrobial resistance. The effect of used footbath contents entering the slurry pool is unknown.

Careful consideration should be given to biosecurity and how new stock, and therefore their faeces, are added to the general population and the implications that may have for the spread of disease. This area has not been studied and is poorly understood. For this and other disease control reasons, material from isolation pens should not be added to the pool for separation.

- Control of separation process to achieve the optimum dry matter content.
  The composition of the slurry to be separated has a significant impact on consistency and quality of the extracted solid fraction. The content of the slurry pool needs to be managed to optimise the RMS output. Recycled solids should be prepared and stored under cover to avoid an increase in water content prior to application.

- Control of storage to minimise pathogen multiplication
  Extracted RMS should be used immediately unless some further processing/preservation is employed. Further processing could encompass processes such as forced air drying, heating, composting, digestion or anaerobic ensiling.

- Control over ventilation in the building
  Good ventilation is essential and overstocking should be avoided to ensure further drying of RMS once applied to bedding as well as to minimise the levels of ammonia in the housed atmosphere.

- Control over further drying and temperature on the beds
  Material should be added to the beds in limited quantities to allow further drying to take place. Beds should be managed to minimise 'heating' and therefore bacterial multiplication after application.

- Control of hygiene of the bed
  As with any bedding material, beds should be designed and managed to minimise contamination with urine and fresh faecal material.

- Control over animals using the bedding

Avoid use with calving cows. Bedding hygiene is of increased importance around the time of calving. Grooming of calves post calving could result in the ingestion of significant quantities of RMS by cows. Exposure of new born calves to pathogens of adult animals which might be present in the bedding presents a high risk, particularly for Johne's Disease. RMS should therefore not be used in calving areas. RMS use should also be avoided in transition cow accommodation due to the risk of early parturition.

- Avoid use with youngstock
  Even for weaned youngstock, there are risks attached to the use of the material, since younger animals are potentially naïve to pathogens in the adult herd which may be present in the bedding. Welfare legislation may preclude the use of RMS as bedding for calves, however we suggest that RMS must not be used for youngstock under the age of 6 months. As a precautionary measure we suggest RMS should not be used for youngstock under the age of 12 months.

- Control of teat hygiene by parlour practices
  Pre-milking teat preparation and pre-dipping should be a pre-requisite of herds using RMS in view of the reports of increased numbers of thermoduric and psychrotrophic bacteria in bulk milk in herds employing RMS.

- Avoid risk of cross contamination of feed
  There should be no shared equipment for the handling and processing of feed and RMS. If any equipment is shared (loaders *etc*) it must be thoroughly cleaned between uses.

- Control of end product (*eg* milk) processing
  Until there is a better understanding of the changes in risk associated with the use of RMS as bedding, advice should be that milk from farms utilising RMS for lactating cows must be pasteurised and its use in "artisan" milk products should be avoided.

- Personal protection for farm workers
  Farm personnel should be provided with appropriate PPE and made aware of the importance for personal hygiene during and following the handling of RMS.

- Herd health monitoring
  A final stage of any risk mitigation process should be for the user of RMS as dairy cow bedding to actively monitor cow health, in particular intramammary health, as well as bulk tank milk quality, to ensure the effective implementation of mitigation strategies.

11. Risk modelling

Unfortunately, insufficient quantitative information was available to inform a Bayesian based risk analysis for major diseases and health issues.

12. Interim guidelines on the use of RMS as bedding

Based on the information in this report, suggested 'interim guidelines' have been drawn up and are presented in the main body of the report. Lack of data means it has not been possible to base many of these guidelines on robust scientific evidence, meaning that it is essential that key issues/deficiencies highlighted in the report are addressed so that these guidelines can be refined. Key points are:

Sources of RMS

- Bedding must be made from slurry produced on the farm where it is to be used.
- Only waste from adult cattle should be used as a raw material for RMS
- Excreta from calving and hospital pens should not enter the reception and processing area
- Excreta from other species must not enter the reception and processing area
- The following materials should not enter the source of slurry to be used for bedding:
  - Placentas, and manure from calving areas.
  - Unsaleable milk - *ie* from fresh calved cows or cows under treatment.
  - Output from washing the milking plant should if at all possible be diverted from the reception pit, as the presence of disinfectants may increase the risk of development and persistence of antimicrobial resistance.
  - Waste footbathing material should ideally not be added to the reception pit for RMS processing for the same reason as that outlined for plant washings.
- The use of RMS as bedding should be suspended in herds experiencing a TB breakdown.

The separation process

- Target DM (dry matter) content of end product should be at least 30% and ideally 35 % at initial separation.
- Consistent and homogeneous input material is important.
- Monitoring machine performance and servicing as required is important.
- Storage of freshly separated solids in a pile is not generally recommended due to the risk of uncontrolled changes in bacterial populations with heating.

On farm management of RMS

- Buildings need to be well ventilated and well drained to ensure the humidity of the environment remains as low as possible.
- RMS can be used as both a thin layer (2-5 cm) on mattresses and in "deep beds" (7.5 cm or more deep). Where deep beds are created, they should be built up gradually to allow the bedding to dry out as depth is created.
- As with all livestock bedding material, the surface should be kept clean and dry and soft. Soiled material should be removed from beds at least twice daily.
- Whether using a thin surface layer or creating a deep bed always apply as a thin layer but ensure bedding cover is maintained to achieve a good level of comfort and dryness.

- It is recommended that cattle under the age of 12 months are not bedded on RMS, predominantly to reduce the risk of infection with MAP bacteria that cause Johne's disease, but also with gastro-intestinal and respiratory pathogens.
- Pre-milking teat disinfection should be practised on farms using RMS as bedding.

Contingency plans

- An alternative source of bedding material, compatible with the slurry handling machinery employed on farm, should be readily available.

Human health protection

- Farm workers working with RMS should employ the normal personal protection measures and personal hygiene associated with handling slurry and manure.
-

Product/food safety issues

- To guard against any possible increase in bacterial numbers in milk it is recommended that milk from RMS bedded cows is pasteurised before human consumption.
- Farms utilising RMS as bedding should not be allowed to sell unpasteurised milk to the public.
- It is recommended that RMS is not used on farms providing milk for artisan cheese making or by producer processors, as milk will not be mixed with milk from non RMS farms, so any effect of RMS use will be more marked.

13. Economic and environmental assessment

- From farmers' reports, the bedding can be economically attractive if the size of the herd is large enough to cover the capital costs of equipment.

In general and on average, RMS is likely to be cheaper than most other commonly used bedding materials in the UK. Estimated costs are outlined in the body of the report, but are dependent on current prices and individual farm situations. Table ES4 outlines an estimated cost per cow per week, in a 400 and a 200 cow herd, for different bedding materials (2013 prices). RMS capital cost based on finance at 5% over 6 years.

Table ES4: Comparison of bedding costs

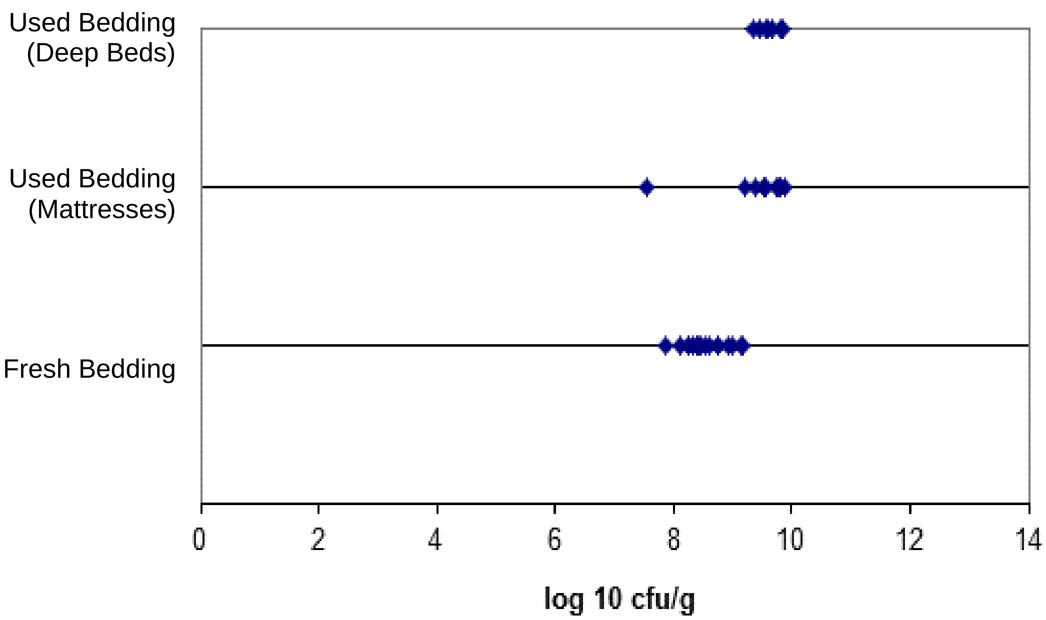
Bedding material	Illustrative cost per cow: pence/week in a 400 cow herd	Illustrative cost per cow: pence/week in a 200 cow herd
RMS	71	130
Sand	140	140
Straw	160	160
Sawdust	75	75
Paper by-product	95 - 135	95 - 135

- The greatest environmental benefit of using RMS as bedding appears to be the replacement of operations with a large "carbon footprint", and other potential negative environmental impacts of the production and haulage of alternative materials.
- The overall impact and net release of gases from the slurry itself is unlikely to be changed by the extra step in the chain of recycling the manure.
- The more efficient uptake of nutrients by plants from separated slurry could be considered an environmental benefit, but this is not linked to the use of the material as bedding.

14. Bacteriological analysis of bedding samples from UK farms

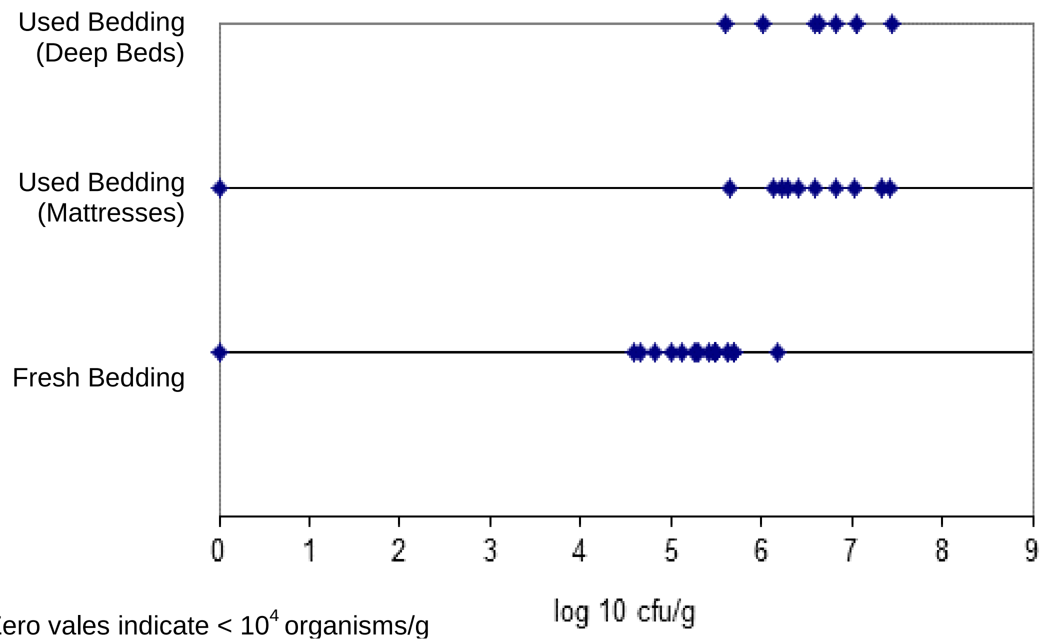
Samples of RMS bedding from farms (16 freshly separated and 18 from beds immediately prior to adding fresh bedding) were submitted from farms for bacteriological analysis. The results of total bacterial counts are illustrated in Figure ES3.

Figure ES3: Total bacterial count (log cfu/g) in unused RMS and used bedding from mattresses and deep beds. Samples from 16 farms.



The results of total coliform counts are illustrated in Figure ES4.

Figure ES4: Total Coliform count (log cfu/g) in unused RMS and used bedding from mattresses and deep beds. Samples from 16 farms.



Further reporting on other microorganisms found in fresh material and used bedding can be found in the main report.

The counts of all organisms were significantly higher in used bedding samples than in bedding before use. There were no significant differences in counts from bedding applied on mattresses compared with those from deep beds (5-12 cm deep) There were numerically higher counts of organisms in samples that were collected in damp weather, though the differences were not significant.

15. Performance review of current users

Data was collated and anonymised to allow a performance review of current users of RMS in the UK. Analysis was undertaken using somatic cell count and clinical mastitis records from ten and six farms respectively. Performance was compared with an anonymised cohort of dairy herds recording with QMMS. It was not possible to undertake a comprehensive analysis of the potential effect of the use of RMS given the short duration of time since adoption and the limited numbers of farms available. However, analysis suggested that the use of RMS is not necessarily associated with deterioration in udder health.

16. Gap Analysis

A gap analysis was conducted and it was deemed that, in particular, more information is needed in the following areas (more specific details are available in main report):

- The presence of pathogens and their survival in slurry.
- Impact of the use of RMS on human and animal health including the long-term effects.
- Management of RMS on farm.
- Risk pathways associated with RMS use.
- Detailed economic analysis of RMS.

1. Introduction

Recycled manure solids (RMS) (often colloquially referred to as 'green bedding') have been used as a bedding material for dairy cows for a number of years in some jurisdictions and the practice is becoming increasingly widespread. More recently there has been increasing interest in the use of this material in the UK, as existing bedding materials have become more expensive and increasingly difficult to source. A number of units in the UK are now using RMS with apparent success, though its use has not been properly evaluated under UK field conditions. There are still significant uncertainties with respect to the associated risks to animal and human health. This in turn makes it difficult to establish whether the material can meet the requirements for safe use. Nevertheless, there are significant potential benefits (financial and otherwise) from the use of recycled manure solids. A better understanding of the current knowledge related to the use of recycled manure solids is needed before an informed decision can be made about its use and potential best practice in the UK.

The EU animal by-products regulation EU 1069/2009 classifies manure as a category 2 animal by-product (ABP). Furthermore, this regulation sets out permissible disposal routes for Category 2 material. Use as animal bedding is currently not listed as one of the permissible routes of disposal. The Regulation does not directly permit uses other than for land application, without further consideration of whether such use may pose a risk to public or animal health. However, it does provide scope for processing ABPs, including livestock manures, for use as technical products. In theory, this could include use for animal bedding, provided it can be demonstrated that any risks to animal or to public health have been effectively mitigated.

DairyCo, along with other industry stakeholders, met with Defra in early June 2013 to better understand the basis on which the EU Regulation has been interpreted. At the meeting, it was agreed that Defra would co-operate with industry stakeholders on undertaking a scoping study, gathering evidence to help clarify the position on future safe use of recycled manure solids as animal bedding. This report presents the outcome of that scoping study.

The aim of the report is to review the current knowledge with respect to the use of RMS as bedding for dairy cattle, with the aim of providing evidence which will enable an assessment of whether its use can be considered safe. More specifically, available information has been collated to provide the evidence to Defra, based on which it can make a decision about whether any risks arising from use of 'Green Bedding' for dairy cattle can be sufficiently mitigated to enable it to be authorised for safe use under the EU animal by-products regulation. In addition, any gaps in the available data, which may preclude a definitive risk assessment, have been identified, and recommendations made for further research.

In exploring the depths of information about the use of RMS as bedding, and assessing its risks, one must not lose sight of the fact that the issue in question is the use of a certain type of bedding material rather than the risks associated with bedding in general and its contamination with faeces.

1.1 Terminology

The term “recycled manure solids” (RMS) may encompass materials prepared from manure by a variety of different processes, generally beginning with physical separation of a solid fraction (although in the case of digested slurry, separation may follow digestion). The properties of the material will be influenced by the method of preparation and therefore, to understand the likely impact, it is important that the preparation method is known. In this report, the term “recycled manure solids” is generally used to refer to material that has undergone only physical separation, since the vast majority of the material used in the UK is of this type. When additional processing such as composting or digestion is included, this will be made clear. Unfortunately, such a clear definition is not always provided in published material, which leads to some ambiguity. In this report the term “green bedding” may be included when used in personal communications or in publications, but is generally avoided as again there is scope for uncertainty as to the provenance and processing of the material. Farmers favour the term “green bedding” to avoid negative connotations for the consumer of including the word “manure”. The issue of consumer perception is an important one but is outside the scope of this study. The term “DMS” variously explained as dried or dehydrated or dewatered manure solids is also found in the literature. We have avoided this abbreviation in view of possible confusion with digested manure solids.

2. Overall approach to the study

2.1 Main scoping study

The objective of the scoping study was to identify information relevant to increasing our understanding of the use of RMS as bedding in UK conditions. Written sources used were peer reviewed journals, conference proceedings, articles in the popular farming press, and technical information available on-line. Experiences of researchers, advisers, machinery suppliers and farmers in countries with longer experience of RMS use were sought, as well as similar contacts in the UK where available (as listed in Section 2.1.1 and Appendix 1). Online searches were carried out and collation of information available through Web searches and on-line databases of publications (Medline, PubMed, Web of Science and CAB Abstracts) was undertaken. Search terms used were “recycled manure solids”, “dried manure solids”, “separated manure solids”. “bedding”, “green bedding”, “slurry separation”, “cattle bedding”.

The remit of the scoping study was not to carry out a full risk assessment but to assess the availability of information to allow this. The findings have been presented to allow alignment with the OIE or CAE risk assessment framework (Appendix 8). Key risk questions are outlined in Appendix 7.The availability of information needed to carry out a risk assessment is outlined in Appendix 8. The report is centred on the use of RMS as currently practised in the UK, with consideration of some amendments that are considered relevant in view of the climatic conditions and possible methods for reducing any risk to animal and human health.

2.1.1 Engagement of DairyCo, DEFRA and Key Industry Contacts

A meeting was held with Defra/DairyCo on 16 Sept 2013 at which the scope and aim of the study was discussed. Other contacts were established with the industry, both in the UK and overseas as outlined below:

Manufacturers: – Three manufacturers and 11 suppliers/distributors of manure separation equipment were identified and contacted. It was established that three manufacturers currently had machinery in use in the UK.

Farmers/Users: Twenty-five farmer users/potential users of RMS bedding were identified. Twenty current users agreed to take part in a telephone survey of which 19 were interviewed. Fourteen users had individual cow production and milk quality data available and ten of these agreed to share this to allow assessment of herd health and performance. Seventeen farmers sent in samples of bedding for microbiological analysis.

Additional UK contacts: Approaches were made to other UK industry contacts through the Nottingham Dairy Herd Health Group and BCVA as well as through DairyCo extension officers and other members of the Stakeholder Group (Appendix 1). This identified a small number of users beyond those contacted via machinery manufacturers.

International contacts: Researchers and/or advisers were contacted in 13 countries. At least one contact responded from nine of these: The Netherlands, Spain, Portugal, Denmark, Poland, Switzerland, Austria, Germany and USA.

The parties contacted are listed in Appendix 1.

2.2 Original work

In addition to the Scoping Study some original UK data were collected in three stages:

2.2.1 Survey of producers

A telephone survey of 19 UK farmers using RMS was carried out to establish methods of preparation and use and experiences with the material - see Section 4.

2.2.2 Bacteriology

Samples of RMS bedding freshly produced and after use on cubicles were submitted by farmers interviewed in the survey and subjected to microbiological analysis - see Section 14.

2.2.3 Herd data analysis

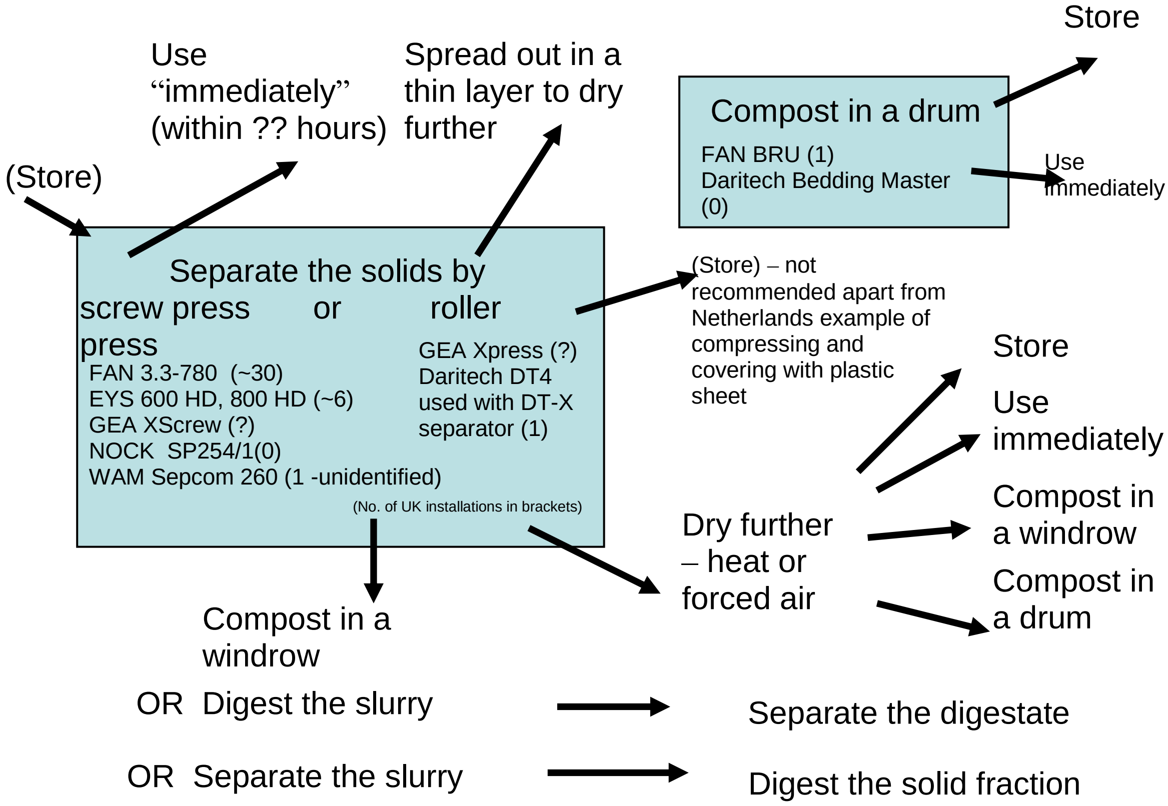
Herd performance data (milk records and in some cases clinical mastitis data) were submitted by ten farmers interviewed in the survey and benchmarked against a larger population using other types of bedding- see Section 15.

3. Review of current technologies

3.1 Introduction

Possible processing steps for recovering manure solids suitable for bedding are shown in Figure 3.1. Currently in the UK the most common method of recovery of manure solids for bedding is separation by screw press separator aiming for 34-36% dry matter (DM). It has been reported by machinery distributors that there were at least 30 users of this process in October 2013 and numbers have been increasing since then. One composting unit, one roller press and one user of digestate have also been identified. However, the use of digestate was soon discontinued due to difficulties with the physical properties of the material produced (too wet and sticky without further processing). Literature and contacts show that composting, and use of digestate, are much more common on the Continent and in America. This scoping study examines the implications of the current technology in use in the UK, and the possibility of using other technologies to mitigate any risks identified. More detailed notes and sources of information on equipment in use in the UK at the time of this report are in Appendix 2.

Figure 3.1: Pathways for creating bedding material from slurry and machinery available



*Numbers in brackets indicate the number of installations or users identified in the UK at the time of this scoping study.

Mechanical solid-liquid manure separators are used by dairy farmers for a number of reasons, including to:

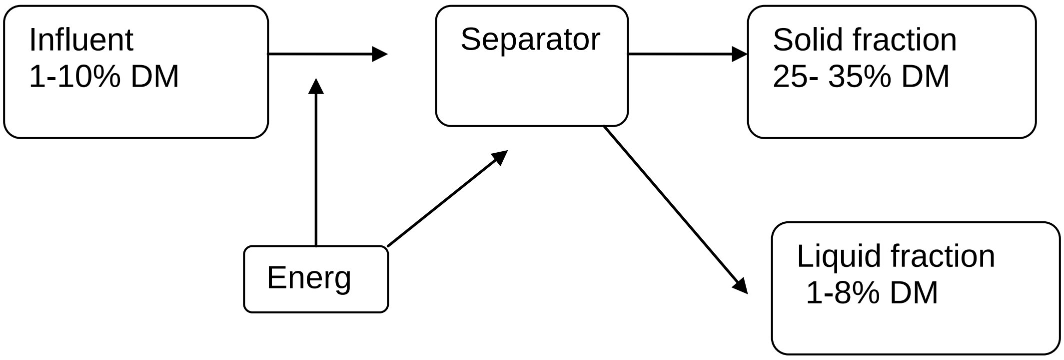
1. Remove a portion of the solids so liquid effluent can be more easily pumped long distances to a remote storage and/or applied to land,
2. Partition nutrients so they can be more easily applied to land,
3. Reduce the size of long-term storage lagoons,
4. Reclaim a portion of the solids for use as a bedding material for cattle.

If a sufficiently high dry matter (DM) content can be reached, the solid fraction of slurry, containing a large proportion of undigested plant fibres, is considered usable as a bedding material. The current minimum DM recommendation from most machinery manufacturers is in the region of 32-34%. It has been suggested that a lower DM content than this will support too high a level of pathogen growth and not provide a clean and hygienic lying surface. The handling characteristics of wetter materials also make them unsuitable for bedding. With specially designed screw presses (FAN 3.3780, WAM Sepcom, HOULE Xscrew, EYS 600 HD or 800 HD) or roller presses (eg DARITEK or HOULE Xpress), it is possible to achieve a DM content of at least 34%.

3.2 Basics of mechanical solid-liquid manure separation

A solid-liquid manure separator, through mechanical and gravitational force, separates liquid manure into two effluent streams (Figure 3.2). The liquid effluent stream has lower DM content than the influent stream while the solid effluent stream has greater DM content than the influent stream. In the past this separation was achieved to some extent on dairy farms by construction of slurry stores with weeping walls or internal separation chambers that allowed natural seepage of the liquid from the manure over a period of several months leaving a drier product in store. Mechanical technologies now allow the influent stream of raw slurry to be separated daily using either a roller press or a screw press. The solid fraction is the product capable of use as a bedding material. It should be noted that not all separators on the market are capable of producing a solid fraction dry enough for use as bedding.

Figure 3.2: Flow chart for a typical mechanical solid-liquid manure separator.



3.3 Types of separation machinery

(links to brochures for a number of separators are included in Appendix 2).

3.3.1 Screw Press Separator

At the time of this report, the Screw Press separator was the most commonly used separator on farms that had adopted RMS in the UK. A submersible pump lifts raw slurry from a slurry reception pit to a cylindrical slotted screen separator mounted on a frame 3 to 4 metres above ground. A geared motorized screw forces the liquid fraction of the slurry under pressure through the screens. The liquid fraction is discharged to a storage tank or lagoon whilst the solid fraction falls by gravity from the outlet of the screw press into a heap beneath the separator. The elevated height of the separator press allows easy access to remove the solid product. The dry matter of the solid fraction is determined by the slot size of the screens. To achieve optimum dry matter for the use of the solids as a bedding material it is important that the screens are maintained by regular cleaning (the frequency of which will be determined by the extent of use). This may be a manual task or set to be automatic by reversing the screw mechanism. The separator is set up to produce a consistent solid fraction but to achieve this it is important that the product presented to the separator is itself consistent. Management of slurry and external liquid inputs, such as parlour washings and yard rainwater run-off, is important to ensure a similar slurry consistency is maintained. A mixer within the reception pit is fitted by some farmers to produce slurry with a standard viscosity.

In high rainfall areas the separator unit and solid fraction is best sited under a roof to protect the solids from rain prior to use.

3.3.2 Roller press separator

At the time of this report roller press separators were less used in the UK for the purpose of producing RMS bedding. These operate by taking slurry pumped from the reception pit firstly through a dewatering reception drum in which the fibre in the slurry is lifted and taken over a roller screen. No pressure is applied and the fibre length is not affected. The fibre is then scraped off the screen and passes through one or more mangle like rollers that squeeze out the liquid fraction. The liquid fraction is discharged to a storage tank or lagoon. The solid fraction falls from the end roller to a stacking pile. The target dry matter of the solid fraction for use as a bedding material is 30-34%. The attraction of the roller press lies in its flexibility in being able to handle sand and its low power requirement.

3.4 Storage

It is generally recommended that the separated solids should be used immediately, rather than being stored, to avoid the risk of pathogen proliferation. One example of storage has been found in the Netherlands (see Section 9 and Appendix 6).

3.5 Further processing

Further processing can contribute to reducing the pathogen load of separated manure. The material may be heated using an external source or dried further using forced air. Alternatively microbial activity during composting the material, in an enclosed insulated drum, or a windrow, can be harnessed to achieve an increase in temperature and reduce pathogen load.

3.5.1 Composting

A composting unit can provide additional processing of the solid fraction produced by the screw press. The only model in use in the UK is commercially known as the FAN Bedding Recovery Unit (Bauer). The separated solids are fed into a Compost Drum Dryer and subjected to an intense aerobic process for 24 hours with air and heat monitored and controlled. The aerobic composting, resulting in a temperature of at least 65^{o}C being reached in the insulated drum, serves to dry and 'sanitise' the product, modifying the bacterial flora of the manure. The target dry matter of the solids produced by the composting unit for use as a bedding material is 40-42%. At the time of this report, just one of these systems was known to be operating on a farm in the UK. There are reports that composted bedding is stored in the Netherlands (Hartley, 2013).

3.5.2 Anaerobic digestion

Slurry may also be subjected to an anaerobic digestion process, producing methane. The resulting digestate could also be used for bedding. The dry matter content would need to be reduced either before or after digestion, by similar physical separation methods. This method is commonly used in the USA, but not currently in use in the UK. It is given further consideration under the section on treatment and processing (Section 5).

3.5.3 Additional methods of drying

Other methods can be used to achieve further drying beyond physical separation. For example, in early experiences the US, manure solids were spread in an open corral occupied by young heifers, to dry in the sun before being used for bedding adult cow cubicles (Carroll & Jasper, 1978). A fan may be used to blow the solid to a storage area and this process makes the solid drier. Another possible method is blowing air in pipes through a pile of the material. However, such methods are not currently used in the UK and no further detailed information on them has been found. Using extra energy to heat and dry the material will greatly increase the cost of the operation. There are also anecdotal reports of separated solids being laid out in rows to dry in the Netherlands (Hartley, 2013) but it is not clear whether this involved a composting process or not.

4. UK telephone survey of farmers using RMS

4.1 Methods

Farmers using RMS as bedding were identified through contacts with machinery distributors, veterinary surgeons, agricultural consultants and DairyCo extension officers. A letter explaining the Scoping Study and the contribution farmers could make to it was circulated. Farmers were then contacted by telephone and invited to undertake a telephone questionnaire. Set questions were asked, but the farmers were also encouraged to describe their experiences in more detail. The telephone questionnaire was carried out in October 2013 with 19 farmers (six further users were identified; two were not willing to participate, one did not have time and three had the machinery but had not yet started using the bedding material). In February 2014 follow-up telephone calls were made to the 19 participants to capture any changes in management, or new experiences.

4.2 Results

Length of experience and farm size

Only five farmers have been using the system for a year or more. The average length of time was nine months, the maximum was four years. On 12 of the farms the milking cows were housed all year round. Average herd size was 413 cows (SD 266, range 180 to 1200).

Machinery type and use

All but two farmers used the Bauer FAN separator. In addition one had a Bedding Recovery Unit, incorporating a process of heating to 60^{o}Cfor 24 hours. After passing through the separator the material passes into a drum 3ft long and 6ft in diameter, rotating at 30 RPM. The material is composted there for one day, with heat being generated by micro-organisms. The machine runs continuously. One farm had a Daritech DTX roller press (from USA). This had been chosen for its ability also to process slurry from sand bedded cubicles.

On all farms, slurry was collected in a reception pit, then pumped to the separator. Reception tanks varied from some which were emptied every day to one which could hold a month's production of slurry. Table 4.1 indicates sources of material entering the reception tank. There was a general consensus that consistent product entering the separator was crucial for effective operation (Tables 4.3 & 4.11). Eight farms had stirring equipment to achieve a consistent slurry entering the separator and these farmers considered this to be important for successful operation. Five farmers stated that either the pumping action, or the return of separated liquor to the tank caused sufficient stirring action. Three farmers mentioned adding extra liquid (eg from "dirty water" storage) or recirculating separated liquor to maintain the appropriate slurry consistency for optimum separation. One suggested that 6% DM was the optimum for input (but did not measure this). Eleven farmers ran the separator daily, and eight of them, two or three times a week. The frequency of operation was generally dictated by the frequency of replenishing bedding, but on two farms the separator ran every day for slurry management purposes, irrespective of whether the material was needed for bedding. The majority of separators were under cover but on four farms separation took place in the open air. One of these farmers did not carry out separation if it was a wet day. Most of the separators were run for between one and six hours, depending on herd size, often overnight to use cheaper electricity. Two farmers mentioned that the use of the separator was restricted by the electricity supply.

Table 4.1: Sources of material entering the reception pit feeding the slurry separator in addition to slurry from adult cows

Source of material	No of farms	No of farms with a response	% of farms responding
Slurry from in calf heifers	6	14	43
Slurry from younger weaned cattle	5	14	36
Manure from calves	1	14	7
Waste milk	6	18	33
Milking machine washings	14	19	74
Silage effluent	5	7	72

The bedding was used within 12 hours of separation, with one exception (see Table 4.2).

Table 4.2: Length of time bedding material is stored before use – number of farms

Max length of time stored	Number of Farms
<1 hour	4
3 hours	3
6 hours	5
9 hours	1
12 hours	4
Up to 3 days*	1
Unspecified	1

* spread in a building 6'' deep - had problems and discontinued use

Properties of the bedding material

Farmers were aiming for a product of at least 34% DM, with targets quoted of 34 to 38% DM. Descriptions of suitable material were “dry and fluffy like snowflakes”, “feels slightly damp when first separated but very quickly dries out on the beds”; “flows freely through the AG dispenser”, “if too wet it holds together”; “leaves hands completely clean”; “should be cool”. One farmer considered that the extra weights required on the machine (and hence power) to apply sufficient pressure to reach 38% was not justified by any advantage in the material. However, no-one had a way of measuring the DM on farm with the exception of one farmer who had used a grain moisture meter, and another who had used a microwave for one sample. Two had had one-off laboratory reports of 36 and 37% DM respectively. One farmer had results for pH of 7.9 for freshly separated and 7.5 for used bedding.

Only two farmers had submitted samples for bacteriological evaluation.

The factors which, in the opinion of farmer users, affected the DM content and quantity of solids produced are outlined in Table 4.3.

Table 4.3 Factors affecting the dry matter content and quantity of solids produced

	No of farmers mentioning
Separation	
Consistency of input material	5
Weather (separation outdoors)	2
Correct settings of machine	1
Cow diet (less fibre and product when at grass)	1
Cow digestion (more product during bouts of acidosis as cows are digesting less fibre)	1
Foreign material (avoid cow hair in slurry – clean sieves regularly)	1
Bedding Recovery Unit	
Silage effluent increases the temperature of composting. Cold weather can cause problems with steam in the building Wetter input material results in smaller amounts of a drier product The machine must be fully fed	1 Bedding Recovery Unit

Use and management of the bedding material

The groups of animals and types of beds for which RMS were used are shown in Table 4.4, and frequency of bedding in Table 4.5.

Table 4.4: Animal groups and bed types for which RMS is in use (19 respondents)

Group/setting	No of farms using
Milking cows in cubicles	19
Milking cows in loose housing (added to some other material, usually only if surplus RMS to be used)	3
Dry cows/in-calf heifers in cubicles	7
Young heifers in cubicles	4
Heifers in loose housing	1
Weaned calves in pens	1
Bulls in pens	3
Type of bed where RMS used	
All mats or mattresses	7
All deep beds	4
Changed from mats to deep	2
Changed from deep to mats	1
Some of each (deep and mats)	7
Sleeper base	2
Concrete base	3
Loose yards/pens	4

Table 4.5: Frequency of bedding

	Mattresses	Deep beds
Daily	6	2
Every other day	1	1
2 or 3 x per week	5	5

Depth of bedding reported was variable. On mats or mattresses descriptions of the bed depth in the cow's lying area included "a dusting", 1, 2 and 3 inches. In most cases there would be deeper material at the front of the cubicle, which would be raked forward two or three times a day. On "deep beds", depths of 2 to 6 inches were reported. Some of these beds were originally designed and used for sand. Other "deep beds" were created by placing a wooden or metal ("angle iron") rail along the back of existing mattress bedded cubicles, to retain the bedding. Following instructions from machinery distributors or the example of other farmers, the "deep beds" were generally created by gradual build up, with initial applications that compacted to approximately 1" deep. Adding large quantities of bedding at the start was reported to result in heating and proliferation of microorganisms, so it had been recommended that this should be avoided.

Estimates of the amount of bedding applied at one time ranged from 13 litres per cubicle (described as "a dusting") to 40 litres per cubicle for mattresses, and 30 to 70 litres per cubicle for deep beds. A frequent comment was that greater quantities were used than with previous materials since the bedding was always freely available. Farmers were prepared to apply more bedding even though it might be quickly lost from the bed into the passageway. Five farmers reported some initial handling difficulties for automatic scrapers with the amounts shed into the passages. This was dealt with in various ways, by reducing the amount of bedding applied, adjusting the opening into the slatted area, or hand scraping. No difficulties with tractor scraping were reported.

Good absorbency of the bedding material was frequently commented upon. Six farmers reported that the beds were noticeably drier in dry, windy weather, but the remainder had not noticed any effect of weather on the beds. Bed management always included removing any soiled bedding from the rear of the cubicles (frequency dependent on milking frequency). One farmer commented that more wet material had to be removed than with gypsum or sawdust, and another that the material was much easier to manage than 'Envirobed'. Six farmers mentioned bringing forward fresh bedding from a heap at the front of the cubicle, either daily or at every milking. Levelling and raking the beds was common practice for deep beds, although two farmers did not do this, saying "the bed stays level". Three specifically mentioned raking the deep beds to promote drying and one had recently started using a mechanical rake for this. However, during a visit to America he was advised not to do so, and discontinued the practice.

Eight farmers added lime to the beds, three once or twice a week and two daily. Three used lime intermittently, in response to somatic cell count levels in the bulk tank. One used a commercial bedding conditioner. Farmers did not have a good record of lime application rates.

Farmers' opinions on cow welfare and health

Farmers were asked to compare various aspects of health and welfare before and after use of the bedding (Table 4.6). Not all farmers provided information about all of these, while in some cases they provided answers separately for mats/mattresses and deep beds, therefore the total number of responses sometimes exceeds 19.

The majority reported an improvement in cleanliness of cows. Reports on changes in lying time were equally split between improvement and no change, Three farmers considered that grip was slightly poorer, having changed from bedding on sand. The majority reported a benefit to the condition of hocks. Two farms reported poorer conditions for hocks in the initial stages of building up deep beds, due to the thinner layer of bedding at this stage. There were no reports of any other injuries to cows. At the initial interview, with the exception of two farms, clinical mastitis incidence and somatic cell counts (SCC) were qualitatively generally considered to be equal to or lower than before the change to the use of RMS as bedding,.

Table 4.6: Farmers' perception of welfare and udder health indicators before and after using bedding

	n	Better	Same	Worse	No info
Cleanliness	19	12	4	0	3
Lying Time	21	7	7	0	7
Grip	21	2	10	3	6
Hocks	20	10	3	2	5
Clinical Mastitis	19	7	6	2	4
SCC	19	6	6	2	5

Farmers generally reported that teats were cleaner, and easier to clean, than with the previous bedding (Table 4.7). The majority had kept their teat preparation the same, but one discontinued a barrier post-dip (previously on 'Envirobed'), and one had introduced pre-dipping (previously on sand).

Table 4.7: Farmers' opinions on teat cleanliness, and teat preparation with RMS compared with previous bedding material (- less satisfactory, = the same, + better/easier)

Previous bedding	n	Cleanliness			Teat preparation		
		-	=	+	-	=	+
Sand	3	2		1			1
Sawdust	11		1	5		5	
Envirobed	3			3	1	1	
Various	2						

- At the first interview, five farms gave reports of "mastitis episodes", since using the bedding. In several cases these were considered by the farmer to be attributable to other causes. Two farmers considered the episodes might be linked to the introduction of, or problems with, the bedding material - usually when it was "not dry enough" or beds were not well maintained.
- Two farmers later reported mastitis problems and two reported intermittent SCC increases. Lack of access to data did not allow us to quantify these issues fully.
- There were two types of situation mentioned as leading to wetter bedding and apparently linked with mastitis/cell count issues – **1)** weather conditions (either wet weather during separation or damp atmosphere within the cattle housing), and **2)** incorrect performance of the separating equipment.
- At the follow-up telephone call, three farmers reported low mastitis incidence and one an improvement in SCC over the course of time using green bedding. However, two farms had discontinued use of RMS by this time, partly influenced by an apparent detrimental effect on cell counts and/or mastitis.

Economic considerations

Seven farmers estimated electricity costs which average out at 2 pence per cow per day, ranging from 0.3 to 5.2. There are probably discrepancies between those who have included the separator only and those who have also included pumps, which may explain some of the variation. Two separators ran on diesel powered generators. The costs of installation quoted ranged from £28,000 to £60,000. Some installations costs included building reception tanks and/or covers for the separator, and pumps, as well as the cost of the separation machinery itself. All farmers initially perceived financial savings related to the change in bedding type. Estimates of previous expenditure on bedding ranged from £100 to £480 per cow per year, depending on type and source of material. One farmer reported a saving on maintenance of slurry handling machinery as a result of changing from sand. However, four farmers mentioned that the frequency and expense of replacing screens in the separator was higher than expected (£2500, sometimes needing replacement after 8 months) and noted that screens need to be cleaned and checked for wear on a regular basis, to minimise the need for costly replacements.

Other financial benefits, each mentioned by one farmer, were: reduction in mastitis costs, an increase in crop response to nutrients in slurry thereby reducing fertiliser costs and less tractor work pumping slurry.

The perceived effect on labour input varied, depending on the previous system. Eight farmers spent an extra 10-20 minutes per day, either pumping slurry, or in manual work cleaning cubicle beds, while three spent less time as they were now bedding three times a week rather than daily as with sawdust. Eight reported no difference in the time spent working with bedding. Three farmers reported that the system required more management input in terms of monitoring the separation and adjusting the machine.

Environmental benefits perceived by farmers

Farmers' responses to an open question on the environmental impact of green bedding are summarised in Table 4.8.

Table 4.8: Farmers' opinions of the environmental impact of switching to green bedding

	Number of farmers mentioning
Reduced fossil fuel use on bedding deliveries to farm	10
More efficient and effective use of nutrients in slurry	8
Increased slurry storage capacity reducing risk of overflow or untimely spreading	6
Using a "waste" product	1
Less stirring of slurry, possibly less ammonia loss	1
Avoiding sand extraction	1

Opinions on the bedding material

Farmers were asked open questions about their reasons for choosing to use green bedding (Table 4.9), and perceived benefits (Table 4.10) and problems (Table 4.11) with the system

Table 4.9: Reasons for choosing Green Bedding (farmers could give more than one answer).

	Number of farmers mentioning
Cost compared with alternatives	11
Cow comfort	9
Difficulties with supply of alternatives	6
Saw it used elsewhere	3
Difficulties of handling sand	2

Table 4.10: Benefits identified by users in response to an open question

Benefit	**Number of farmers mentioning**
Cost savings	10
Ease of slurry storage and handling	9
Cow comfort or increased lying times	8
Cow cleanliness	8
Availability, making it easy to use bedding liberally	7
Reduced dust in buildings	7
Udder cleanliness	4
More effective utilisation of slurry	4
Cow welfare - reduced hock lesions	3
Bedding easy to handle	1
Not "buying in bugs" in bedding	1

Table 4.11: Problems reported and solutions proposed by farmers

Problem	No. of times mentioned	Solution
Getting initial machine set-up correct	3	Work with the supplier.
Inconsistent, wet product when input material is inconsistent	5	Mix input material thoroughly and add water if necessary.
Inconsistent, wet product when screens are worn or blocked	4	Check product and screens daily
Cell count/mastitis outbreaks connected to wet bedding –either when separator not working properly, or when weather caused damp conditions inside (old) buildings, or when separation occurred outdoors in wet weather	3	Ensure separator is working properly. Separator should be covered. Ensure good ventilation, drainage and state of repair of buildings
Time to build up material for deep beds (availability of sufficient material, and cow comfort while beds are being gradually built up)	3	Do not start building up in summer when less slurry is available? Possibly use another material in base? Effects unknown
Mastitis outbreak when waste milk was entering the reception tank – overcome by diverting the milk	2	Do not include waste milk
Slurry scraped out is stiffer and harder to work with if a lot of bedding ends up ion the passages	4	Add water to help move slurry; adjust opening to slats; scrape by hand
Passages more slippery than with sand – autoscrapers can create a slippery surface film	1	Consider grooving, or apply sand
Not suitable for bedding calves pre-weaning – beds get too wet	1	Do not use for youngstock
More management input needed – not an easy option	4	Include time for monitoring and be observant; training for staff using the system

Farmers suggested the following situations would be unsuitable for use of green bedding:

- Calving cows and young calves, due to the risk of transfer of Johne's disease, and the likelihood that the bedding would become very wet
- If the separator and separated material cannot be kept under cover
- Poorly ventilated buildings
- Cows with teat end damage

Farmers gave the following advice on use of green bedding:

- Need to be able to understand the machine and prepared to spend time monitoring it and the product and adjusting as necessary
- Need to be prepared to invest time and labour in manual bed management
- Calculate the minimum number of cows to make investment worthwhile.

Changes during three months of contact.

During the period of contact through the study, the following changes were made, following the initial interview:

- Two farmers had discontinued use of the green bedding in response to mastitis and cell count problems. In one case, problems were attributed to the difficulties of maintaining dry product without cover for the separator, and the stress on a block calving herd in early lactation. In the second case, an alternative cause for the problem was identified, and green bedding was resumed.
- In response to increases in SCC one farm started applying lime to the beds, while another completely cleaned out the deep beds – but reported that this made no difference and an alternative explanation for the problem was found.
- One farmer changed to a robotic milking system. Despite concerns over how the bedding could be achieved without a fixed period when cows were absent for milking, this was possible to overcome by timing bedding to follow feeding, so that the majority of cows were already in the feeding area, and moving the rest to a loafing area caused minimal disturbance.
- Three farmers changed the cubicle design to a deeper bed, by fitting a bedding retainer (metal or wood) to the back of cubicles, on top of mattresses. One reported that cell count reduced following this change, and clinical mastitis remained very low. Two farmers constructed new cubicles with purpose built “deep beds” (concrete bases and lips to contain bedding).
- Two farmers started using lime on the beds, with the aim of creating drier conditions. One started raking the beds daily, using a mechanical rake, to promote drying, but later discontinued this.

The remaining farmers reported that all was still going well, with no changes.

DairyCo

5. Review of key pathogens

5.1 Introduction

This section indicates, largely in table form, information on the pathogens likely to be found in UK cattle slurry, the availability of information on their survival in slurry, or on their preferred growing conditions and survival in the environment in the absence of information for slurry. This was collated as a result of a literature search using the terms below in CAB Abstracts:

1	dairy cattle. mp. OR exp dairy cattle/
2	dairy cows. mp. OR exp dairy cows/
3	exp cattle/ AND dairy.mp.
4	calves. mp. OR exp calves/
5	heifers. mp. OR exp heifers/
6	1 OR 2 OR 3 OR 4 OR 5
7	animal manures. Mp. Or exp animal manures/
8	faeces. Mp. Or exp faeces/
9	cattle manure. Mp. Or exp cattle manure/
10	slurries. Mp. Or exp slurries/
11	7 OR 8 OR 9 OR 10
12	exp plant pathogens/ OR exp pathogens/ diseases.mp. or exp milkborne diseases/ or exp prion diseases/ or exp young animal diseases/ or exp animal diseases/ or exp diseases/ or exp vector-borne diseases/ or exp travel associated diseases/ or exp viral diseases/ or exp rickettsial diseases/ or exp systemic diseases/ or exp tropical diseases/ or calf diseases/ or exp cattle diseases/ or exp chronic diseases/ or exp mycoplasmal diseases/ or exp bacterial diseases/ or organic diseases/ or exp waterborne diseases/ or exp infectious diseases/ or exp fungal diseases/
13	hazards.mp. or exp health hazards/ or exp hazards/
14	exp risk analysis/ or exp risk/ or risks.mp. or exp risk assessment/
15	12 or 13 or 14
16	bedding.mp. or exp litter/ or litter.mp.
17	15 AND 16
18	exp cattle manure/
19	exp risk analysis/ or exp risk/ or exp risk assessment/
20	18 and 19
18	10 and 15

In the first instance, information relating to a “long list” of pathogens divided into viruses, parasites, Gram positive bacteria, Gram negative bacteria and fungi likely to be found in cattle faeces was collated (see Appendix 3). From a review of literature on pathogens in slurry, those perceived, or known, to be likely to have a high load in cattle slurry were identified and are listed in Table 5.1. NB Notifiable diseases and relevant information on these are covered in Table 5.6.

Having drawn up the list in Table 5.1, the consortium consulted on drawing up a short list, based on the findings of the literature review, existing knowledge, experience and consultation, to include those pathogens though likely to be have high load in slurry, and other pathogens unlikely to have a high load, but likely to be of major significance if present – these are outlined in Table 5.2. The criteria for inclusion were 1) zoonotic pathogens, 2) those most likely to be present at high load in slurry on UK farms, 3) those pathogens of greatest consequence if present, even if at low levels (*eg* notifiable diseases).Information supporting the rationale for including or excluding certain pathogens is available in Section 5.4 where the exposure risks via various routes of contact are considered, although this exercise did not in itself constitute a formal or complete risk assessment.

Information relevant to selection of key pathogens and important for assessing the risks associated with the use of RMS is organised in the following Tables:

Appendix 3: Consideration of all possible pathogens
Table 5.1 All pathogens considered to have potentially high load in cattle slurry in UK
Table 5.2 Explanation of rationale for shortlisting pathogens – further explained in Section 5.4.
Table 5.3 Details of information available on survival of shortlisted pathogens
Table 5.4 Information relevant to assessment of animal health risk for shortlisted pathogens
Table 5.5 Information relevant to assessment of human health risk for zoonotic pathogens
Table 5.6 All notifiable diseases

DairyCo

5.2 Tables

Table 5.1: Pathogens likely to have a high load in slurry in the UK

Pathogen	Zoonotic*	Figures on load in slurry (cfu/ml) (Ln)	Likely to be present in slurry on UK Farms	Survival in the environment
Viruses				
Bovine Viral Diarrhoea Virus	N		Some	100 days at cool temperature (Botner, 2012)
Rotavirus	U			
Coronavirus	N			
Calici-like virus	N			
Astrovirus	N			
Breda virus	N			
Reovirus	N			
Adenovirus	N			
Enterovirus	N			Environmentally stable. Survives 13 days at 35°C
Bovine parvovirus	N			Environmentally stable. Survives 13 days at 35°C In anaerobic conditions, at 5 °C takes 200 days to decrease 1 log unit, at 20 °C 20 days to decrease 1 log unit. (Srivastava & Lund 1980)
Parasites				
Eimeria spp	N			
Cryptosporidium spp	Y		Mainly from calves	14% survival after 250 days at 4°C (Hutchison 2000)
Giardia spp	Y			150 vs 4 days for a 10% reduction in cysts at 5 and 25°C (Hutchison, 2000)
Psoroptes ovis	N		Unlikely	48 days in the laboratory (Liebsich et al 1985)
Fungi				
Prototheca spp	N	5	All	
Gram Positive Bacteria				
Streptococcus uberis	Y	15	All	Survive up to 41°C and 30 to 83% moisture > 3 months (Wang, 2004)

Other Streptococcus spp	Y	15		Survive up to 41°C and 30 to 83% moisture > 3 months (Wang, 2004)
Coagulase negative *staphylococcus* spp	N	7	Most	
Staphylococcus aureus	Y	7	Most	
Mycobacterium bovis	Y		Some	
Bacillus spp	N	15	All	Survival reduced by composting
Mycobacterium avium subsp. *paratuberculosis*	U		Most	At least 2 months despite composting, and over 6 months in liquid storage (Grewal, 2006)
Clostridium spp	N			
Erysipelothrix spp	Y			
Listeria monocytogenes	Y	15 - 18		Reduces with increased temp. Stable at least 4 months at 5°C
Gram Negative Bacteria				
E. coli	Y	9-12	All	> 3 months at =< 27°C (30 to 83% moisture); (Wang, 2004)
Proteus spp	N			> 3 months at =< 27°C (30 to 83% moisture); (Wang, 2004)
Pseudomonas spp	N			> 3 months at =< 27°C (30 to 83% moisture); (Wang, 2004)
E. coli 0157	Y	9-12		> 3 months at =< 27°C (30 to 83% moisture); (Wang, 2004)
Salmonella spp	Y	14	Some	Temp more important than pH. > 3 weeks at 30°C. > 20 weeks at 5°C. Greater heat tolerance with lower available water
Campylobacter spp	Y	7-16		Microaerophilic (in lab)
Treponema spp	N			
Spirochaetes	N			
Leptospira spp	Y			
Klebsiella spp	N			Extremely common in the cattle housing environment (Zadoks et al, 2011)
Yernsinia spp	Y			Live up to 10 days in soil and cattle manure between -4 and 30 ºC
Coxiella burnetii	Y		Some	Very persistent. 20 days in soil (Evstigneeva et al 2007)

* Y = Yes, N = No, U = Uncertain

Having drawn up the list in Table 5.1, the consortium consulted on drawing up a short list to include those pathogens though likely to be most significant, and other pathogens unlikely to have a high load, but of major significance if present (Table 5.2). Rationale for selecting pathogens as significant, or excluding them was partly on the basis of risk, considered by exposure route, and this is presented in section 5.4. More detail in relation to these pathogens is given in Tables 5.3 and 5.4.

Table 5.2: Shortlist of significant pathogens in need of further consideration

Pathogen	Rationale for short-listing
Salmonella spp	Zoonotic, potential high load in slurry
Campylobacter spp	Zoonotic, potential high load in slurry
Listeria spp	Zoonotic, potential high load in slurry
E. coli (inc 0157)	Zoonotic, potential high load in slurry, potential impact on udder health
Klebsiella spp	Reported as an udder health issue in other studies, potential high load in slurry, replication favoured?
Cryptosporidium spp	Zoonotic, potential high load in slurry
Giardia spp	Zoonotic, potential high load in slurry
S. uberis	High load very likely, potential impact on udder health
M. bovis	Zoonotic, notifiable, potential high load in slurry but only if cattle have reached an advanced stage of disease - unlikely
Mycobacterium avium subsp. *paratuberculosis*	Potentially zoonotic, potential high load in slurry
Enterococcus spp	High load in slurry, potential issue with perpetuating antibiotic resistance?
Prototheca spp	Potential high load in slurry, potential udder pathogen common in countries using RMS as bedding
Bacillus cereus	Zoonotic, reported as an issue in The Netherlands with potential for impact on milk quality
FMDV	Exotic disease, shed in faeces, likely to be recycled
Corona virus	Suggested by Defra
Coccidia spp	Suggested by Defra
Yersinia enterolytica	Zoonotic. Potential high load in slurry. Some reports of outbreaks linked to dairy farms through unpasteurised milk/ soft cheese. Can survive in milk if post-pasteurisation contamination occurs.
Coxiella burnetii	Zoonotic. Outbreaks linked to intensive goat farms in the Netherlands. Very low minimum infective dose
Psoroptes ovis	Suggested by Defra as a re-emerging threat in cattle with serious welfare and economic impacts. However, not closely linked with faecal/slurry transmission route.

DairyCo

Table 5.3 Key pathogens and conditions for survival

Pathogen	Likely load in slurry	Figures available on load in slurry (ln/cfu/ml)	Survival in slurry	Survival in the environment	Theoretical conditions for growth	Possible Mitigation	General References
Coronavirus	High		Unknown	Viruses unable to multiply outside host. Nothing found so far on coronavirus but rotaviruses can survive up to 6 months in anaerobically stored animal waste		Ensure calf bedding materials are not used as source material for RMS to control Rotavirus	
Cryptosporidium spp	High		14% survival after 250 d at 4 ^{o} C ; Hutchison 2000	Oocysts can persist for hours in wet environments but do not resist drying. Not heat resistant		Composting 55 ^{o} C up to 1 month. Decline with storage (3 mo) even at 4 degrees. Aeration leading to > 20 degrees = total kill. Sensitive to desiccation. Rare in calves older than 4 months. Pasteurisation of milk	**Dixon 2011; Hutchison 2000; Pell 1997; Cempirkova 2007**
Giardia spp	High		150 vs 4 days for a 10% reduction in cysts at 5 and 25 ^{o} C ; Hutchison	Killed by freezing		Composting 55 ^{o} C up to 1 month. Decline with storage? (study in pig slurry) Peak shedding in calves 4-5 months so avoid their	**Dixon 2011; Hutchison 2000; Pell 1997; Cempirkova 2007**

Pathogen	Likely load in slurry	Figures available on load in slurry (ln/cfu/ml)	Survival in slurry	Survival in the environment	Theoretical conditions for growth	Possible Mitigation	General References
			2000			manure	
Prototheca spp	High	5	Unknown	Depends on species. Optimal pH 5 to 9. Decreased survival with increased salinity; Marques 2010		Use of spruce shavings as bedding?	**Adhikari 2013**
Streptococcus uberis	High	15	Survive up to 41 °C and 30 to 83% moisture > 3 mo; Wang 2004	More likely with low humidity and solar radiation; Lopez 2005			**Blowey 2013; Husfeldt 2012**
Mycobacterium bovis	High		In absence of UV light; up to 6 mo in slurry Menzies 2000.	*M. bovis* persisted up to 88 days in soil, 58 days in water and hay, and 43 days on corn. (Fine et al 2011)		Regular testing of cattle	**Ramirez-Villaescusa 2010**
Bacillus spp	High	15	Survival reduced by composting	Survives adverse condtions as spores			**Husfeldt 2012; Pell 1997**
Mycobacterium avium subsp. Paratuberculosis	High		At least 2 mo despite composting, Over 6 mo in liquid storage;	At least 2 months. Very likely to survive in an environment contaminated with faeces from adult	In laboratory, pH5.5 or above; 25 - 45 °C; optimum 37 °C	Effect of composting uncertain. Thermophilic digestion likely to be more effective than	Grewal 2006; Cempirkova 2007

Pathogen	Likely load in slurry	Figures available on load in slurry (ln/cfu/ml)	Survival in slurry	Survival in the environment	Theoretical conditions for growth	Possible Mitigation	General References
			Grewal 06	cattle.		mesophilic. Do not use bedding for youngstock	
Listeria monocytogenes	High	15-18	Reduces with increased temp. Stable at least 4 mo at 5 ^{o} C	Survives at low temperature	Psychrotrophic. Max temp 45 ^{o} C. Minimum water activity 0.92. Aerobic and anaerobic. Readily inactivated above 70 ^{o}.C	Composting 55 ^{o} C.Some strains resistant to anaerobic digestion	Cempirkova 2007; Pell 1997; Hutchison 2000
E. coli	High	9 to 12	> 3 mo at =< 27 ^{o} C (30 to 83% moisture); Wang 2004	Varies on conditions < 3 mo expected; Depends on cattle diet and soil management; Franz 2005		Composting at 55 ^{o} C up to 1 month. Desiccation. Aeration	Husfeldt 2012; Blowey 2013; Cempirkova 2007; Hutchison 2000;
E. coli 0157	High	9 to 12	> 3 mo at =< 27^o C (30 to 83% moisture); Wang 2004	Varies on conditions < 3 mo expected; Depends on cattle diet and soil management; Franz 2005	Generally acid tolerant. NOT heat resistant (5 min at 57 ^{o} C kills 90% of bact)	50-60 ^{o} composting (NOT heat resistant : 5 min at 57 ^{o} C kills 90% of bact)	Cempirkova 2007; Franz 2007; Ibekwe 2003
Coxiella Burnettii	Mod - low if reproductive material excluded			20 days in soil (Evstigneeva et al 2007). Up to 1 year in soil (Kersch et al 2013) Highly resistant to		Exclude reproductive material from slurry.	Arricau-Bouvery & Rodolakis, 2005, Kazar 2005.

Pathogen	Likely load in slurry	Figures available on load in slurry (In/cfu/ml)	Survival in slurry	Survival in the environment	Theoretical conditions for growth	Possible Mitigation	General References
				destruction by heat, desiccation, or common disinfectants			
Salmonella spp	High	14	Temp more important than pH. > 3 weeks at 30 °C, > 20 weeks at 5 ° C.	Varies on conditions < 3 mo expected	7 - 48 ° C. opt pH 6.5 - 7.5; Relatively resistant to drying	Sensitive to heat (70 ° 2 mins) S. typhimurium DT104- more heat resistant. Increased heat tolerance in higher dry matter material	Hutchison 2000; Pell 1997; Finn et al 2014
Campylobacter spp	High	7 to 16	Microaerophilic (in lab)	Varies on conditions < 3 mo expected		Sensitive to heat at 60 °, drying, and acidification	Cempirkova 2007; Franz 2007; Pell 1997; Hutchison 2000
Treponema spp	High		Unknown	Unknown			Capion 2013
Spirochaetes	High		Stable at least 4 months at 5 ° C, and for 21 months at 15 °	Reduces with increased temperature		Composting 55 ° C	Cempirkova 2007; Pell 1997; Hutchison 2000
Klebsiella spp	High		As for *E. coli*	As for *E. coli;* common in cow environment; Zadoks et al 2011		As for *E. coli*	As for *E. coli*
Enterococcus sp	High		Unknown	Unknown			
FMDV			> 100d at cool temperature; Botner 2012	Reduces with increased temperature		Anaerobic storage; Botner 2012	

Pathogen	Likely load in slurry	Figures available on load in slurry (ln/cfu/ml)	Survival in slurry	Survival in the environment	Theoretical conditions for growth	Possible Mitigation	General References
Coccidia spp	High if from youngstock		Survives freezing and below 35 °C	Oocysts Inactivated by sunlight	>15 °C	Composting ; Fayer 1980	
Yersinia spp	High		Up to 10 days between -4 and 30 ºC	Up to 10 days between -4 and 30 ºC	Grows slowly on most media	Composting ; Mohaibes 2004	
Psoroptes ovis	Low		Unknown	48 days in the laboratory Liebsich et al 1985	Needs host to replicate but adults can survive in environment		Hourigan 1979; Liebsich, 1985; Sarre 2012

Table 5.4: Key pathogens, information relevant to animal health risks

Pathogen	Likely load	Transmission routes to cattle	Cattle consequences	Data on levels in bedding in general	Data on levels in RMS	Minimum infective dose cattle
Coronavirus	High	Faecal-oral	Diarrhoea / Winter dysentery			
Cryptosporidium spp	High	Faecal-oral	Diarrhoea (calves)			Very low ID50 for calves in comparison with environmental shedding (Zambriski 2013)
Giardia spp	High	Faecal-oral	Diarrhoea (calves)			
Prototheca sp.	High	Intramammary	Mastitis			
Streptococcus uberis	High	Intramammary	Mastitis	Env streps, Paduch, 2013	Zehner et al 2009	
Staph aureus	High	Intramammary	Mastitis			1,000 cells/mL but depends on virulence; Slanetz 1963
Mycobacterium bovis	Low frequency and irregular excretion of organisms in faeces, even from heavily infected cattle (Neill et al 1988) Possibly more shedding in urine	Aerosol /intramammary/ faecal-oral	TB			1 cfu for respiratory transmission of the bacterium via aerosols to calves) Dean 2005. Successful transmission via the faecal-oral and milk-borne (digestive) route requires a dose two or three orders of magnitude bigger.(Defra)
Bacillus sp	High	Intramammary	Mastitis	Magnusson et al 2007	Feiken, 2012, Husfeldt 2012	
Mycobacterium avium subsp.	High	Faecal-oral	Diarrhoea, wasting (Johnes Disease)		Harrison et al 2008	

Paratuberculosis						
Listeria monocytogenes	High	Faecal-oral	Septicaemia / Facial palsy / Abortion			
E coli	High	Faecal-oral /intramammary/umbilical	Mastitis / Diarrhoea with some strains (calves)	Van Gastelen et al 2011	Zehner et al 2009, Harrison et al, 2008, Bishop et al 1980 - composted	
E coli 0157	High	Faecal-oral	None			
Coxiella burnetii	Mod – low if reproductive material excluded	Inhalation	Abortion, still births			
Salmonella spp	High	Faecal-oral	Diarrhoea/ Septicaemia/ Abortion			150-200 million organisms per kg. body wt. (calves); Prithulin 1959
Campylobacter spp	High	Faecal-oral	Abortion			
Pathogen	**Likely load**	**Transmission routes to cattle**	**Cattle consequences**	**Data on levels in bedding in general**	**Data on levels in RMS**	**Minimum infective dose cattle**
Treponema spp	High	Skin contact	Digital Dermatitis			
Klebsiella spp	High	Intramammary	Mastitis	Hogan et al, 1999, Zdanowicz et al 2004, Zadoks et al 2011, Kristula et al 2005	Zehner et al 2009, Harrison et al, 2008,	
Enterococcus spp	High	Faecal-oral	Mastitis / Diarrhoea (calve)		Zehner et al 2009, Godden et al, 2008 (digested)	

Coccidia	High	Faecal-oral	Diarrhoea in youngstock or subclinical. Rare neurological disease			
FMDV	Zero unless disease introduced	Faecal-oral, aerosol	FMD			Cattle and sheep can be infected by inhaling 10 to 25 infectious units. For the oral route almost 1million units is required. Donaldson, 1987
Psoroptes ovis	Low	Mainly animal –animal contact , sometimes via fomites	Psoroptic mange			

Table 5.5: Information relevant for human health risks

Pathogen	Zoonotic	Transmission routes to humans	Human consequences	Minimum infective dose human	Human infective dose ref
Cryptosporidium spp	Y	Faecal-oral / Consumption of unpasteurised milk	Diarrhoea	10 - 30 oocysts	Hvlasa et al 2005
Giardia spp	Y	Faecal-oral / Consumption of unpasteurised milk	Diarrhoea	May be as low as 10 viable cysts	Rentdorff 1954
Mycobacterium bovis	Y	Faecal-oral / Aerosol / Consumption of unpasteurised milk	TB		
Mycobacterium avium subsp. Paratuberculosis	Uncertain	Faecal-oral / Consumption of milk ?	Crohnes Disease ?		
Listeria monocytogenes	Y	Consumption of unpasteurised soft cheese / raw milk	Listeriosis	1000	Leggett et al 2012 Schmid-Hempel 2007
E. coli	Y	Faecal-oral / Consumption of unpasteurised milk	Diarrhoea	1 to 3 log 10 dose	Schmid-Hempel 2007
E. coli 0157	Y	Faecal-oral / Consumption of unpasteurised milk	Diarrhoea/ Haemolytic Uraemic Syndrome	10	Leggett et al 2012
Coxiella burnetii		Largely via inhalation of contaminated aerosol particles or contaminated dust	Q-fever	ID 50 1 to 10 organisms	Arricau-Bouvery & Rodolakis, 2005, Kazar 2005
Salmonella spp	Y	Faecal-oral / Consumption of unpasteurised milk	Diarrhoea	S enterica can be as low as 284 esp in high fat foods, (Leggett et al 2012); 1 to 3 log 10 dose but generally105 - 106 (Lawley et al 2008)	Lawley et al 2008; Leggett et al 2012 Schmid-Hempel 07
Campylobacter spp	Y	Faecal-oral / Consumption of unpasteurised milk	Diarrhoea	550	Leggett et al 2012
Yersinia enterolytica	Y	Faecal-oral / Consumption of unpasteurised milk	Diarrhoea	1 to 6 log10 dose	Schmid-Hempel 07

Table 5.5 Cont'd: Information relevant for human health risks

Pathogen	Zoonotic	Transmission routes to humans	Human consequences	Minimum infective dose human	Human infective dose ref
Staph. aureus including MRSA	Y	Consumption of unpasteurised milk	Diarrhoea	5 to 6 log 10 dose	Schmid-Hempel 07
Streptococci	Y	Faecal-oral / Consumption of unpasteurised milk		4 to 6 log 10 dose	Schmid-Hempel 07
Coccidia	Y	Faecal-oral	Diarrhoea/ abdominal pain		

Table 5.6: Notifiable diseases

Disease	Infectious agent	Presence in UK	Potential source for presence in RMS on infected farms	Survival in slurry	Comment
Foot and mouth disease	Virus	Exotic	Faeces, milk, urine	> 100 d at cool temperature; Botner 2012	Mitigation through existing controls
Vesicular stomatitis	Virus	Exotic	Unknown	Unknown	Mitigation through existing controls
Lumpy skin disease	Virus	Exotic	Unknown	Unknown	Mitigation through existing controls
EBL	Virus	Exotic	Milk	Unknown	Mitigation through existing controls
TB	Bacteria	Endemic	Faeces, milk, urine	Can survive 6 mo in slurry particularly in absence of UV light (Menzies 2000; Ramirez-Villaescusa 2010)	High risk in some circumstances but shedding in urine and faeces unlikely in most UK herds as a result of frequent testing and removal of infected animals (Menzies & Neill, 2000; Prof. E Wellington, Personal communication)
BSE	Prion	Exotic	Unknown	Unknown	Mitigation through existing controls
Bluetongue	Virus	Exotic	Unknown	Unknown	Mitigation through existing controls
Aujeskys	Virus	Exotic	Pig slurry	15 weeks at 15 deg C in pig slurry (Botner 91)	Avoid mixing slurry from different species
Rabies	Virus	Exotic	Unknown	Unknown	Mitigation through existing controls
Rift Valley Fever	Virus	Exotic	Unknown	Unknown	Mitigation through existing controls
CBPP	Bacteria	Exotic	Unknown	Unknown	Mitigation through existing controls
Anthrax	Bacteria	Exotic	Unknown	As for Bacillus sp. ?	Mitigation through existing controls
Brucellosis	Bacteria	Exotic	Uterine fluid	Unknown	Mitigation through existing controls
Rinderpest	Virus	Exotic	Faeces, milk, urine	Unknown	Eradicated
Warble fly	Insect	Exotic	Unknown	Unknown	Mitigation through existing controls

5.3 Notifiable diseases

Bovine Tuberculosis.

Excretion of Bovine Tuberculosis (bTB) in faeces, urine and milk is considered to be rare in the UK, since lesions of the alimentary tract are very uncommon compared with those of the respiratory tract (see review by Menzies & Neill, 2000). Current limited understanding of shedding patterns of bTB suggests that a heavy load in faeces and urine is unlikely to occur until the disease reaches an advanced stage and even then can be sporadic (Neill et al, 1988).

With regular testing, the chances of reaching this stage are much reduced (Prof Liz Wellington, personal communication). However, information on the shedding patterns of cattle throughout the development of the disease is limited.

If bTB were present in the slurry, it is not likely to be reduced merely by physical separation, therefore it could be present in the bedding material. Survival in slurry ranges from ten weeks to six months, and is dependent on temperature (see review by Phillips et al, 2003). Anaerobic digestion (probably thermophilic at 49-57^{O}C) or heat treatment would be needed to ensure killing this pathogen, but this is an area that would need further investigation. Solid manure must be composted at 60-70^{O}C for three weeks to destroy the pathogen (see review by Phillips et al, 2003))

EXOTIC DISEASES

With respect to exotic diseases, given current knowledge and faecal shedding, FMDV was considered the most likely to have the potential to be affected by a change to the use of RMS for bedding (see Table 5.6).

FMDV

Transmission is possible by direct contact of susceptible animals with contaminated inanimate objects (hands, footwear, clothing, vehicles, etc.). Infective agents can occur in faeces and urine up to four days before clinical signs, although relatively little of the infective agent is excreted in faeces compared with oral secretions and output of respiration (Botner et al, 2012). Therefore, there is a theoretical risk that the pathogen could be in slurry and be transmitted to other animals bedded on a product of that slurry, before clinical signs became apparent. However, uninfected animals on the farm will already be in contact with slurry and infected animals. Recent evidence suggests that transmission from animal to animal on farm is unlikely to occur at a significant level prior to the onset of clinical signs and therefore the risk of significant recycling and 'up regulated' transmission as a result of the use of RMS as bedding is likely to be small (Chase-Topping 2013).

Considering influences on the farm before disease controls are put in place, i.e. before detection:

In general, if a notifiable disease is present on a farm, but as yet undetected, there is no evidence or reason to believe that use of RMS would delay detection. For diseases transmitted through faecal material or other substances that might be incorporated in slurry, use of the material might theoretically increase risk of spread within farm before detection. However, assuming stockmanship is adequate and rapid, transparent reporting occurs, any risk would only be increased if there was significant shedding before the onset of clinical signs. Additionally, there could be increased risk if pathogen proliferation were faster in stored slurry than in fresh slurry, but the information to quantify this has not been found.

Considering spread to other premises:
Separation of slurry may result in aerosol production – but since separation may occur independent of use as bedding, this risk is not related to use as bedding *per se*. Handling of the bedding may result in aerosols, but this will occur predominantly inside a building and thus be local to the area of use and probably less of a risk than spreading of dirty water which would occur out of doors. Thus, if the material used is kept within buildings on the farm there is unlikely to be any quantifiable increase in risk of transfer of notifiable disease by aerosol (*ie* Foot and Mouth Disease) to remote premises.

5.4 Exposure risk section – linking to short listing of pathogens

Rationale for selecting pathogens as significant, or excluding them, was partly on the basis of risk, considered in terms of both likely presence in slurry (Table 5.1) and exposure route, covered in this section. This exercise did not in itself constitute a formal or complete risk assessment. The information in this section is also relevant to the subsequent section on risk pathways under the impact of use of RMS (Section 8).

5.4.1 Animal health exposure pathways

Exposure risks for intramammary infection

Major mastitis pathogens were included since the exposure risks for mastitis are high. The teats are bound to come into contact with the bedding and bacterial counts show high levels of coliforms and environmental streptococci in this bedding material (as in other organic materials) i.e release assessment indicates an increased risk. Levels of *Klebsiella* spp and Gram negative bacteria on teat ends have been shown to be higher for RMS than for sand (Harrison et al, 2008). Bishop et al (1981) found significantly higher counts of *E. coli* and *Enterobacter* spp in teat swabs from cows on rubber mats than on “composted dairy waste solids” of 26% DM, (but not in counts from the milk of the two groups of cows).

Exposure risks for the integument

With types of bedding that result in “sticky” slurry, the contact with digital skin might be increased. Anecdotally, some farmers report that cows’ feet are cleaner with RMS. Personal observations suggest that in some cases aspects of building design, especially narrow passageways, will have a greater effect on foot hygiene than bedding type. Therefore, overall we did not consider that contact of the digital skin with pathogens would be increased by this type of bedding. In terms of release assessment, the spirochaetes associated with digital dermatitis are known to thrive in moist conditions, and their growth is less prolific in drier conditions. For this reason we did not consider that there would be an increased load of spirochaetes, although they are known to be associated with the digestive tract and therefore likely to be present in faeces and slurry (although hard to culture). Moreover, strains recovered from the digestive tract and foot lesions differ (Evans, 2011, 2012).

Exposure risks for the respiratory tract

Contact via the respiratory route is another possibility but again, there has been no quantification of the population of micro-organisms or spores in the aerial environment, specifically in the case of RMS compared with other bedding types. The number of spores has been shown to be higher in RMS than in sawdust by Driehuis et al (2012) but no air sampling was carried out in this study. The reports of reduced dust would suggest a reduced risk, although it is possible that invisible aerosols might still carry organisms or spores. Bioaerosols should be considered even if dust is not reported, since direct correlations between concentrations of dust and bioaerosol components are not always seen (Gladding et al 2003). However, no information on bioaerosols specifically linked to RMS has been found. Lower levels of dust might reduce the risk of transmission of MAP via dust particles, which have been shown to be a source of MAP on infected farms (Eisenberg et al, 2014).

Animal health exposure risks for the GI tract

Exposure for the GI tract could occur through ingestion of the bedding material itself, either deliberately, by grooming, or through food contaminated with bedding material. Deliberate ingestion is much more likely with young animals. According to the farmer survey, no animals have been seen eating the bedding. The risk of ingestion of RMS through self-grooming cannot be quantified, but anecdotal reports are that both cows and the environment are far less dusty with RMS bedding than with sawdust, so that intake of bedding particles by this route is not likely to be high. The visual lack of dust does not preclude the presence of micro-organisms, but there is no information on the presence of micro-organisms on the body of cows bedded specifically on RMS, apart from that on teats already mentioned. If present on the teats, microorganisms are also likely to be on the coat, but no data on this are available.

Animal health exposure risks for the reproductive tract

Risk of contact with the reproductive tract is greatest during calving. Any risk of infection could be mitigated by avoiding use of RMS in calving areas. This could potentially need to include transition cow housing in view of the risk of unexpected calving in this group.

Table 5.7: Exposure risks for livestock

Possible routes	Likelihood	Evidence for likelihood	Suggested mitigation
Intrammamary			
Intramammary infection	Pathogen load levels appear high, but other bedding materials can soon reach the same level	Harrison et al, 2008, Hogan et al, 1989; Van Gastelen et al. **2011**	Good bed hygiene, teat hygiene
Integument			
Digital dermatitis via digital skin infection	Possibly lower than in other types of bedding	Feet reported to be cleaner and drier.	
Abrasion	Less than with abrasive sawdust, probably similar to sand	Zehner et al, 2009, Husfeldt et al, 2012	Maintain a good depth of bedding but ensure bedding retainers will not cause pressure on hocks
Skin irritation	Possibly lower than with some other bedding materials, though ammonia content could have impact.	Hock lesions still occur in systems using RMS Zehner et al, 2009, Husfeldt et al, 2012	
Respiratory			
Inhalation of dust	Low	Farmers report "no dust"	
Inhalation of pathogens in aerosols	Unknown	No information	Buildings must be well ventilated
Inhalation of ammonia	Possibly higher risk than some other bedding materials	Large capacity to absorb moisture Ammonia emissions greater than from straw but overall impact on total emissions small (Section 9)	Buildings must be well ventilated
Creation of a humid atmosphere	Likely to be higher than other bedding materials in similar circumstance	The material is hygroscopic, but does dry within a building so has potential to release a lot of water into the atmosphere.	Bedding should be as dry as possible when applied Buildings must be well ventilated

Ingestion			
Deliberate ingestion of bedding material	Very low for adults	Farmer survey – no cows seen eating bedding	None required
	Possible for calves	General calf behaviour	Do not use RMS for youngstock
Swallowing material trapped by muco-ciliary apparatus	Possible	No information. Reports of low dust levels lessen the likelihood of particles in the air. Possibly still invisible pathogens/aerosols	Buildings should be well ventilated
Ingestion as a result of suckling	Relatively high for newborn suckling calves		Do not use RMS in calving areas
Ingestion by grooming	Relatively low	Survey – cows are not dusty with this material	
Contamination of feed	Dependent on handling of the material		Use separate or cleaned equipment for handling bedding and feed
Reproductive tract			
Infection of reproductive tract exposed at calving. Navel ill in calves	Possible	Some potential pathogens at high levels in RMS - *eg E. coli*	Do not use RMS in calving areas (or transition cow housing)

There is no information on the likely load of viruses in bedding material, so this aspect of risk cannot be quantified or compared with other bedding material.

5.4.2 Exposure risks for human health - farm workers

Exposure by ingestion

When handling any bedding material there is a risk of hand to mouth transfer of pathogens present in bedding. If bacterial load is higher the risk will be higher. The usual personal protective and hygiene protocols should be applied.

Exposure by inhalation

The reports of less dust from RMS compared with other bedding materials suggest that inhalation of physical particles will be less, however aerosols would still need to be considered. The steps in use of bedding most likely to produce aerosols are the separation and the distribution of bedding. Since the separation process may be carried out anyway, for slurry management purposes, we will consider only the handling of bedding. There is no information on the production of aerosols from RMS.

Composted bedding materials can contain spores of *Thermoactinomyces* which, along with other micro-organisms found in compost, are hazards that carry the risk of causing respiratory disease if inhaled with compost dust (Driehus, 2010). Although not directly relevant to fresh RMS, these might be present if heating in the bedding had caused a partial composting effect, and might be disturbed and airborne in bed maintenance.

There is a theoretical risk of inhalation of bTB pathogens if these are present in the slurry, but based on the evidence in section 5.3 this is unlikely to be a significant threat to human health, when compared to the output of respiratory shedding from infected cattle. However, in considering this pathogen one needs to consider the theoretical transmission pathways from cattle to humans and their relative risks. For example, the highest risk will be through the consumption of unpasteurised milk whilst infection through the respiratory route is less likely. Currently less than 1% of UK cases of TB in humans are caused by bTB and a significant proportion of these are in humans over 70 years old (reactivation of ancient infections) or immigrants from developing countries.

Human Health - farm workers

Possible routes	Likelihood	Evidence for likelihood	Suggested mitigation
Integument	Higher pathogen levels in "fresh" bedding than other materials, but little difference in "used" bedding		Personal protective equipment and hygiene as for working with animals, slurry and other bedding materials
Respiratory	Likelihood of dust lower than with other bedding – may reduce MAP exposure	Farmer survey – "no dust"	
	Possibly via aerosols	No information	
	Possibly via spores	Composted materials contain more spores	
	Ammonia	Slightly higher emissions than from straw	
Ingestion – contact with materials at work	In general, higher pathogen levels in "fresh" bedding than other materials, but little difference in "used" bedding. Possibly higher MAP exposure?	Sections 7 and 14	Personal protective equipment and hygiene as for working with animals, slurry and other bedding materials

5.4.3 Human health - consumers

For consumers there would be increased risk of ingestion of pathogens if more pathogens are found in milk than with other bedding materials. Levels of bacteria in bulk milk from cows bedded on RMS have been assessed in only six non-peer reviewed papers (see Appendix 4). Aerobic mesophiles (21-321 cfu/ml) and *Enterococci* (158-500 cfu/ml) were found in similar levels as in milk from cows bedded on compost (Zaehner et al 2009). Lower levels of *Staphylococcu aureus* (approx 316 cfu./ml) and higher levels of *Streptococci* non *agalactiae* (approx 1500 cfu/ml) were found compared with cows bedded on dolomitic limestone. Mitigation in these circumstances would be through pasteurisation.

Possible routes	Likelihood	Evidence for likelihood	Suggested mitigation
Transfer of pathogenic organisms from bedding to milk is possible	Some risk	Higher levels of thermophilic and mesophilic spore- bearing bacteria, butyric acid bacteria and B. cereus in RMS than with straw (even more with composted bedding). Not necessarily at levels to cause problems but should be borne in mind (Feiken and van Laarhoven 2012)	Pasteurisation of milk

5.4.4 Milk Quality

There is some evidence of an increased load of potential food spoilage bacteria in milk from cows bedded on RMS, although levels were not as high as with composted materials (Feiken and van Laarhoven 2012). Although levels are not excessively high the implications should be considered, in particular because thermophilic bacteria are more likely to escape pasteurisation.

Possible routes	Likelihood	Evidence for likelihood	Suggested mitigation
Transfer of food spoilage organisms from bedding to milk is possible	Some risk	Higher levels of thermophilic and mesophilic spore- bearing bacteria, butyric acid bacteria and *B. cereus* in RMS than with straw (even more with composted bedding). Not necessarily at levels to cause problems but should be borne in mind (Feiken and van Laarhoven 2012)	Pasteurisation of milk

5.5 Implications for antibiotic resistance

Although antibiotic resistant bacteria specifically in recycled manure solids may not have been studied, there is a growing body of literature on the presence of antimicrobial resistant organisms, and the genes that convey antibiotic resistance, in livestock manures in general (Chee-Sandford et al, 2009). Higher levels of antibiotic resistant microbes can be found in manure from livestock treated with antibiotics than in control animals (Sharma et al, 2009). The effects of manure treatment have been investigated. In a trial using cattle fed Tylosin and a control group with no antimicrobials, composting of manure reduced high initial levels of the genes for resistance to tetracycline and erythromycin occurring in the treated group, even though windrows did not reach the recommended temperature of 55°C for 15 days. A reduction in resistant *E. coli* was seen as early as week 2 of composting. However, resistance genes could still be detected (Sharma et al, 2009). Wang et al (2012) report that composted pig manure contained lower levels of genes encoding for antimicrobial resistance than manure kept in lagoons at ambient temperature with moderate aeration, or treated with biofilters.

It has been estimated that livestock may excrete 75% of the antimicrobials with which they are treated (Chee-Sandford et al, 2009). Thus there is potential for these products to contaminate the slurry and affect its microbial population, possibly facilitating the dissemination of antimicrobial resistance.

There is also some evidence that the presence of disinfectants can contribute to the development of resistance to both disinfectants and antimicrobials in the microbial population (Webber et al, 2007; Tandukar et al, 2013). Whitehead et al (2011) found that although exposure to low levels of biocides did not alter microbial genotype, a single exposure to a biocide at working concentration could lead to the development of multidrug resistance capabilities in *Salmonella typhimurum*. Karatzas et al (2008) worked specifically with farm disinfectants; an oxidizing compound blend, a quaternary ammonium disinfectant containing formaldehyde and glutaraldehyde, and a tar acid-based disinfectant, and obtained evidence that these can select for *Salmonella enterica* strains with reduced susceptibility to antibiotics. Long-term exposure to Benzalkonium chlorides (BACs), a widely used class of quaternary ammonium disinfectants, has been shown to affect microbial community structure and antimicrobial resistance. In a laboratory experiment, long-term exposure to BACs reduced community diversity and resulted in the enrichment of BAC-resistant species, predominantly Pseudomonas spp. Exposure of two microbial communities to BACs significantly decreased their susceptibility to BACs and to three clinically relevant antibiotics (penicillin G, tetracycline, ciprofloxacin (Tandukar et al, 2013)). Our understanding of the persistence of genetic material encoding antimicrobial resistance and resistant organisms in the environment and more specifically the impact of the use of RMS is currently limited. This lack of understanding and current knowledge suggest a cautious approach would be prudent. The potential impact of antimicrobial resistance should be borne in mind when considering the effects of incorporating faeces and urine from animals under treatment and milking machine washings, which will contain disinfectants, in slurry that is to be used for separation to provide bedding materials.

DairyCo

6. Effects of treatment and processing

Although the bacterial load of the initial faecal material feeding into RMS is likely to be high, various stages of processing will alter this. This section covers effects on the bedding material before it is applied to beds. Management once on the beds is covered in Section 9 “Assessment of Housing Effects”.

6.1 Physical separation

No reports on the microbial population of raw cattle slurry before and after separation have been found although there are reports on reductions in pig slurry. Physical separation of pig slurry using a centrifugal mechanism resulted in a solid fraction with a ten-fold reduction in *E. coli* and *Enterococci* compared with the initial material (McCarthy et al, 2013). Watabe et al (2003) demonstrated a marked reduction in the prevalence of *Campylobacter* spp and *Salmonella* spp in the solids component of pig slurry separated using a perforated drum screen. An American case study showed that liquid-solid separation of cattle manure digestate resulted in a reduction in the faecal coliform counts from 4000 mpn/g in the whole digestate to 1000 mpn/g in the solid fraction (Pronto & Gooch, 2009). (mpn, “most probable number”, used for reporting counts from multiple serial dilutions). Separation of anaerobically digested pig manure using a belt separator did not achieve a significant reduction in any microorganisms from the initial manure (although a numeric reduction was seen).

6.2 Composting

Composting manure is relatively common in the US, the principle being to raise the temperature and kill pathogenic bacteria, by encouraging aerobic microbial activity. Air may be introduced by mechanically turning material piled in open windrows or by “tumbling” the material in a closed drum. The temperature and thus the bacterial population can be hard to control. Bishop et al (1981) found that bacterial counts decreased in dairy waste solids composted over 14 days and considered the material suitable for bedding; this was confirmed by later work in a larger survey (Husfeldt et al 2012). However, although coliform counts were reduced to zero (or at least undetectable levels) after composting manure waste, under suitable conditions of moisture and temperature and with use they multiply again (Carrol and Jasper 1978). These authors did not determine whether this was through survival or external contamination. (NB this work was undertaken in California and the composted solids were spread “to dry” in a pen inhabited by yearling heifers before being used for cow bedding). There are reports of drum and windrow composting and storage of composted material in the Netherlands (Hartley, 2013). Not all studies provide unquestionable evidence that composting will reduce all pathogens. On-farm studies by Harrison et al (2008) suggested that with composting bacterial numbers in bedding before use reduced for *Streptococci, E Coli, Klebsiella* and *Corynebacterium*, but levels of *Staphylococc*i and gram negative bacteria increased.

6.3 Manure solids from anaerobic digestion

As anaerobic digestion of dairy waste for energy production has become more widespread, an alternative processing stage has become available. In the US, bedding is made by ”simple primary separation of coarse solids from digestate effluent” and also by further processing such as composting of the solid fraction of the digestate (Sheff et al, 2009). To date this type of bedding has not been used in the UK although interest is developing.
There are several reports of the effect on pathogen populations in this type of bedding, which will be dependent on the feedstock and temperature in the digester (Meyer et al, 2007). In general bacterial levels are considerably reduced and coliforms often undetectable after digestion (Meyer et al, 2007; Tulloch et al, 2009). Anaerobic digestion resulted in a significant reduction in the MAP counts of manure from 4000 cfu/g to 50-100 cfu/g (Pronto & Gooch 2009). *E. coli, Salmonella typhimurium* and *Yersinia enterocolitica* can be reduced by 90% in 1-3 days of mesophilic anaerobic digestion, *Listeria monocytogenes* in 12-36 days depending on the type of digester. However, aerobic digestion had little effect in reducing the viable numbers of *Campylobacter jejuni* (Kearney et al, 1993). The temperature in the digester is critical: mesophilic digesters running at temperatures of 30-38^{o}C can increase bacterial numbers (Tulloch, personal communication). Coliforms multiplied most rapidly in organic bedding at 30-40^{o}C (Bramley 1982 - cited by Hogan et al 1989).

Also, if additional materials are included as feedstock this will bring new risks. With separated digested material, as with others, levels of contamination again increase very rapidly once it is in place on beds. (Meyer et al, 2007; Harrison et al, 2008, Tulloch et al, 2009).

6.4 Other drying and heating processes

Further drying, for example by the use of fans, or additional heat is unlikely to increase risk but rather may help with mitigation, although it will increase the cost of the operation. Such processes have not been considered in detail since they are not currently in use in the UK.

6.5 Altering the pH

Altering the pH of a material will alter the microbial population it supports. Although this type of treatment is generally applied once the bedding has been applied to the beds, there are reports of the separation of pre-acidified slurry in Denmark (Katholm, pers comm.). The acidification treatment is carried out to reduce the ammonia emissions for environmental reasons. Once this has been carried out, the addition of alkali treatments to the bedding is not effective as the pH cannot be raised sufficiently to control microbial growth. Anecdotally, mastitis outbreaks have been associated with acidified material.

7. Pathogen numbers in bedding, changes with use and comparisons with other materials

Data on pathogen numbers in bedding materials, and how they change, were collated from peer reviewed literature and industry contacts. Harrison et al (2008) conducted the most comprehensive study of pathogens in bedding materials including some recycled manure solids and concluded that individual farm factors and management, and input of pathogens through faeces had a strong influence, alongside that of the underlying bedding type. Although the comparisons are not replicated and can only be viewed as Farm-Bedding System combinations, the study provides a valuable source of information. However, it must be borne in mind that these data were collected in America, and only one or two of the farms included prepared the recycled bedding in a similar way to that currently most common in the UK. Appendix 4 tabulates the references with data on pathogen load in RMS comparable to that currently used in the UK, indicating the availability of this information.

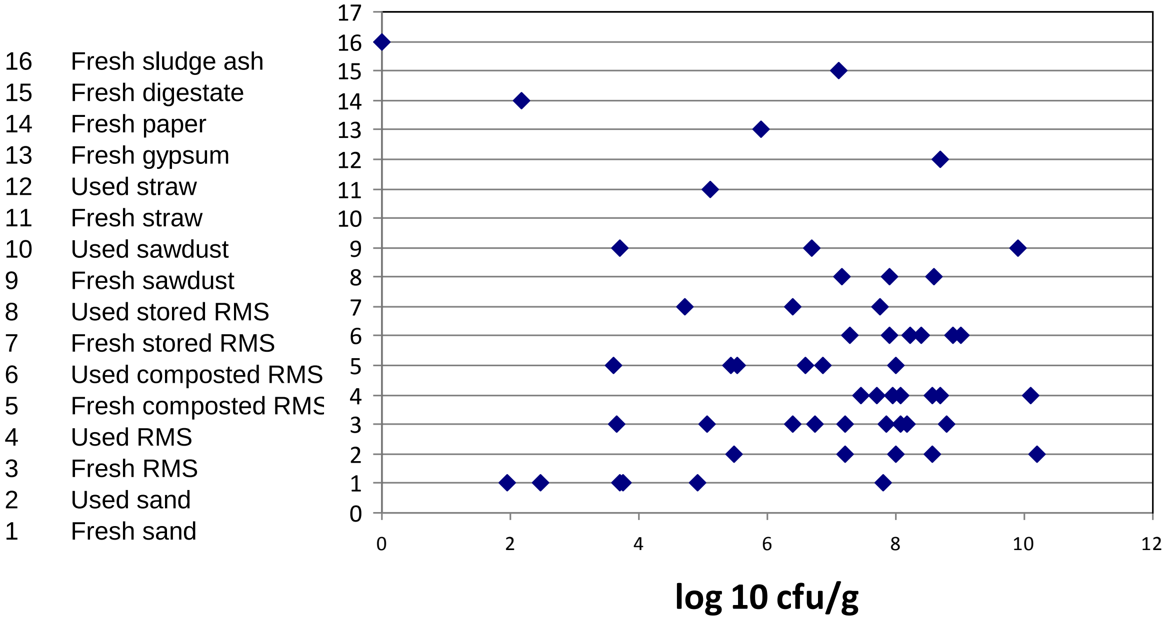
Figures 7.1, 7.2, 7.3, 7.4, 7.5 and 7.6 illustrate the range of values of load in bedding which have been found for various pathogen groups expressed in cfu/g fresh bedding. Data for RMS bedding in UK conditions are relatively limited. Published data and data from QMMS and other laboratories for other materials have been included for comparison. The ability to compare studies is often limited by differences in the methods or units used to express results (eg cfu/ml, cfu/g freshweight, cfu/g DM).

These data suggest there can be as much variation within as between bedding materials once they have been applied to the bed. In a comparison of sand and RMS on the same farm, these authors were surprised to find less difference between bedding types than expected, and concluded the bacteria initially present in the bedding material, and stall management, had more influence on the bacterial population of beds after use than the type of bedding per se. In fact, an association between lower initial bacterial counts in “fresh material” and higher counts on used bedding suggested to the authors that there might be an element of protection from competition between bacteria, with sterile bedding allowing greater proliferation of pathogens than bedding with an initial population of benign organisms.

Data sources for Figures 7.1-7.6: Blowey, 2013, Driehuis, 2012, Fairchild *et al* 1982, Harrison et al, 2008 Zaehner *et al* 1986, QMMS samples received prior to this study. (See Section 14 for the results of samples collected specifically for this study).

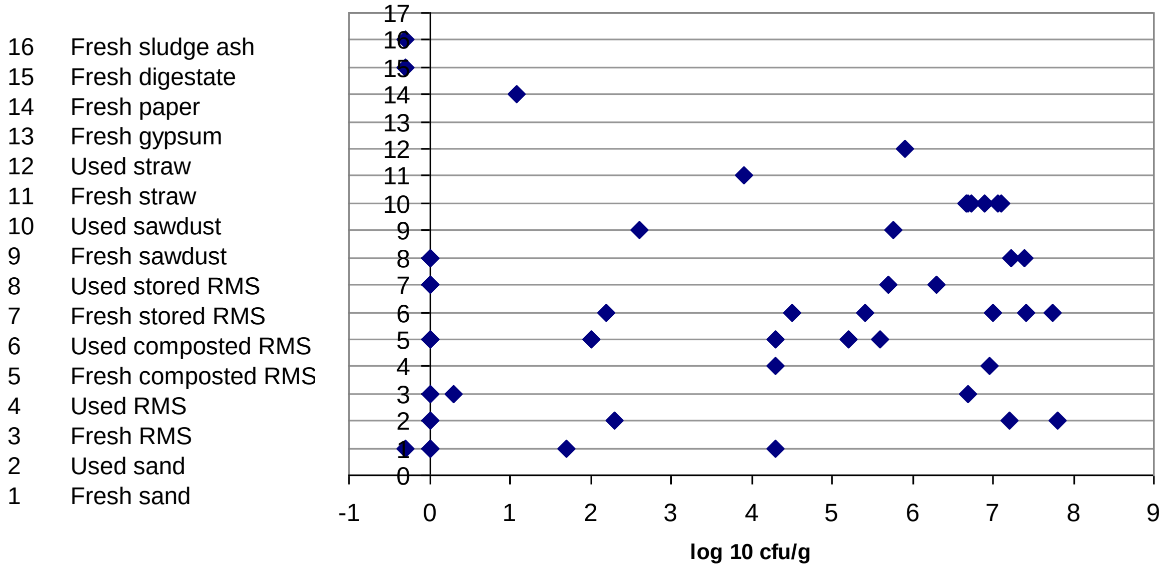
Other sources are available but differences in units reported preclude direct comparison

Figure 7.1: Total Bacterial Counts in different bedding materials



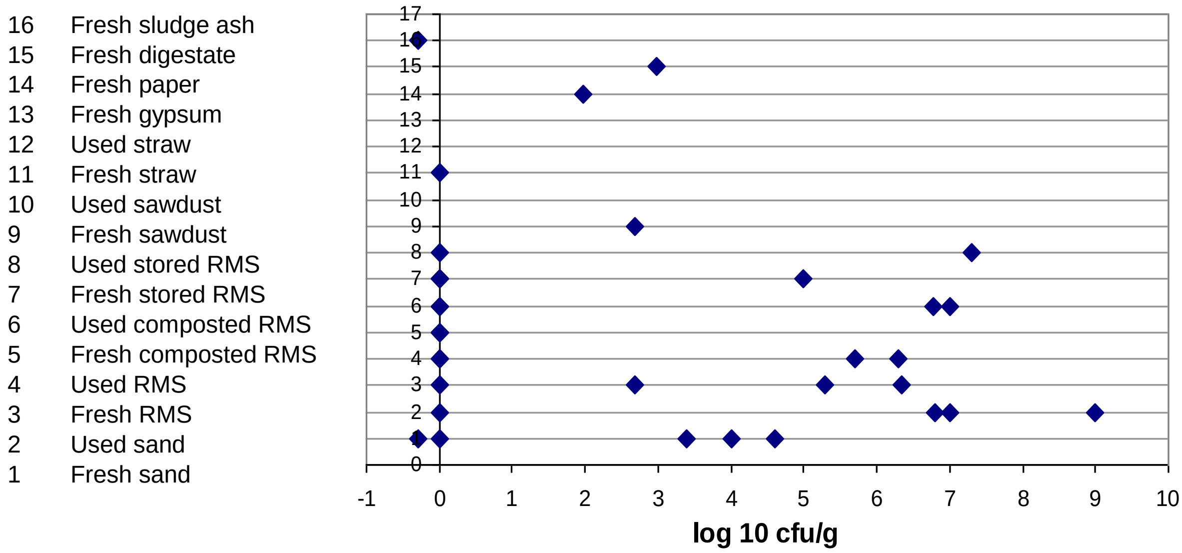
Total bacterial counts in fresh RMS of the order of 10^4 and 10^8 cfu/g of fresh bedding have been reported. With storage the range of comparable results was surprisingly similar although the general advice in this country is not to store the material. Fresh sawdust showed a similar range and even "fresh" sand, claimed to be inert, provided some samples with very high load. No papers in the peer reviewed literature reported on fresh straw, measured using these units; only a commercial sample was available, again falling within the same range as RMS. In this range of samples, even composted and digested RMS had relatively high levels of total bacteria. With use, there was a trend for all products to move towards or beyond the higher end of the range for fresh material.

Figure 7.2: Total Coliform counts in different bedding materials



Coliform counts were very variable. In some samples, including one for fresh RMS, this group of organisms fell below the level of detection, but in many cases of both fresh and used material, levels were high.

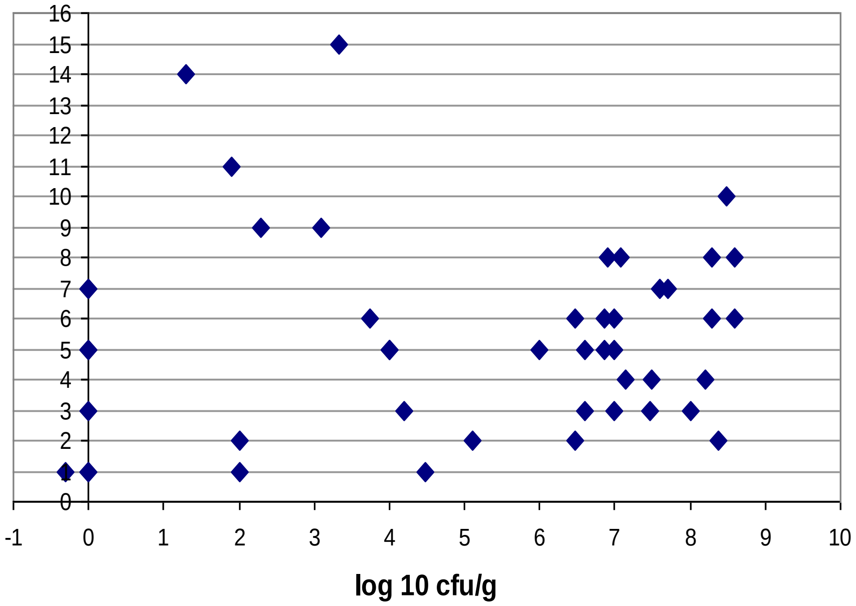
Figure 7.3: *Staphylococcus* spp counts in different bedding materials



Staphylococcus spp were much less frequently detected in bedding materials. However, in some cases high levels could be found, particularly in fresh and stored separated RMS ("fresh stored RMS"), and also in used sand.

Figure 7.4: *Streptococcus* spp counts in different bedding materials

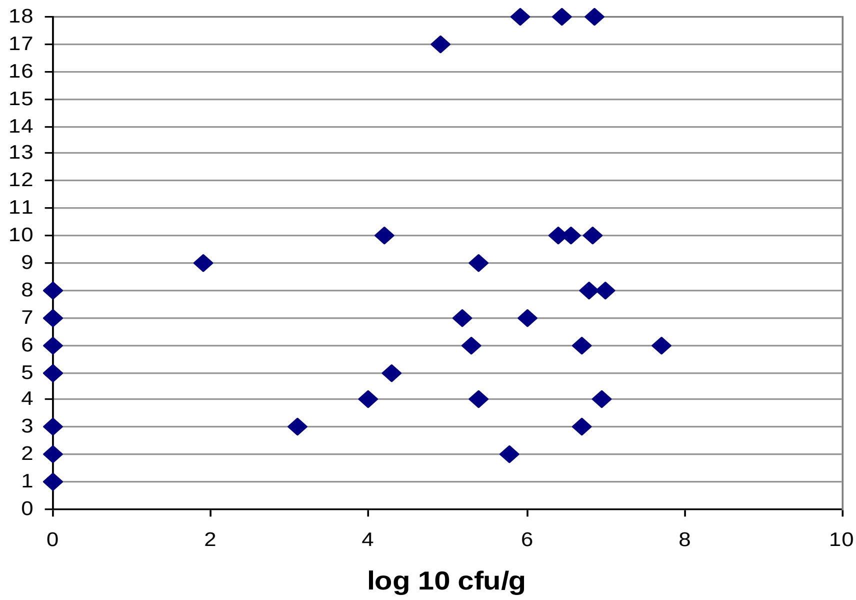
16 Fresh sludge ash
15 Fresh digestate
14 Fresh paper
13 Fresh gypsum
12 Used straw
11 Fresh straw
10 Used sawdust
9 Fresh sawdust
8 Used stored RMS
7 Fresh stored RMS
6 Used composted RMS
5 Fresh composted RMS
4 Used RMS
3 Fresh RMS
2 Used sand
1 Fresh sand



Streptococcus spp were also undetected in some materials, including samples of unused separated, stored and composted RMS, but could also often be found at above 10^6 cfu/g in each of these materials both before and after use.

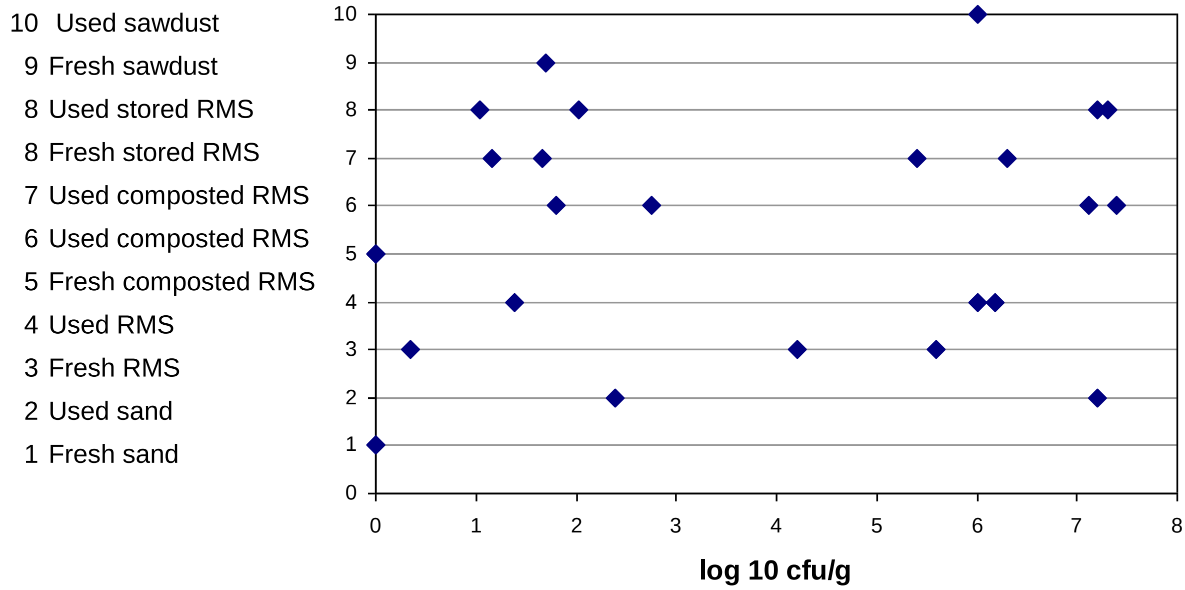
Figure 7.5: *Klebsiella* spp counts in different bedding materials

18 Used sawdust + lime
17 Fresh sawdust + lime
16 Fresh sludge ash
15 Fresh digestate
14 Fresh paper
13 Fresh gypsum
12 Used straw
11 Fresh straw
10 Used sawdust
9 Fresh sawdust
8 Used stored RMS
7 Fresh stored RMS
6 Used composted RMS
5 Fresh composted RMS
4 Used RMS
3 Fresh RMS
2 Used sand
1 Fresh sand



Klebsiella spp counts were extremely variable within bedding types, but were reported at least once at relatively high levels (10^4 or more) in all materials apart from sand both before and after use. Interestingly, the addition of lime to sawdust did not prevent *Klebsiella* spp multiplication.

Figure 7.6: *E. coli* counts in different bedding materials



E. coli detection in all materials except fresh sand and fresh composted RMS. Used RMS, whether or not composted or stored, demonstrated some of the highest levels of *E. coli* (10^6 cfu/g or more). Counts from fresh and used sawdust were also high.

8. Review of impact

8.1 Impact on cow comfort and welfare

8.1.1 Lying surface

In terms of cow comfort and welfare, as distinguished from health, the main impact of RMS is likely to be on lying comfort. Potentially beneficial physical attributes are that the material is soft, easily deformed, and non-abrasive (Harrison et al 2008). There may be some differences between the use of RMS on mats and in deep bedded cubicles, with the deep bedding likely to provide greater comfort, as indicated by Husfeldt and Endres (2012). Increasing the depth of commonly used bedding materials is known to increase lying times and reduce hock damage (eg Tucker et al, 2009). The fact that the material is freely available encourages more liberal applications to mats and mattresses (farmer survey - Section 4.2).

Anecdotal reports suggest that changing to RMS reduces **hock lesions** (section 4.16). However**, reported hock lesion** prevalence of 45-53% on RMS deep beds and 63-72% on mattresses (Husfeldt & Endres, 2012), and 41% on deep RMS beds (Zaehner et al, 2011) suggests that use of the material, as bedding, does not overcome the problem. Reported prevalences are lower than some reported for mats and sawdust (Weary & Taszkun, 2000, Fulwider et al, 2007) but higher than those reported by Weary & Taszkun (2000), and Fulwider et al (2007) for cows on deep sand. Husfeldt & Endres (2012) considered that this might be as a result of the RMS being more easily compressed than sand and therefore more likely to result in exposure of the "heelstone" of the cubicle bed, making it more likely to come into contact with the cow. In univariate analysis, the type and degree of exposure of the stall base had an equal probability of effect to the type of bedding material Lombard et al (2010). However, use of the data in a model predicted slightly higher levels of severe hock lesions in cows bedded on dried or composted manure solids (2.7%) than on sand (0.7%).

The two published papers reporting **cow preferences** for recycled manure solids give contrasting results. Keys et al (1976) compared the amount of time cows spent **lying** on a choice of stalls with "Dewatered manure solids" (29% DM), "Dehydrated manure solids" (81% DM), and sawdust at 10 cm depths, finding by far the shortest proportion of time spent lying on the dewatered solids (9 cows with choice between 27 stalls). They speculated that the DM content of the material influenced the cows' choice, since times on sawdust and dehydrated solids were similar. Yet, cows have shown preference for cubicles bedded with "manure separates" (processing undefined) compared to those with straw, sand and sawdust (Adamski, 2011). In a comparison with RMS, straw, sawdust and compost bedded cubicles, cows were no less likely to lie down on RMS (Feiken & van Laarhoven, 2012). Lombard et al (2010) reported 50% of cows lying in sand bedded stalls compared with 40% in those bedded with organic materials, including RMS. (However, this analysis did not distinguish between bedding materials used on mattresses and on deep beds). Use in deep bedded cubicles should by definition provide a deep layer and good comfort.

Good bed maintenance is vital for any material. It is claimed (and experienced) that the RMS can be easily raked to retain an even surface.
In general it is expected that there will be benefits for cow comfort with use of RMS, whether on mats or in deep beds, compared to the situation with mattresses and sawdust. There may be little difference between the situations with deep bedded sand and deep bedded RMS.

8.1.2 Locomotion

Harrison et al (2008) reported better locomotion in cows bedded on RMS cubicles than on sand cubicles, although no explanation has been given. However, one 4000 cow US farm which changed from sand to DMS experienced an increase in foot and leg injuries, attributed to the loss of sand particles that had improved grip in the alleyways (Ostrum et al, 2008). On this farm the DMS material was the product of a physical separation that was then stockpiled for several days, reaching a temperature of 55 degrees C. The material was used in 8 inch deep cubicles beds that were bedded “at least once per week”.

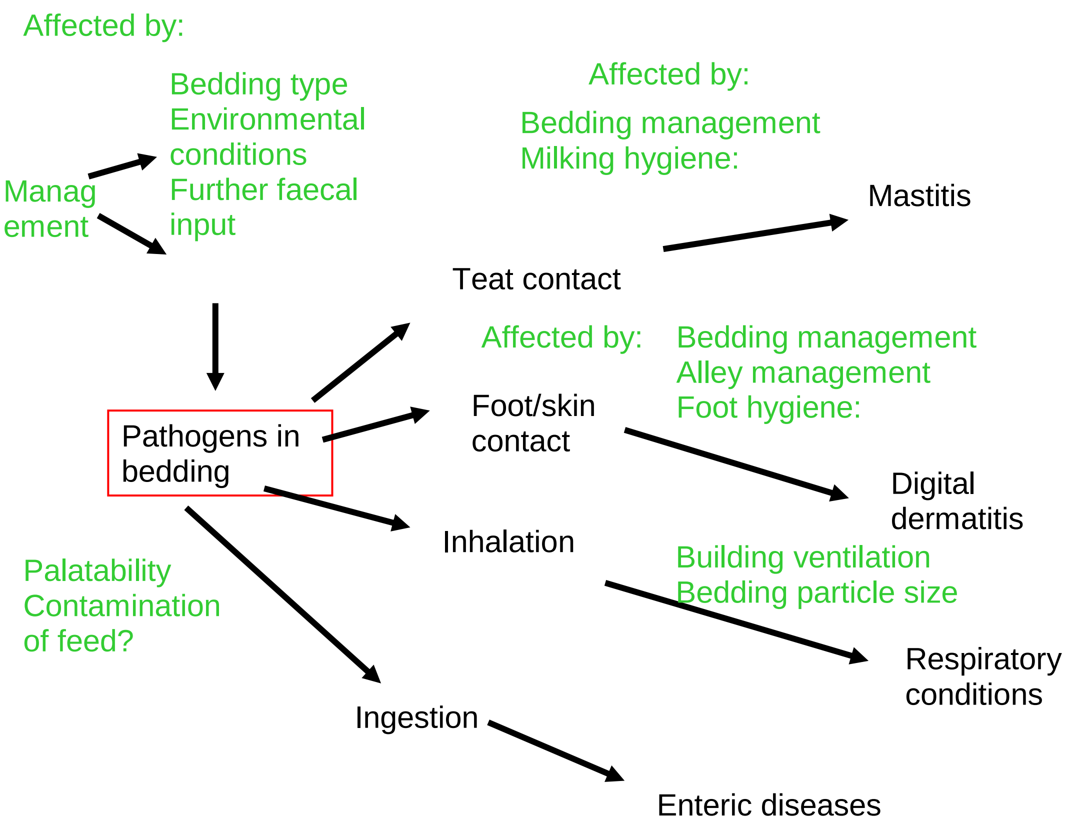
8.1.3 Cleanliness

Anecdotal reports are that cows are clean when bedded on RMS – unless the bedding is infrequently refreshed (Spain; UK survey, section 4.13). Cow **cleanliness** was assessed in a comparison including RMS by Hippen et al, (2007) who reported a trend for cleaner cows than on dolomitic limestone. Timms (2007) reported an “improvement” in cleanliness on RMS from a previous, unspecified bedding material. Feiken & van Laarhoven (2012) found cows on RMS to be slightly more dirty than those bedded on sawdust and wheat straw, but cleaner than those on compost. Visual cleanliness is not a guarantee of absence of pathogens, but bacterial counts on the legs of cows are lower with better cleanliness (Zadoks, 2011). Poor cleanliness is a risk factor for diseases including mastitis (Breen et al, 2009), digital dermatitis (Stokes, 2011) and psoroptic mange (Sarre et al, 2012).

8.2 Impact on animal health

In covering the potential impact of the use of RMS on animal health, this report considers issues in a risk assessment framework as outlined below, referring the reader to sections in this report where relevant information (where known) can be found. Risk pathways have also been constructed and considered and are illustrated in Figure 8.1. NB this figure does not include an exhaustive list of diseases but illustrates examples of different exposure pathways which are discussed in sections 5.4 and this section and Appendix 8.

Figure 8.1: Risk pathways for animal health associated with the hazard of pathogens in bedding (influential factors are shown in light type, hazards are shown in red in boxes)



8.2.1 Frameworks for carrying out risk assessments

In this report we structure information around the OIE framework. Any health risks can be considered in three stages, according to the OIE risk assessment framework (Appendix 8):

- A **release** assessment, indicating the likelihood that pathogens are present
- An **exposure** assessment, indicting the likelihood that animals or humans will come into contact with the pathogens, in a manner that carries a risk of disease transmission
- A **consequence** assessment, that considers the likelihood that infection takes place, and the implications of this.

It is difficult to draw a clear line between release and exposure, indeed, the CAC framework does not distinguish between these.
Further sections linking findings to this framework are Appendix 8 (indicating the availability of information needed to make these assessments) and Section 5 where reference is made to the framework in the context of selection of a shortlist of pathogens for consideration.

Release Assessment

A release assessment could be based on the information on pathogen load available from Sections 5, 7 and 14. It is apparent that freshly separated manure solids are likely to contain relatively high levels of pathogens, if these were present in the original slurry that was separated. However, the findings of Harrison et al (2008), and commercial bedding samples analysed at UK laboratories to date, suggest that other bedding materials can sometimes demonstrate a relatively high load, and soon reach the same levels of environmental mastitis pathogens as RMS. The influence of a short time with higher pathogen load compared with other bedding materials might need to be considered. RMS may present cows with a high pathogen load more continuously than some other bedding materials, which are “cleaner” when initially applied to the bed, but rapidly become contaminated to similar levels. It would be of interest to investigate whether a relatively constant higher level challenge has a different impact from a fluctuating challenge which reaches similar peak levels.

There are very few papers which report on pathogens other than mastitis pathogens in RMS. The only references found have been to *Mycobacterium avium* ssp *paratuberculosis* (MAP), responsible for Johne’s Disease (Meyer et al, 2007; Harrison et al, 2008, Timms 2008b; Pronto & Gooch, 2009), and *Salmonella* spp (Meyer et al, 2007; Timms 2008b). From Harrison’s small sample of six farms, it appeared that untreated separated solids need not necessarily contain high levels of MAP, even when the disease is known to be present on farm, but also that the pathogen is not necessarily destroyed by digestion or composting, and can be found in unused sand bedding. On the other hand, Pronto and Gooch (2009) and Timms (2008b) provide some evidence that digestion can considerably reduce the load of MAP. Composting unseparated manure in an experimental windrow reaching 55 ^{o}C was effective in reducing MAP to undetectable levels within five days (Bonhotal et al, 2011).

Exposure Assessment

We have not identified any differences in the element of exposure risk associated with the degree of physical contact, as opposed to pathogen load, for this bedding compared with others, apart from 1) a reduction in the amount of dust (reported in the survey) which might reduce the risk of inhalation of pathogens, particularly MAP (Eisenberg et al, 2014) and subsequent ingestion via sputum, and 2) reports from farmers that teats and legs are cleaner with RMS than with sawdust which would be expected to reduce the risk of contact. However, the scale of this reduction and its consequences are not known. Although visible cleanliness cannot be taken as a direct indicator of bacterial load, it does provide part of the explanation for variation in udder infections and foot disorders. There is evidence at individual cow level that dirty teats increase the risk of udder infections (Breen et al, 2009) and dirty feet increase the risk of digital dermatitis (Stokes, 2011). Bacterial counts on cows’ legs have been correlated with cleanliness scores (Zadoks et al, 2011). Nevertheless, pathogens not visible to the naked eye may be on the teats. It is possible that if cows are visibly clean, teat preparation may be relaxed, allowing contamination of teats during milking and possibly contamination of milk and intra-mammary infections

(Endres, personal communication). Data from teat swabs suggest that levels of many bacteria and moulds may be no higher on teats where cows are bedded on dried manure solids than on straw (Harrison et al, 2008), or differ between composted RMS and clean rubber mats (Bishop et al, 1981). However in Harrison's work, cows in the sand pen had significantly lower levels of *Streptococcus, Klebsiella*, gram negative and gram positive bacteria on their teat ends than did cows bedded on RMS from the separator. Hogan et al (1989) reported higher levels of all bacterial groups in teat swabs from cows bedded on RMS (bedding preparation unspecified) than on sawdust initially, but levels converged over six days without further application of bedding.

The effects of bed management factors, such as frequency of bedding, depth of bedding, removal of soiled bedding and use of "bedding conditioners" can be found in Section 9 and Appendix 5 (literature review).
To minimise the risk of transmission of MAP, Harrison et al (2008) suggested that RMS should not be used to bed youngstock.

Consequence Assessment

A consequence assessment (i.e. the likelihood that clinical or subclinical disease occurs) would need to be based on the pathogen load and minimum infective dose for individual pathogens, where this information is available. However, this is lacking for many of the diseases under consideration (See Table 5.4). In the absence of this, implications would need to be drawn from experiences of farms using the material. There are a relatively small number of reports of disease levels on farms using RMS and these are almost exclusively for mastitis eg (Harrison et al, 2008, Gooch et al, 2006; Husfeldt et al, 2012). Unpublished data from a survey of 38 American Midwest dairy operations showed that, although farms can keep at or below the US cell count limit (700,000 cells/ml – NB compare this with the EU regulatory limit of 400,000 cells/ml) there are more cases of clinical mastitis in herds with RMS than with sand. Data suggests twice as many cases, although the majority are not fatal. However, mortality due to *E. coli* mastitis was 15% for the RMS farms, compared with other published figures of 8% for sand bedded herds (Marcia Endres, personal communication). The median SCC for the 38 RMS herds studied by Husfeldt et al (2012) was 275, lowest 120. There was seasonal variation, as with other bedding materials, with higher SCC in summer months. Endres considers that it is difficult to achieve a SCC <150,000 cells/ml when using RMS. and gave a recent anecdotal report of SCC increasing with a change to RMS, reducing again on reversion to sawdust. In an unpublished report, Endres and Husfeldt (2012) concluded that excellent cow preparation at milking time, sanitation of milking equipment, cow hygiene, adequate dry cow housing and bedding/stall management appear to be critical in maintaining a low SCC while successfully using manure solids for bedding. Type of manure solids used-digested, raw or composted had no association with SCC (see http://www.thecattlesite.com /news/37018/recycled-manure-solids-for-cow-bedding-effective - accessed 27/2/14).

Later in this report udder health data is presented from a cohort of farms currently using RMS in the UK. We have not found quantitative reports of the influence of bedding with RMS on any other diseases.

8.2.2 Consideration of the pathways and risks associated with the use of RMS as compared with other types of bedding

The main risks to animal health that may **alter** as a result of a switch to the use of RMS as bedding are considered to be:

1) infectious diseases transmitted by pathogens present and persisting in the recycled bedding;
2) effects of inhalation of bedding particulates
3) exposure to a higher level of ammonia and ammonium compounds

The likely routes of infection are:

1) Intramammary - via the streak canal
2) Contact with skin (particularly digital dermatitis)
3) Respiratory - pathogens carried on dust particles.
4) Ingestion - the oral route
5) Reproductive – via the reproductive tract and navel

These routes have been discussed to some degree in section 5. , explaining the rationale for selecting key pathogens. They are considered separately below, not in an exhaustive manner for every pathogen, but rather to demonstrate the principles of 'transmission' and therefore understand opportunities for mitigation:

1) The Intramammary Route

This route has generally caused greatest concern among those considering the use of RMS as bedding. Information is available on the pathogen load on bedding of various types, however, the strength of the relationship between pathogen load on bedding prior to application and intramammary infection is unclear. There are several papers that indicate that the pathogen load on the "fresh" bedding material is less important than the way the bedding is managed once applied.

Review of literature can provide considerable information on pathogen load on various bedding materials, but the information for separated RMS is limited (see Appendix 4,Table A4.2).

Information on the relationship between use of RMS and clinical and subclinical mastitis is available from some research papers (see below and literature review, Appendix 5), and from some provisional UK case study data collated later in this report (Section 15).

Although Rendos et al (1975) demonstrated a relationship between bacterial populations in bedding and on teat ends for straw, sawdust and shavings, Bishop et al (1981) failed to do so for a comparison between composted manure solids and rubber mats. Although the manure solids had a higher bacterial load, this was reflected in the teat end swabs only for *E. coli* and *Enterobacter* spp and was not reflected in results from bacteriology of milk samples. (This topic is further elaborated in the "main literature review" provided as an appendix to this report (Appendix 5)).

Husfeldt & Endres (2012) studied 34 herds in the US mid-west bedded on various types of RMS, including deep beds and applied to mattresses. The herds showed a wide range of mastitis incidence, from 10 to 109 cases / 100 cows / year (mean 62) on deep beds, and 13 to 108 cases/100 cows/year (mean 49) on mattresses. There was no significant difference between the two types of stall surface (RMS on mattresses and in deep beds). An overview of culling revealed that the predominant culling reason in the RMS study herds was mastitis, whilst reproductive problems were the predominant reason for culling countrywide. These authors considered on the basis of these findings that RMS might compromise udder health in these herds, though surprisingly they based these conclusions on comparisons with mastitis rates seen in other countries rather than in the US (eg Peeler et al, 2000).

Information on somatic cell counts from 38 herds using RMS in the US was presented by Husfeldt et al (2012). The average SCC of 274,000 cells/ml (+/- 98,000) was considered to compare favourably with an average of 305,000 cells/ml reported in a study of sand-based freestalls in Minnesota (Lobeck et al, 2011). Harrison et al (2008) found that bacterial levels in bedding were not closely associated with the number of animals with increased SCC. In further unpublished analysis, Endres and Husfeldt (2012) concluded that excellent cow preparation at milking time, sanitation of milking equipment, cow hygiene, adequate dry cow housing and bedding/stall management appear to be critical in maintaining a low SCC while successfully using manure solids for bedding. Type of manure solids used-digested, raw or composted had no association with SCC (http://www.thecattlesite.com/news/37018/recycled-manure-solids-for-cow-bedding-effective)

2) Skin Contact

Skin contact with RMS could impact animal health either directly through physical damage to the integument or indirectly through an increase in the risk of transmission of infections disease such as Digital Dermatitis (DD).

Wet and unhygienic underfoot conditions and dirty feet and legs (Stokes, 2011) have been identified as risk factors for DD. Reports that cows bedded on RMS are cleaner, and that alleyways are drier would suggest that this risk of DD might be reduced. Treponemes are the micro-organisms consistently associated with digital dermatitis lesions, although a range of other pathogens have also been isolated (Evans et al, 2009). Treponemes are abundant in the environment of the dairy cow (Evans et al, 2011) although the specific phylotype that is associated with DD has not been detected in slurry. This phylotype has, however, been isolated from the recto-anal junction so the failure to detect it in slurry may be due to shedding patterns and detection methods. Desiccation of slurry would be expected to prevent growth of the organism, since it is associated with damp environmental conditions and grows best in moist conditions in the laboratory (N Evans, personal communication). However, the ability to survive at the specific DM contents of RMS is unknown. Overall, the environmental effect would be expected to reduce the risk of DD lesions, but the effect of pathogen load in the bedding itself cannot be defined.

3) Respiratory Exposure

The chance of transmission by the respiratory route will be a function of the atmospheric load of a given pathogen and other factors affecting air quality. Anecdotally, environments in which RMS is used are less dusty and one might therefore reasonably expect that aerosol challenge and compromise of the mucociliary apparatus would be reduced, though one cannot rule out any impact of increased ammonia concentrations if ventilation is inadequate.

4) Ingestion – the Oral Route

Pro-active ingestion of RMS is unlikely to occur, though the highest risk is likely to be in youngstock. ‘Accidental’ ingestion as a result of grooming and contamination of feedstuffs is more likely.

Johne’s disease is perceived as the greatest risk by many authors and practitioners and the greatest risk of infection is to young animals if MAP is present in the herd. For this reason, it has been recommended that RMS is only used for bedding adult cows.

5) Reproductive tract

Risk of contact with the reproductive tract is greatest during calving. Newborn calves would also be at risk of exposure to pathogens via the navel. Any risk of infection could be mitigated by avoiding use of RMS in calving areas. This could potentially need to include transition cow housing in view of the risk of unexpected calving in this group.

8.2.3 An illustration of the release, exposure and consequence approach using the mastitis infection pathway

The only disease on which sufficient information is available to facilitate a partial risk assessment is mastitis, and even in this case it is not possible for all pathogens.

Various stages of the infection risk pathway from bedding to teat end to udder infection have been studied but surprisingly few papers give data on the complete pathway, particularly for RMS (see Appendix IV). The number and type of bacteria on bedding have been related to the bacterial load at the teat end, for materials including unspecified “Dairy Waste Solids” (Bishop et al, 1981) and “Composted Dairy Waste Solids” (Janzen et al, 1982) (see Hogan et al. 1989). Neave et al (1966) demonstrated a correlation between bacterial load on the teat end and intramammary infections. Bramley and Neave (1975) are often quoted as reporting that a coliform load in bedding of $< 10^6$ cfu/g of bedding is “safer” (for udder health) than a load above 10^6 cfu/g. However, Hogan et al, (1989) pointed out that this figure is implied from examples, rather than experimentally demonstrated. Natzke et al (1976) and Fairchild et al (1982) failed to demonstrated a relationship between the bacterial count on bedding and intramammary infection, despite coliform levels exceeding 10^6 cfu/g on bedding. Hogan et al (1989) considered that this might be due to the short term exposure in these experiments, and undertook a year long study monitoring nine commercial farms using a variety of bedding materials (none used any recycled manure). This indicated, with small but significant regression coefficients) that rates of clinical mastitis were related to bacterial counts in bedding (of Gram negative bacteria and *Klebsiella* spp, but not other coliforms or *Streptococci*). The type of bedding *per se* did not have an effect. The small number of reports such as those by Reithmeier et al (2004) and Harrison et al (2008) which cover the whole chain from “fresh” bedding materials to intramammary infection fail to show the clear correlations that might be expected throughout the entire chain between bacterial load on “fresh” bedding materials, on the beds as in use, on teat ends, and incidence of clinical and/or subclinical udder infection. Todhunter et al (1995) found no correlation between numbers of *Streptococci* on RMS beds and rate of streptococcal intramammary infections in the dry period. Harrison et al (2008) concluded from their results (which did include RMS) that management of the bedding and cows, and cow factors, might ultimately be more influential than pathogen load on the “fresh” bedding material, because pathogen levels changed so rapidly after addition of fresh material. Maintaining cool, clean and dry conditions on the surface of the bed is the general best practice advice emerging from understanding of underlying concepts and anecdotal evidence, but is not currently substantiated with hard data.

Published material on the impact of RMS bedding on mastitis is largely in the form of case studies. By 2008, Buelow reported that a large number of American dairies were using separated manure solids, with or without composting or digestion, with varying degrees of success in terms of mastitis control, but a clear association between RMS management and udder health could not be established. Many farms used the material with apparent success (Buelow, 2008), while some experienced large problems and discontinued the practice (eg Ostrum et al, 2008). In this particular case, in a 4000 cow herd, there were severe outbreaks of *Klebsiella* spp mastitis, which meant that cows were 2.1 times more likely to suffer mastitis, and 1.3 times more likely to be infected with *Klebsiella* spp than on the previous sand bedded system. Monthly cull rates increased from 1.6% to 2.7%, The bedding used was separated, and then stockpiled (for an unspecified length of time). Possible explanations for the problem were offered including 1) high humidity in both winter and summer, 2) a particularly high level of *Klebsiella* spp in the herd prior to introduction of SMS, resulting in heavy shedding of the organism in faeces and concentration in the bedding and 3) one predominant strain of *Klebsiella* spp was identified, which might have been particularly pathogenic. There is some evidence, from a small telephone survey, that producers in the upper Mid-West United States using “fresh” separated solids were experiencing difficulties in keeping SCC below 400,000, while those using digested solids were able to remain below 250,000 (Endres, 2008).

Harrison et al (2008) investigated the effect of us of RMS on SCC by studying a “linear score” measure for SCC over time for six herds where the time of switching to RMS was known, and 65 herds from the same region where bedding type was unknown but it was unlikely that many were using RMS. The RMS herds showed an increase of 0.07 per cow per year during 2000 and 2007, while the 65 herd showed an increase of 0.007 per cow per year. The increase in the RMS herds was significantly greater, but the authors were reluctant to draw firm conclusions on account of the sample size. Individual farm comparisons before and after use of RMS for a total of eight farms showed that only three of these increased their linear score while using RMS. Harrison et al (2008) made an assessment of the effect of RMS on mastitis by comparing the odds of cows getting mastitis in pens bedded with sand, “fresh” RMS and composted RMS on the same farm. The odds of getting mastitis were highest in the pens with cows bedded on fresh RMS. The odds were 1.1 times greater than for cows bedded on sand. However, when comparisons between all three systems were made using Poisson regression, the significant influences were individual cow cell count, the amount of moisture and fine particles in the bedding and milk production, but not bedding type *per se*. This suggests that other factors may be more influential than merely the type of bedding.

8.2.4 Published information on consequences for other animal diseases

There is no published information on the consequences of RMS bedding for any infectious diseases other than mastitis. A total of five reports mentioning influences on lameness from peer reviewed and grey literature give some conflicting impressions (Harrison et al, 2008, Hippen et al, 2007, Husfeldt & Endres 2012, Ostrum et al, 2008; Timms, 2008b). None of the studies combined design and length of time sufficiently well to give robust results.

8.3 Impact on human health

A similar approach to that taken for considering the impact of the use of RMS on cattle health has been adopted in the assessment of impact on humans. Potential risk pathways for human health are illustrated in Figure 8.2 for farms workers and 8.3 for consumers.

Figure 8.2: Risk pathways for farm workers associated with RMS bedding (influential factors shown in light (green) type; hazards shown in red in boxes)

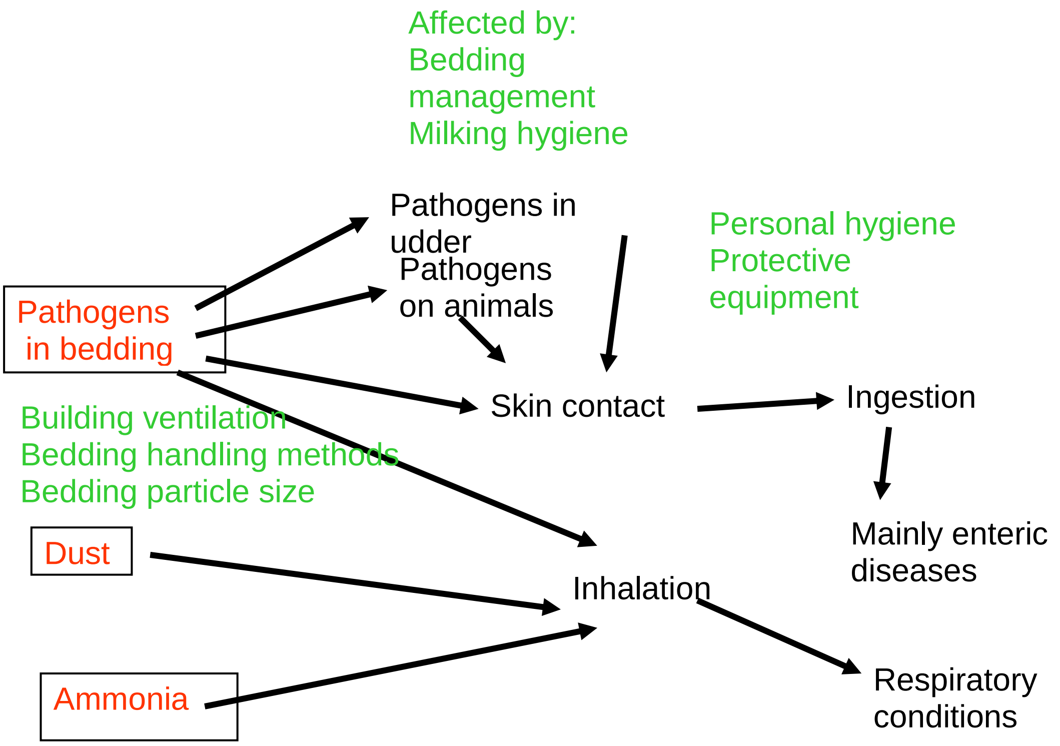
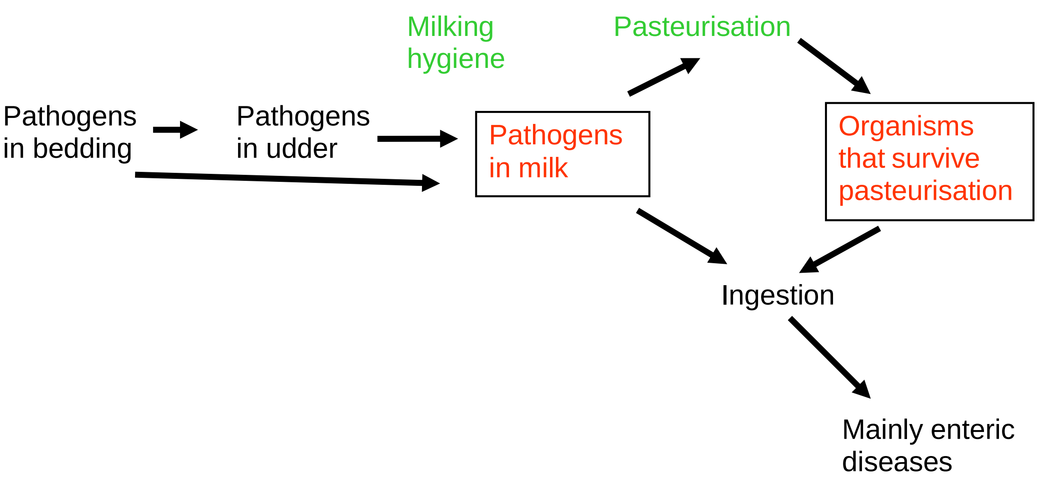


Figure 8.3: Risk pathways for consumers associated with the hazard of pathogens in bedding (influential factors shown in light (green) type; hazards shown in red in boxes)



Framework for risk assessment

The release assessment for farm staff would be the same as for animals living in the housing, though limited to the zoonotic pathogens. The release assessment for on-

farm consumption of unpasteurised milk would be based on the likelihood of pathogens appearing in milk. The release assessment for the majority of human consumption would be based on the probability of zoonotic pathogens surviving pasteurisation or any processing of unpasteurised products.
There is some data available on the presence of spores of spore forming bacteria in milk on farms using RMS in the Netherlands. (Driehuis, 2012, 2013) – see next section on Food Quality for details.

Exposure to pathogens might be through working with the material, for farm staff, or through consumption of contaminated products, for the general public. The likelihood of contact for farm staff is far greater than the likelihood of consumption, if milk is pasteurised. Contact on farm could be through handling the material or inhaling dust or spores arising from it.
The **consequence** of exposure will be determined in the same way as for animals, ie a balance between challenge and immunocompetency.
There is no published information on the impact of use of RMS on human health.

8.4 Impact on food quality

The main risk identified is of coliforms, bacterial spores, yeasts and fungi in the milk, increasing the risk of food spoilage, particularly for artisan cheeses.

Magnusson et al (2007a) identified a positive relationship between levels of *Bacillus cereus* spores in bedding and levels in milk. They recommended that levels of spores on beds should be kept below 4 log10 per g, to achieve acceptable levels in milk (<100 *B. cereus* spores/l). With further work, Magnusson et al (2007b) concluded that the possibility of keeping spore numbers consistently low in deep sawdust bedding was limited, because laboratory experiments indicated that for sawdust, a DM percentage of 70% was needed to achieve available water capacity below 0.95 needed to prevent growth of *B. cereus* (Kramer & Gilbert, 1989). However, they suggested that with good bedding management and teat cleaning procedures, spores in milk could be kept at acceptable levels. Indeed, although levels of *Bacillus cereus* and butyric acid bacteria in the bedding material were higher in RMS bedding than in sawdust, (Driehuis et al, 2012), spore levels of *B. cereus*, butyric acid bacteria and mesophilic aerobic spore formers in milk were no higher in RMS farms using "fresh" (non-composted) RMS than in those using straw or sawdust (Driehuis et al, 2013). However, use of any composted materials as bedding increased the levels of spores in milk (Driehuis et al, 2012).

Key pathogens to consider with respect to food safety would be *Salmonella* spp and *E. coli* (especially O157). The risk of increased levels of these organisms in RMS is not well defined, but mitigation is relatively straight forward if milk is pasteurised.

9. Assessment of housing effects

Information was gathered from the survey of UK users and reports from other countries of the structural and infrastructural aspects different types of housing in which RMS is being used, and the performance achieved. An overview of the potential hazards and risks from the literature is given below and illustrated in Figures 9.1 and 9.2. It should be noted that a considerable amount of the published information on use of recycled manure solids as bedding comes from countries with hotter, drier climates than the UK, and is therefore not directly transferable. The most closely related conditions are in Northern Europe, but the peer reviewed information from Northern European countries is limited. Some anecdotal information from other countries is available in Appendix VI (Other country experiences).

9.1 Hazards and risks associated with or influenced by the housing environment

Although the literature suggests there are a number of potential hazards and risks associated with the use of RMS it should be stressed that much of the available information is based on RMS systems where the separated solids originate from digestate or where the RMS has been composted or drum heated.

It is also worth noting that much of the identified risk associated with RMS is also as applicable to other forms of organic dairy cow bedding.

Temperature

The most commonly identified risk is the bacterial growth associated with increased ambient temperatures (Cempirkova, 2007, Godden et al., 2005, Kristula et al., 2005). Rates of bacterial growth are reportedly greater during summer than winter, and Harrison et al (2008) found the highest levels of the majority of organisms in RMS bedding in the summer. This may also be associated in part with the differing DM% of the untreated separated solid.

Dry matter content

Cornell Waste Management Institute suggest the DM% of used RMS can vary between 27and 36% (Harrison et al, 2010). Higher DM% leads to a slight reduction in bacterial numbers (Cempirkova, 2007, Godden et al., 2005), with the notable exception of *Salmonella* spp.

Iowa State University Animal Industry Report 2008 states the DM% of fresh separated solids seen on farms varies between 28 and 40%. Once the RMS was placed in the cubicles, the DM% increased to between 60 and 80%. This reflects the effect of air-drying and cow body heat. The lower ambient temperatures seen during the winter months resulted in a less marked increase in DM% when the RMS was applied to cubicles (50-60%).

Humidity

When factors that support bacterial growth are considered, it is likely that humidity will also pose a significant risk. Warm, poorly ventilated buildings with heavy stocking rates will suffer from higher levels of humidity. The relatively damp RMS material itself may contribute to higher humidity in a building. The material is hygroscopic – has a high affinity for water – and can therefore both absorb and release large amounts of moisture. There is some anecdotal evidence that cell count and mastitis problems have followed damp weather in poorly ventilated buildings with RMS bedding, but this is also the case for other bedding materials. Farmers observe that the bedding becomes drier on drier, warmer and windier days.

Ventilation

When the literature is considered (both peer reviewed and grey literature), there is great emphasis placed on maintaining airflows and ventilation within the building. Poorly ventilated buildings will have higher humidity which in turn can facilitate bacterial replication and reduce the DM% of the RMS.
Within livestock buildings increasing the ventilation rate dilutes ammonia concentration by removal. Ventilation also increases the drying rate of the bedding, decreasing in-house ammonia levels. As RMS is highly hygroscopic it is strongly recommended that users of RMS ventilate housing areas well. RMS prepared by separation followed by composting and drying has been shown to absorb 4.22 g of urine per g of dry bedding, considerably more than five other bedding materials tested (see Table 9.1).

Table 9.1: Absorbency of bedding materials (Misselbrook & Powell, 2005)

	Chopped straw	**Sand**	**Pine shavings**	**Chopped newspaper**	**Chopped corn stalks**	**Recycled manure solids (separated, composted and dried)**
Grams of urine absorbed per g of dry bedding	2.85	0.27	2.63	3.79	2.77	4.22

Ammonia emissions

The potential negative impacts of gaseous ammonia are many and are well documented. Indoors, elevated ammonia levels can impact human and animal health and production by irritating lungs and eyes. The type of bedding can influence the emissions of ammonia within and from livestock buildings, due to interactions between the bedding material and urea deposited in urine. Table 9.2 gives the ammonia emissions from six different bedding types measured in a laboratory situation (Misselbrook & Powell, 2005). Emissions increased linearly with absorbance capacity of bedding material, and were inversely related to bulk density of the bedding material. The properties of RMS meant that emissions from this bedding were relatively high. Danish work carried out in farm conditions and currently ongoing suggests that ammonia emissions are slightly higher from stalls bedded with RMS than with straw, but the difference is very small, amounting to 57g N per cow per year (Jensen, personal communication).

Table 9.2: Ammonia emissions from bedding materials (Misselbrook & Powell, 2005).

	Chopped straw	**Sand**	**Pine shavings**	**Chopped newspaper**	**Chopped corn stalks**	**Recycled manure solids (separated, composted and dried)**
NH3 emissions from urine soaked bedding in g of NH_3 N per m^2	4.7	10.9	7.6	10.0	7.7	18.3
Urine N remaining on bedding after 48 hours (mg/g of dry bedding)	12.8	1.3	9.2	15.6	11.6	16.2
NH3 emissions from equal amounts of urine added to equal depths of bedding in g of NH_3 N per m^2	10.2	5.3	7.8	11.4	12.7	12.1
Urine N remaining on bedding after 48 hours (mg/g of dry bedding)	15.1	0.7	10.0	14.47	10.9	5.0

Dust particles

No published data have been found on measurement of dust in buildings using RMS but the consensus from UK farmers is that dust levels are low or non-existent and far preferable to the conditions prevailing with the use of sawdust or chopped straw. This is likely to reduce the MAP levels in a building environment since MAP has been detected in dust particles (Eisenberg et al, 2014).

Depth of bedding and particle size

RMS may be used as a thin layer on cubicle mats, or as a deeper layer, the former reaching a higher DM content (Harrison et al, 2008; Husfeldt et al, 2012). As would be expected, the deeper layer was found to provide better cow comfort and lower incidence of hock lesions (Husfeldt & Endres, 2012).

The depth of bedding has been related to the DM% by Harrison et al (2008). The DM% of RMS in a deep bed cubicle system ranged from 40-57%. When the material was laid in a 50mm layer on mats or mattresses, the DM% ranged from 50-71%. The particle size of the RMS was also related to the ability to adhere to the cows teats. Finer particle size led to greater teat soiling. The percentage of particles <2.0mm ranged from 30-71% depending on the separator used to generate the RMS.

Sorter et al, (2014) compared deep beds with shallow layers on a mattress, but the comparison was confounded by different management of the two bed types. Conclusions were that daily removal of bedding and replacement of bedding on mattresses reduced total coliform and *Klebsiella* spp counts compared with deep bedded stalls that were managed by removal of faeces and minimal bedding replacement, but there was no measurable effect on *Streptococcus* spp.

Feedback from the user survey and the stakeholders meeting suggested farmers were applying RMS in thin layers over time to build up the bed. Thin layers are added once or twice a week until the bed is full.

No evidence has been found to support disturbing the beds (eg raking as in the Spanish approach), as the material remains soft and loose enough to provide comfort. A small proportion of farmers in the UK survey were raking the beds daily with the combined objectives of leveling, and promoting further drying. One was using a mechanical rake. However there is no firm evidence of advantages of this procedure.

DairyCo

Frequency of bedding

The literature indicates that bacterial populations increase with time when there are suitable environmental conditions to support bacterial growth. The number of environmental pathogens in organic bedding materials are generally low prior to the material being placed in the cubicles, however studies have shown that numbers can increase 100 to 1,000 fold within 24hrs (Smith and Hogan, 2006).

Frequency of removal and replenishing of RMS has been related to lower total bacterial populations (Harrison et al, 2010, Godden et al., 2005). However, Schwarz et al (2011) report little effect of bedding frequency on deep beds. Only *E coli* was found at higher levels with weekly than with daily bedding, in a study of two farms, and bedding was drier in the weekly bedded stalls, which would be expected to restrict growth of many pathogens. Sorter & Hogan (2014) reported a tenfold reduction in *Klebsiella* counts as a result of completely replacing all bedding from the back third of deep bedded stalls daily. Thus the relationships between bacteria in bedding and udder infections are not as simple as might be expected. As with any dairy cow system, suitable design and management of the cubicle bed is important. Additional accumulation of faecal material, urine and milk on the back of any cubicle, irrespective of the bedding material, increases the bacterial population and the associated mastitis infection risk.

The literature suggests that it is common practice to apply the RMS material up to three times a week. Marcia Endres, University of Minnesota in a personal communication, suggested that more frequent application of RMS prevented the bed drying naturally leading to lower %DM.

Design of cubicle bed and management

Irrespective of the bedding material, well managed cubicles require the cubicle bed to be correctly designed and prudently managed. The design should ensure that a cow is positioned correctly in the bed so that urine and faecal material fall into the scraping passage rather than contaminating the rear portion of the cubicle bed.

The surface of the bedding material must be kept clean to prevent the accumulation of pathogens. Gooch et al (2006) advocate removal of surface soiled or wet material at every milking. This is common practice among those using RMS in the UK (Section 4).

Storage of bedding

In general, the current UK advice is that RMS should be used immediately, to avoid heating and causing conditions that encourage growth of pathogens. In Denmark it is forbidden to store the separated material for longer than a day without a cover, in view of potential gaseous emissions (Jensen, pers com).

Although the majority of farmers in the Netherlands have their own separators some farms use a contractor who brings a mobile machine and separates enough RMS to last a month (Feiken and van Laarhoven 2012). The separated material is compacted and covered with a plastic sheet. Little fermentation is assumed to take place due to the relatively low availability of sugars, but the preservation through exclusion of air seems to result in a relatively stable product. The temperature rises to 75 ^{o}C for 3-4 days, then falls to 50-55 ^{o}C. According to van Laarhoven (personal communication), simply covering without excluding air results in a temperature rise, without anaerobic conditions, and favours the growth of *Bacillus* spp. The bacterial activity during storage breaks down the organic material and the material becomes lumpy, and lumps need to be broken down before use, so storage just under plastic without compacting is not recommended in the Netherlands. Daritek report US farms leaving the separated solids in a heap for 3 days before use, for convenience. During this time the material heats but does not decompose. There is little evidence to help address risks associated with storing untreated RMS. The literature predominately focuses on storing separated digestate or composted RMS, eg Gooch et al (reported that levels of bacteria in digested/composted material reduced with storage. Of the farmers questioned in this study, with the exception of one, all were using the RMS straight from the separator without storing the material. One was spreading the material in a building, at a depth of 15 cm, for a day before use, and found that this resulted in a drier product – however this user had discontinued use of RMS within a few months of the telephone survey.

The nutrient composition of the RMS, dependent on its source, along with the existing bacterial composition, will influence bacterial growth. The nutrient composition can be associated with the raw material and possibly influenced by cows' diet, but is also affected by the addition of extra nutrients (milk, faeces or urine) from poorly managed beds.

Use of conditioners

Manipulation of the pH of the RMS has been evaluated to try understand methods for control of pathogenic populations. Hogan et al (1999), examined bacterial counts of fresh RMS and compared these with RMS bedding treated with either an alkaline commercial bedding conditioner, acidic commercial bedding conditioner, or hydrated lime. Each of the bedding treatments significantly reduced bacteria in recycled manure prior to use. The alkaline conditioner and hydrated lime effectively inhibited bacteria in recycled manure for 1 day. Bedding counts and teat swabs of cows housed on recycled manure treated with the alkaline conditioner were reduced until day 2 post application. In a further study, Hogan et al (2007) reported the addition of an acidic conditioning agent reduced the population of Gram -ve and *Streptococcal* bacteria for a period of only 24hrs. Two days after treatment, the bacterial populations were the same in the treated and control samples. Feiken and Laarhoven (2012) added hydrated lime and an alkali conditioner to RMS and were unable to demonstrate a significant change to the bacterial population.

The main influences on hazards and risks associated with aspects of the housing and its management are illustrated in Figure 9.1 and inter-relationships of these are illustrated in Figure 9.2.

Figure 9.1: Factors affecting hazards and risks associated with bedding materials in dairy cow housing

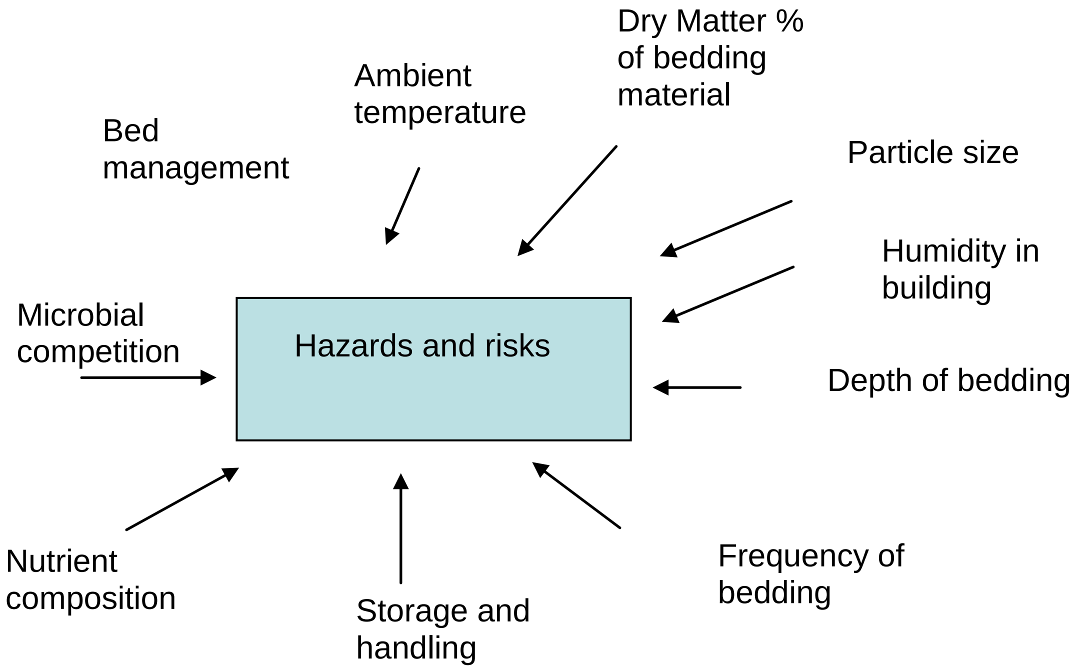
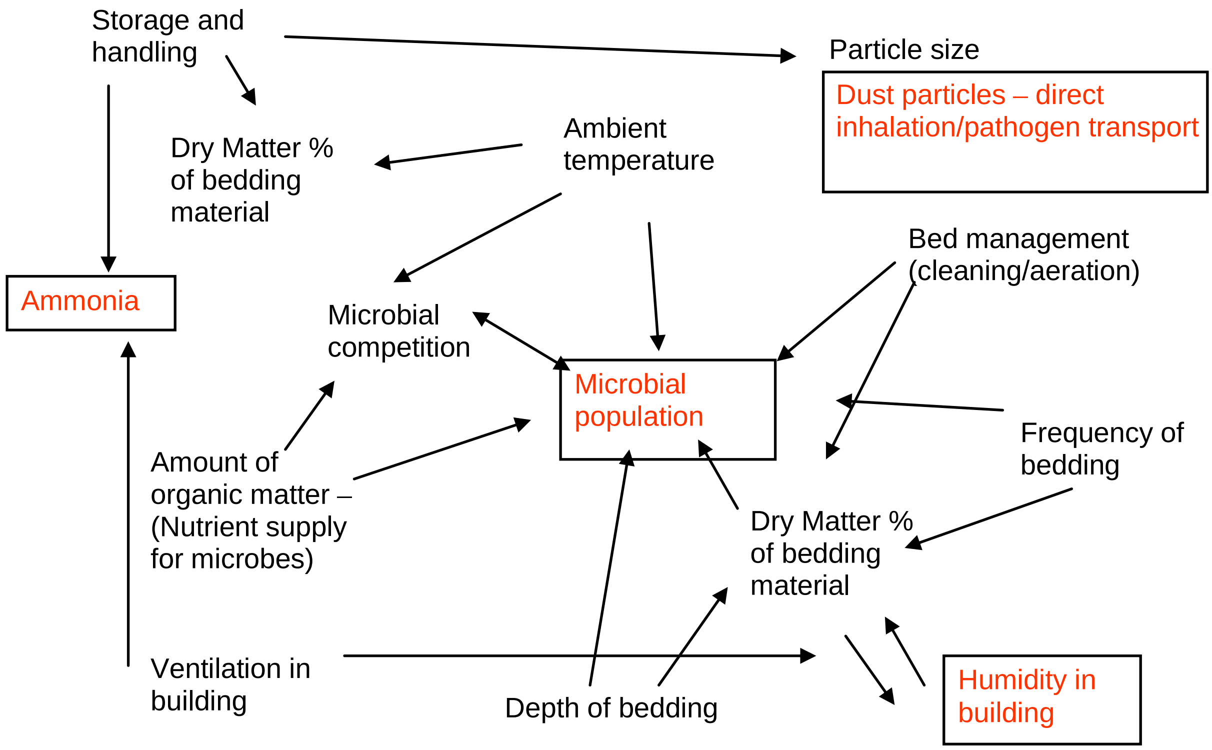


Figure 9.2: Inter-relationships between factors affecting hazards and risks associated with bedding materials including RMS in dairy cow housing (hazards are shown in red in boxes)



10. Risk mitigation

The overall aim in the use of any bedding material is to provide a comfortable surface, maintain cow cleanliness, minimise pathogen challenge and not adversely affect the housing environment. Bearing these objectives in mind, risk mitigation strategies were developed based on the pathways illustrated in Figures 8.1, 8.2, 9.1 and 9.2 and the critical control points outlined below:

Critical control points were considered to be:

1. Overall source of material
2. Control of material entering the pool for separation within farm
3. Control of separation process to achieve the optimum dry matter content
4. Control of storage to minimise pathogen multiplication
5. Control over ventilation in the building
6. Control over temperature of the bedding in the beds
7. Control of hygiene of the bed
8. Control of animal group in contact with bedding
9. Control of teat hygiene by parlour practices
10. Avoiding risk of cross contamination of feed
11. Control of end product (*eg* milk) processing
12. Herd health monitoring

Options for risk mitigation were considered for each of the issues identified above in the context of the overall objectives of the use of RMS as a bedding material and are considered point by point below:

1. Overall source of material

The main issue considered by this report has been the use of fresh recycled manure solids on the farm of origin. However, there would be additional risks of disease transmission associated with the use of material not originating from the premises on which it is being processed and used. For this reason RMS should only be generated on the unit on which it is to be used and only from product originating from that unit - *ie* manure should not be moved between units either before or after processing. Separate consideration would need to be given when digesters are used and 'foreign' material is used in the digester – for example household waste should not be used in digesters where the fate of the digestate is to be used as animal bedding, to avoid any risk of introduction of unexpected pathogens from unknown sources. RMS as the name implies is recycled manure solids and not other material.

2. Control of material entering the pool for separation within farm

For a within-farm source, there also needs to be control over the material entering the pool for separation. Manure from a particular species and age group should be recycled as bedding **only** to that species and age group.

For some diseases, the distribution of infected and shedding animals across age groups is very variable. Taking *Salmonella* spp as an illustrative example, in a study of grazing suckler cattle, Looper et al (2003) found only calves to be shedding Salmonella in faeces, while Huston et al (2002), studying milking cows and unweaned calves in dairy herd in the absence of clinical signs, found cows more likely to shed. Kirchner et al (2012) compared dairy herds infected with *S. dublin* and *S. typhimurium* (3 of each). Two herds infected with *S. dublin* demonstrated shedding mainly in calves, while in the third there was more shedding by cows. For the three farms infected with *S. typhimurium* shedding animals were detected equally across all age groups.

With evidence that the likelihood and extent of shedding can vary between age groups, risk of disease transmission might be minimised preventing youngstock from having contact with faeces and slurry from adult cattle, and vice versa. To achieve this while using recycled manure solids as bedding for all animals would require keeping slurry from different age groups separate. As this is likely to be difficult to achieve practically on farms, a workable solution reducing risk of disease transmission between age groups would be to avoid the use of recycled manure solids for bedding youngstock, while avoiding or minimising the input of slurry from youngstock to the slurry pool to be separated for bedding of adult cows.

Calves should not be bedded on adult manure (eg increased risk of MAP transmission) and adults should not be bedded on calf manure (eg possible increased risk of *Salmonella* spp transmission). Manure from different species should not be introduced as this increases the risk of introducing different pathogens. Care should be taken to make sure that 'runoff' from manure sources from other species, such as from a midden, does not reach the pool for separation.

Additional consideration should also be given to certain notifiable diseases. In the case of notifiable exotic disease additional controls over the use of RMS as bedding may be implemented. Consideration should be given as to whether the use of RMS should be suspended in herds experiencing a TB breakdown.

The introduction of other material should also be minimised – waste milk carries the risk of recycling mastitis pathogens onto the bedding and the inclusion of milking machine wash water carries a similar risk albeit at a lower level. Additionally, wash water will potentially bring disinfectants into the slurry pool. This may have adverse effects with respect to the development and perpetuation of antimicrobial resistance, with selection potentially accelerated by the selection pressure within a "closed cycle" (Section 5.5).

3. Control of separation process to achieve the optimum dry matter content

The composition of the slurry to be separated has a significant impact on consistency and quality of the extracted solid fraction (Section 4). The content of the slurry pool needs to be managed and handled to optimise the RMS output.

Recycled solids should be prepared and stored under cover before use to avoid a drop in the dry matter content prior to application.

4. Control of storage to minimise pathogen multiplication

Extracted RMS should be used immediately for bedding unless some further processing/preservation is employed. Further processing could involve forced air drying, heating, composting, digestion or anaerobic ensiling.

5. Control over ventilation in the building

Adequate ventilation is essential and overstocking should be avoided to ensure further drying of RMS once applied to beds, as well as to minimise the levels of ammonia in the housed atmosphere.

6. Control over temperature of the bedding in the beds

Beds should be managed to minimise 'heating' and therefore bacterial multiplication after application.

7. Control of hygiene of the bed

As with any bedding material, beds should be designed and managed to minimise contamination with urine and fresh faecal material. Frequent removal (at least daily) of freshly soiled material from bedded should be undertaken. The bedding is unsuitable for unweaned calves; there are anecdotal reports that the beds become 'too wet and soggy'. Bedding hygiene is of increased importance around the time of calving and in young stock which are potentially naïve to pathogens in the adult herd. For this reason, amongst others (see below), RMS should not be used for youngstock or in calving areas.

8. Control of animal group in contact with bedding

Bedding hygiene is of increased importance around the time of calving, since calving increases exposure of the reproductive tract. Grooming of calves post calving could result in the ingestion of significant quantities of RMS by cows. RMS should therefore not be used in calving areas. RMS use should also be avoided in transition cow accommodation due to the risk of early parturition. Newborn animals are at particular risk of infection eg through the navel.
Even for weaned youngstock, there are risks attached to the use of the material, since younger animals are potentially naïve to pathogens in the adult herd which may be present in the bedding and particularly susceptible to respiratory and gastro-

intestinal infections. Welfare legislation may preclude the use of RMS as bedding for calves, however we suggest that RMS must not be used for youngstock under the age of 6 months. As a precautionary measure we suggest RMS should not be used for youngstock under the age of 12 months.

9. Control of teat hygiene by parlour practices

Pre-milking teat preparation and pre-dipping should be a pre-requisite of herds using RMS in view of the reports of increased numbers of thermoduric and psychrotrophic bacteria in bulk milk in herds employing RMS. In addition this should also help mitigate any potential increased risk of intramammary infection.

10. Avoid risk of cross contamination of feed

There should be no shared equipment for the handling and processing of feed and RMS. If any equipment is shared (loaders *etc*) it should be thoroughly cleaned between uses.

11. Control of end product (*eg* milk) processing

Until there is a better understanding of the changes in risk associated with the use of RMS as bedding, advice should be that milk from farms utilising RMS for lactating cows should be pasteurised and its use in “artisan” milk products should be avoided.

12. Personal protection for farm workers

Farm personnel should be provided with appropriate PPE and made aware of the importance for personal hygiene during and following the handling of RMS.

13. Herd health monitoring

A final stage of any risk mitigation process should be for the user of RMS as dairy cow bedding to actively monitor cow health, in particular intramammary health, as well as bulk tank milk quality, to ensure the effective implementation of mitigation strategies.

11. Risk modelling

Unfortunately, insufficient quantitative information was available to inform a Bayesian based risk analysis for major diseases and health issues.

12. Interim guidance on the use of RMS as bedding

These guidelines are based on knowledge available and accessible to the authors at the time of collation of this scoping study. Whilst every attempt has been made to consider all possible risks associated with the use of RMS as bedding, suggestions for interim guidance on use cannot be expected to provide "fool proof advice". All users of RMS have to accept responsibility for their own decisions with respect to its use.

Lack of data means it has not been possible to base many of these guidelines on robust scientific evidence, meaning that it is essential that key issues/deficiencies highlighted in the report are addressed so that these guidelines can be refined.

Transfer of bedding material between units
To minimise the risk of transfer of disease, it is recommended that bedding should be made from slurry produced on the farm where it is to be used.

Components of the material to be separated
Excreta from youngstock
Since there is evidence that the likelihood and extent of shedding of pathogens can vary between age groups, risk of disease transmission could be minimised by preventing youngstock from having contact with faeces and slurry from adult cattle, and vice versa. Therefore it is recommended that only waste from adult cattle is used as a raw material for RMS and the material is only used to bed adult cattle.
Excreta from adult cows
Excreta from calving and hospital pens should not enter the reception and processing area because of the increased risk of the presence and load of pathogens.
Excreta from other species
Excreta from other species must not enter the reception and processing area, to minimise risk of transfer of diseases that are insignificant in one species but potentially devastating in another (*eg* Botulism from Poultry). The risk of run off should also be considered as well as deliberate addition of manure.

The presence of specific diseases
Additional consideration should also be given to certain notifiable diseases. In the case of notifiable exotic disease additional controls over the use of RMS as bedding may be implemented. Consideration should be given as to whether the use of RMS should be suspended in herds experiencing a TB breakdown.
Other materials
The following materials should not enter the source of slurry to be used for bedding:

- Placentas, and manure from calving areas.
- Waste milk – *eg* unsaleable milk from fresh calved cows or cows under treatment.

- Output from washing the milking plant can be added to the reception pit, but if possible should be diverted as the presence of disinfectants may increase the risk of development and persistence of antimicrobial resistance.
- Waste footbathing material should ideally not be added to the reception pit for RMS processing for the same reason as that outlined for plant washings.

Separation

Target DM of end product

General guidelines from separation machinery manufacturers are that the bedding material needs to be at least 30%DM and ideally 35 % DM at initial separation. The rationale being based on 1) physical properties that allow easy handling and prevent compaction into a wet mass and 2) ability to restrict microbial growth.

Consistent input material is important

Separation machinery works successfully (achieves an efficient output at suitable DM content) when a consistent product is fed into it at high pressure and volume. Ensure material of an even viscosity is fed to the separator to achieve a consistent product. This may be achieved by returns of surplus slurry from the pump to the reception pit and may require the addition of a stirrer, if the pumping operation alone does not achieve good enough mixing. Similarly, preventing variable quantities of rain water from entering the reception pit can help ensure a more consistent end product.

Monitoring machine performance and servicing as required is important.

Manufacturers guidance should be sought and followed. The screw press separator action is altered by adjustment of weights and the hole size of the screen. This needs to be done carefully when the machine is set up and the performance monitored through the dry matter of the product produced. The screens need to be regularly checked and cleaned and periodically replaced. If the product is not performing as expected, the screen should be inspected immediately.

Storage

Storage of freshly separated solids in a pile is not generally recommended due to the risk of the material heating under uncontrolled conditions and potentially supporting the growth of pathogens.

In the Netherlands a system of compacting and covering separated solids has been developed. Successful storage for up to a month has been achieved under these conditions.

Types of buildings where RMS is used

Buildings need to be well ventilated and well drained to ensure an optimum environment with as low a relative humidity as possible. This is particularly important with RMS because the material can absorb and release large amounts of water compared with other bedding materials.

Design of beds

RMS can be used as both a thin layer (2 - 5 cm) on mattresses and in "deep beds" (7.5 cm or more in depth). As with any bedding material, the depth of material and design of bed should be sufficient to prevent abrasion against hard surfaces.

Where deep beds are created, attention to detail is need. It has been recommended that deep beds should be built up gradually to allow the bedding to dry out as depth is created.

Management of beds

As with all livestock bedding material, the surface should be kept clean and dry and soft. Soiled material should be removed from beds at least twice daily. Daily removal of all material can help reduce coliform challenge, but is unlikely to have any measurable effect on *Streptococcal* counts.

Whether using a thin surface layer or creating a deep bed always apply as a thin layer but ensure bedding cover is maintained to achieve a good level comfort and dryness.

Common practice is application of new RMS every one, two or three days. However, the frequency of application depends on cubicle management, occupancy and building design. Cow cleanliness and udder health should be monitored to ensure adequate performance.

Lime may be spread on the beds, to absorb moisture and increase the pH, with the aim of making conditions less supportive to bacterial growth. However, literature indicates that the effect of lime on pH and bacterial count on most bedding types only lasts for a maximum of 24 hours.

Animals for which the bedding is used

Young calves are susceptible to infection by MAP which causes Johne's disease. The main disease transmission route is ingestion through contact with infected faeces of older animals. This pathogen has been found in some samples of RMS bedding, although, even in farms known to carry infective animals, not all RMS bedding samples test positive. To minimise the risk of transmission it is recommended that cattle under the age of 12 months are not bedded on RMS.

Management of cows on RMS bedding

Parlour practice

Pre-milking teat disinfection should be practised on farms using RMS as bedding. Cows bedded on RMS are reported to have visually clean udders. There is a danger that this will lead to complacency in teat preparation. However good pre-milking teat preparation is particularly important as increased numbers of psychrotrophic and thermoduric bacteria in bulk milk have been associated with the use of RMS as bedding.

Contingency plans
An alternative source of bedding material should be readily available in case of a problem with the RMS machinery or material. If possible this should be compatible with the separator in anticipation of restarting the separation process.

Human health protection
Farm workers working with RMS should employ the normal personal protection measures and personal hygiene associated with handling slurry and manure.

Product/food safety issues
To guard against any possible increase in bacterial numbers in milk it is recommended that milk from RMS bedded cows is pasteurised before human consumption.

There is some evidence that the numbers of spores from food spoilage bacteria including *Bacillus cereus* may be higher in bulk tank milk when RMS is used, than with sawdust. Therefore, until further evidence is available it is recommended that RMS is not used on farms providing milk for artisan cheese making or by producer processors as any milk will not have been comingled with milk from non RMS farms therefore any effect of the bedding on milk quality will be marked.

Additional Information
Further processing
Composting
In several countries composting and further drying is carried out with the aim of reducing microbial numbers in the material. It is crucial that the composting should reach a temperature of at least 65^{o}C and even then microbial numbers will still increase rapidly once RMS is added to beds.

Anaerobic digestion
The output of anaerobic digesters fed with slurry has been used for bedding in the US and some other countries. Physical separation may be carried out before or after the digestion process to achieve a suitable dry matter content. A critical factor is the temperature reached in the digester. This should reach 60^{O}C, which has been shown to inhibit certain pathogens, although MAP (the organism responsible for Johne's Disease) has been detected in digested slurry. Mesophilic digesters operating at around 35^{O}C would provide conditions suitable for proliferation of many undesirable organisms and there are uncertainties about suitability of their digestate as RMS. The influence of other feed stock materials being included in the digester is unknown but it is essential that the provenance of any material added to digesters from which RMS is generated is known.

13. Economic and environmental assessment

13.1 Economic assessment

NB Information is based on costs at the time of writing (Feb 2014) and costs and benefits will always be affected by individual situations. The following provides a general guide.

13.1.1 Slurry separation

Slurry separators of the specification required to produce RMS have an installation cost in the range of £43,000 to £58,000 depending on requirement. In addition to this is the cost of a gantry to support and a shed to cover the machine. The separators found on the UK farms surveyed, with herd sizes from to cows, were generally running from 4 - 6 hours per day, however these separators are capable of running 24 hours per day if required by larger herds. For example a 48" roller press separator will run for 24 hours servicing a herd of 3000 cows or for 6 hours servicing a 750 cow herd. Alternatively a lower cost 24" wide roller press separator will service 1500 cows running 24 hours or 375 cows if run for 6 hours. Power requirement to run the separator ranges from 10 to 15 kW including the submersible pump that lifts the slurry from the reception pit to feed the separator. The screw press separators have the higher power requirement due to their screw action. At 9 pence per kW the hourly cost of running the separator is 90p - £1.35/hour. The roller press would run longer than the screw press so daily cost on a 400 cow herd would be similar, at £5.50 per day.

Maintenance costs are low for the roller press, higher for the screw press separator where screens wear is significant, particularly if any sand is in the system. For RMS systems where the machines are processing slurry fibre this cost of maintenance is not likely to be high provided routine cleaning of the screen takes place. However, some farmers have found the screens (currently costing approx £2500) have needed replacement after 8 months rather than after 12 months as indicated by the supplier. Regular checking of the screens is important.

The cost per cow of operating this system will depend largely on the number of cows on the site and the finance arrangements. An investment of £52,000 financed at 5% interest over 6 years will cost £10,244 per year. With power cost of £2000 and maintenance of £2500/year the cost spread over 400 cows would be £37 per cow per year or 71 pence per cow/week.

13.1.2 Comparison with other bedding systems

Sand

Renowned for being an inert material and beneficial in controlling the spread of pathogens, sand may be used as a deep bed or as a surface layer on top of concrete or mats. Only fine washed sand should be used as coarser sand is abrasive and is seen as a possible cause of foot damage. Deep sand is comfortable provided sufficient is used to maintain a depth typically 80 - 100 kg /cow/week. At £16 - £20 /tonne the cost is £1.40/cow/week.. Deep sand beds have the advantage of lower capital cost of the cubicles and the sand can be stored outside. Due to its settlement and abrasive properties it is vital to plan the slurry handling and drainage system to suit sand.

Straw

The most familiar material, straw provides comfort and warmth to the cow and has good absorbency of liquid. Supply can be limited and cost affected by geographical location and season. Typically used at 10 - 20kg/cow/week the cost with straw at £80/tonne is 80 pence to £1.60/cow/week. Savings of up to a half can be made by using chopped or ground straw compared to long straw. Straw should be stored in the dry.

Sawdust

Top quality product is dried, graded and consistent and is ideal for slurry systems. It is free from hazards like sharp shards of wood that cause injury, dust and damp spots found in cheaper alternatives. When managed correctly sawdust provides an effective bedding material. Good quality sawdust is usually sold in 20 kg bags making it easy to store and handle. Damp sawdust supports pathogens so should not be used. Rate of use typically is 0.5 - 0.7 kg/cow/day which places the cost at 75 pence/cow/week. Wood shavings and shredded bark have low absorbency which reduces the effectiveness in keeping beds dry.

Paper products

Several products specifically designed for bedding are available and vary in absorbency from low to high. Granulated materials are well suited and the alkalinity of paper provides some disinfectant properties. Paper can set hard leaving an uneven surface and cows may appear dirty. Costing £90/tonne the product must be stored in the dry as pathogens thrive in wet paper materials. Used at 1.5- 2 kg per cow per day the cost is 95 p - £1.35/cow/week.

Table 13.3 Summary of bedding costs

Bedding material	**Cost per cow pence/week ***
RMS	71
Sand	140
Straw	160
Sawdust	75
Paper by-product	95 - 135

* All figures are estimated based on current prices (2013) and subject to variation for individual circumstances.

Separating slurry can result in up to 10% reduction in slurry storage required and with a cost of between £5-£40 per cubic metre of storage, the ability to perform separation can offer a cost-saving in terms of storage required, although this is independent of the use of the separated materials.

On the basis of the set up and running costs applied here, the RMS system would appear to be economically beneficial to the farm business. For herds smaller than 250 cows, alternative bedding material may be a cheaper option. However the decision for separating slurry will also be based on other factors particularly slurry storage and handling.

13.1.3 Fertiliser value forgone

The opportunity cost of losing the chance to return nutrients to the soil, if manure solids are reused for bedding, is low. In a review of a range of types of equipment achieving pressurised filtration, Hjorth et al (2010) reported, for cattle slurry initially between 3% and 8% DM, that between 13 and 46% of the original DM is retained in the “Solid” fraction, together with between 4 and 13% of the original N and 3 and 28% of the original P. This means that the majority of the nutrients remain in the liquid fraction. Some values for the N content of cattle slurry separated by a screw-press system are given by Flachowsky & Hennig (1990), ranging from 8 to 77 g/kg DM, at 29- 48% DM for the separated solids. The Fertiliser Recommendations RB 209 (Defra, 2010) provide a theoretical figure for N content of the “solid “ portion of separated cattle slurry at 20% DM of 4 kg N per tonne freshweight, or 20 g/kg DM. The equivalent RB 209 figures for P and K are 2 kg total P_2O_5 and 4 kg total K_2O per tonne fresh weight. Experimental work in the UK comparing farm data with RB209 values has indicated that, in separated manure solids of approx 20% DM, the N content is similar, P about half and K around two thirds of the published RB209 values (C. Henry, SRUC, personal communication).

13.2 Environmental matters

Any new technology or practice has an environmental impact and the objective is to adopt practices that are beneficial to the environment or reduce operations that are detrimental. The areas that may be directly influenced by RMS technology are air quality (particularly greenhouse gas and ammonia emissions) and soil and water protection.

Effects on the gaseous environment will be through emissions from the solid and liquid parts of the separated slurry during processing, storage, use and disposal. Effects on soil and water will be through applications of the liquid fraction of the separated slurry, as opposed to unseparated material, and separate application of the solid fraction if it is not all used for bedding. There will also be indirect effects as a result of changing from a different bedding material including reduced use of fossil fuels in providing and delivering alternative material e.g. straw, sawdust or sand. In the case of changing from sand, any detrimental environmental effects of extraction of sand, such as disturbance to river or marine ecology, would be avoided.

Very little work has been carried out specifically on the environmental effect of using RMS as bedding compared to any other material, although there has been work on the environmental implications of slurry separation, within the considerable body of work on reducing the pollution potential of livestock manures in general.

13.2.1 Gaseous losses

Slurries are a significant source of emissions of the two main Greenhouse gases (GHG), methane (CH_4) and nitrous oxide (N_20), and also ammonia (NH_3) to the atmosphere. GHG emissions from slurry are mainly caused by methane emissions during storage and nitrous oxide emissions after field application. Mitigation of GHG emissions can be achieved by a reduction in slurry dry matter and easily degradable organic matter content, suggesting that slurry separation may be beneficial from this point of view (Amon et al 2006). Mechanical slurry separation into a liquid and solid fraction reduces the carbon content in the liquid by 45-50% (Amon 1995) by removal of the organic matter. Amon et al (2006) compared losses during storage (for 80 days at 17 ^oC) and spreading from whole slurry and separated slurry (where the solid fraction was composted). Total ammonia emissions increased with separation, largely as a result of losses from the stored solids, while total methane emissions decreased, and N_20 emissions were very similar, resulting in an overall reduction in the CO_2 equivalent greenhouse gas losses as a result of separation. However, these losses are not directly transferable to the scenario where the solid fraction is used for bedding. By modelling various scenarios, Sommer et al (2009) estimated that separation of slurry from dairy cattle (storing the solid fraction over winter and applying it to land in April) could reduce greenhouse gas losses by between 3% and 60%, depending on the geographical location and climatic conditions. Aeration of slurry does cause ammonia emissions (Amon et al, 2006), and is a necessary stage of handling the slurry for separation, but this process is also incorporated in other slurry handling systems, so the effects are not unique to separation. Fangueiro et al (2008) found under laboratory conditions that screw press separation of slurry, to produce a 28% DM solid fraction, resulted in increased emissions during 48 days' storage, of CO_2 and N_20 coming from the solid fraction, and NH_3 from the liquid fraction. The solid fraction contributed to ammonia losses only for the first three days. This study did not include losses during the spreading phase, as Amon et al (2006) did. It is unknown how these losses from the solid fraction measured in the laboratory in largely anaerobic conditions would compare with those occurring when the material is used as bedding on farm.

Where slurry is stored without separation of the fibre the slurry breaks down under anaerobic conditions at lower levels in the store, producing ammonia, hydrogen sulphide and noxious compounds. A reduction in these reactions, as a result of separation removing fibre from the store, reduces the odour of slurry, improving this aspect of its environmental impact.

Ammonia losses during slurry spreading can be minimized by adopting techniques such as rapid incorporation or application of liquid into sward or the soil by injection or trailing shoe. Separated liquid has a lower viscosity than unseparated slurry and flows more easily through band spreading hoses for field application, permitting easier use of application techniques that will allow rapid incorporation and nutrient uptake. NH_3 emissions after field application of the liquid phase of separated slurry are much lower than after application of unseparated slurry. A reduction in NH_3 emissions by slurry separating of up to 63% is possible (Beudert et al.,1988) . The lower dry matter liquid generated by separation infiltrates the soil more quickly, resulting in greater sorption of ammonium onto soil, thus reducing both the N in soil solution and volatilization.

Ammonia emissions from bedding

Misselbrook & Powell (2005) compared the ammonia emissions from several bedding materials including RMS (the material had been separated, composted and dried). In a laboratory trial where bedding materials were soaked with urine to their absorbance capacity (which was highest for RMS), they emitted similar proportions of the urine N applied. However, when equal amounts of urine were applied to equal depths of packed beddings, emissions from RMS (68% of applied urine N) were similar to those from chopped newspaper (62% of applied urine N) while emissions from chopped wheat straw, pine shavings and sand were lower at 55%, 42% and 23% respectively. It was noted that RMS was the most absorbent material, absorbing 4.22 g of urine per g of dry bedding, compared with 2.85 g for chopped straw and 0.27 g for sand.

The most recent work specifically related to physically separated bedding material, is from Denmark, where the Government has required further information on ammonia emissions, to indicate whether use of this bedding will allow farmers to comply with the existing ammonia emission regulations. This work has so far indicated an ammonia emission level 70g per cubicle per year higher than the baseline measured with straw bedding, but concluded this to be too low a difference to test under normal conditions (Jensen, personal communication).

13.2.2 Soil protection

The separation of slurry to produce RMS has the benefit of improved slurry handling and spreading. The total volume of liquid to be stored is reduced. Manures can be more readily spread at times when the ground is dry, thus avoiding soil compaction. The separated product is compatible with umbilical systems which can be used to spread liquid long distances to grass and crops with minimal soil damage. Avoiding compaction results in a more aerated soil, improved soil biology, deeper rooting plants, better drainage, faster breakdown of organic matter and improved absorption of soil nutrients. This improved soil structure leads to higher crop yield.

13.2.3 Water quality

Slurry separation technology adopted to produce RMS will have a beneficial impact on water quality due to reduced N losses both as nitrates and ammonia from liquid slurry spread on land. The liquid slurry has a narrow C:N ratio (Amon,1995) which reduces the potential for N immobilization in the soil making it easier to predict the nutrient available for plant growth. This can lead to a significant saving in fertiliser N application to crops, and reduce the risk of loss of nutrients into ground and surface water.

The greater ability to make timely applications will reduce the risk of run-off from fields with the associated risk of pollution to water courses and groundwater by nitrates, phosphates and organic pollutants.

13.3 Summary

On balance, the greatest environmental benefit of using RMS as bedding appears to be the replacement of operations with a large “carbon footprint”, and other potential negative environmental impacts of production and haulage of alternative materials. The overall impact and net release of gases from the slurry itself is unlikely to be changed by the extra step in the chain of recycling the manure. The more efficient uptake of nutrients by plants from separated slurry could be considered an environmental benefit, but this is not linked to the use of the material as bedding.

DairyCo

14. Bacteriological analysis of bedding samples from UK farms

Farmers participating in the telephone survey were invited to submit samples of bedding for bacteriological analysis to increase the availability of information on the bacterial load on used and unused RMS bedding in UK conditions.

14.1 Methods

Sampling methods

Eighteen of the farmers responding to the telephone survey submitted samples of bedding for bacteriological analysis. The farmers were provided with instructions and took samples of fresh and used bedding according to the following protocol:

A sample of freshly separated material was taken from beneath the separator as it was preparing material for use (farmers were asked to record the length of time since separation if there was a delay between separation and sampling).

A composite sample of used bedding was also collected from ten cubicles representative of those in use by the cows, immediately before fresh bedding was applied. Samples were taken in the area likely to come into contact with the udder, to a depth of 2.5 cm. The total weight of samples ranged from 100 to 250g. Farmers were given the opportunity to submit samples from both mattresses and deep beds if both systems were in use on the farm.

Samples were then packed in a chilled insulated container and transported to the laboratory (QMMS Ltd, Cedar Barn), arriving within 24 hours of sampling. All samples were processed immediately on arrival.

Laboratory methods

Bacterial Counts

Bacterial growth was evaluated on four different media, with the aim of allowing counts of a number of ‘putative’ bacterial populations to be made - the media used and the bacterial species enumerated are summarised in Table 1.

100g of bedding (by fresh weight) was suspended in 900ml of Maximum Recovery Diluent. Samples were thoroughly mixed and then agitated on an orbital shaker for 10 minutes at room temperature.

Samples were evaluated using a standard pour plate technique using 1ml of the extracted solution and 3 serial dilutions according to the media used and the anticipated numbers of organisms (see Table 1). Plates were read after 48 hours aerobic incubation at 37^{o}C with the exception of the Violet Red Bile Agar plate which was read at 24 and 48 hours to allow enumeration of coliform and all gram -ve organisms respectively. This technique allowed differing thresholds of detection for the different organisms as outlined in Table 1. Positive and negative controls were conducted with each batch of samples tested.

Examples of the two most prevalent colonies were extracted from the count plates and sub-culture to allow some species level identification. All speciation was conducted by MALDI-TOF MS.

Table 14.1: Summary of the media, number of dilutions used in the study, bacterial species enumerated and theoretical thresholds of detection.

Test	Brief Description	No of Dilutions	Threshold of Detection
Total Viable Count (TVC)	A total viable count based on the growth of organisms on Standard Plate Count Agar (APHA) under aerobic conditions.	3	1×10^7
Coliform Count (Putative)	A 'putative' Coliform spp count based on growth on selective media (Violet Red Bile (VRB)).	3	1×10^4
Streptococcus spp Count (Putative)	A 'putative' Streptococcus spp count based on growth on selective media (Edwards Agar).	3	1×10^6
Staphylococcus spp Count (Putative)	A 'putative' Staphylococcus spp count based on growth (and colony morphology) on selective media (Baird Parker). This will not definitively identify Staphylococcus spp but should provide a relatively robust estimate.	3	1×10^3

In order to allow conversion of counts per gram of bedding to counts per ml, and thus facilitate comparison between fresh and used bedding and with a wider range of other published figures, an attempt to estimate bulk density was made using a method from the "On Farm Compost Handbook" (NRAES, 1992) (also used by Harrison et al (2008)) (http://watershedbmps.com/wp-content/uploads/2012/03/01744_FarmCompost.pdf)). A container of known volume was filled to 1/3 capacity with bedding without applying pressure, tapped ten times on the bench, filled to 2/3 capacity, tapped ten times on the bench, filled to the brim, tapped ten times on the bench, and filled once more to the brim without further compaction. The weight of the contents was recorded and divided by the container volume to give bulk density.

Statistical Analysis

Non-parametric statistical analysis was used for bacterial counts in view of the wide distribution of the data and relatively small numbers. The Mann-Whitney U test was used to test for differences between bedding samples taken prior to and after use, between used samples taken from bedding applied to mattresses and to deep beds (5-12 cm deep), and between samples taken in damp and dry conditions. The relatively small number of samples taken on dry days precluded further division into unused and used bedding for this analysis.

Bulk density values were compared for samples taken before and after use and in damp and dry conditions by t-test or ANOVA, since values showed less variance and a more normal distribution.

Significance was attributed at $p \leq 0.05$.

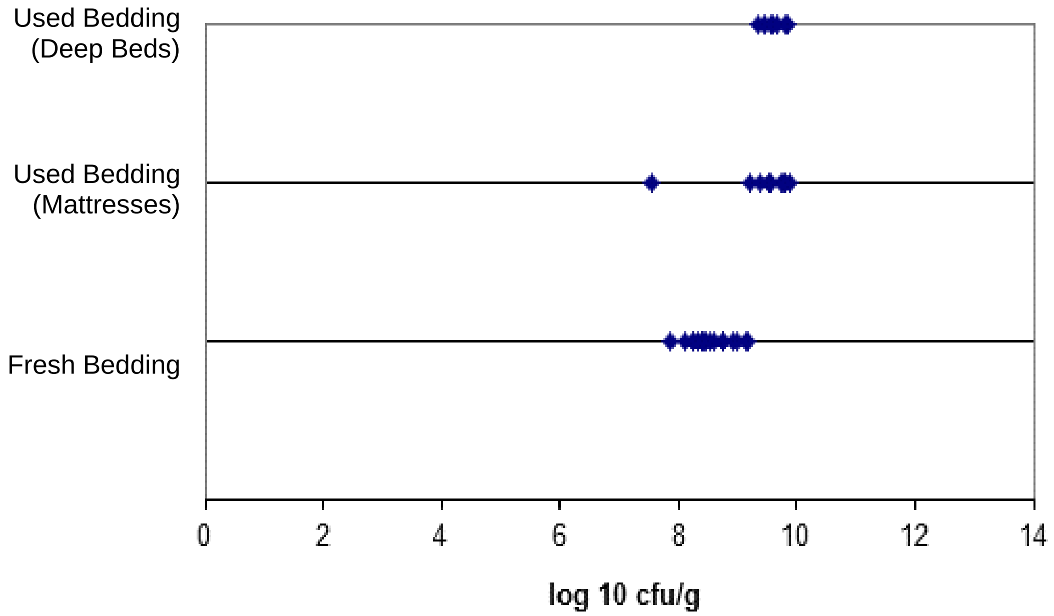
14.2 Results

Thirty-six bedding samples were received for analysis, 17 fresh and 19 used, of which 12 were from shallow coverings on mattresses and 7 from deep beds. The deep beds ranged from 5 to 12 cm depth. The mean length of time from separation to sampling of fresh material was 1.25 hours (range 0 - 8). The mean length of time since applying fresh bedding was 32 hours (range 12 - 96). Ten samples were taken when the weather was dry and the remainder when damp. One farm was 'composting' before use and was not included in the analysis outlined below. The farm that was composting had counts which were at the lower end of those seen in both fresh and used compost, but were not the lowest.

Speciation by MALDI-TOF MS demonstrated that the most common coliform identified was E. coli which was recovered from 88% of samples. *Klebsiella* spp and *Raoultella* spp were recovered from 18% of samples and were present in both fresh and used samples. *Aerococcus* spp and *Enterococcus* spp were most commonly isolated from the Edwards Agar Plates. S. aureus was not identified in any of the samples, though, given the methodology used that cannot be taken as conformation of absence. A wide variety of coagulase -ve *Staphylcoccus* spp and *Corynebacterium* spp were identified on the Baird Parker Agar plates.

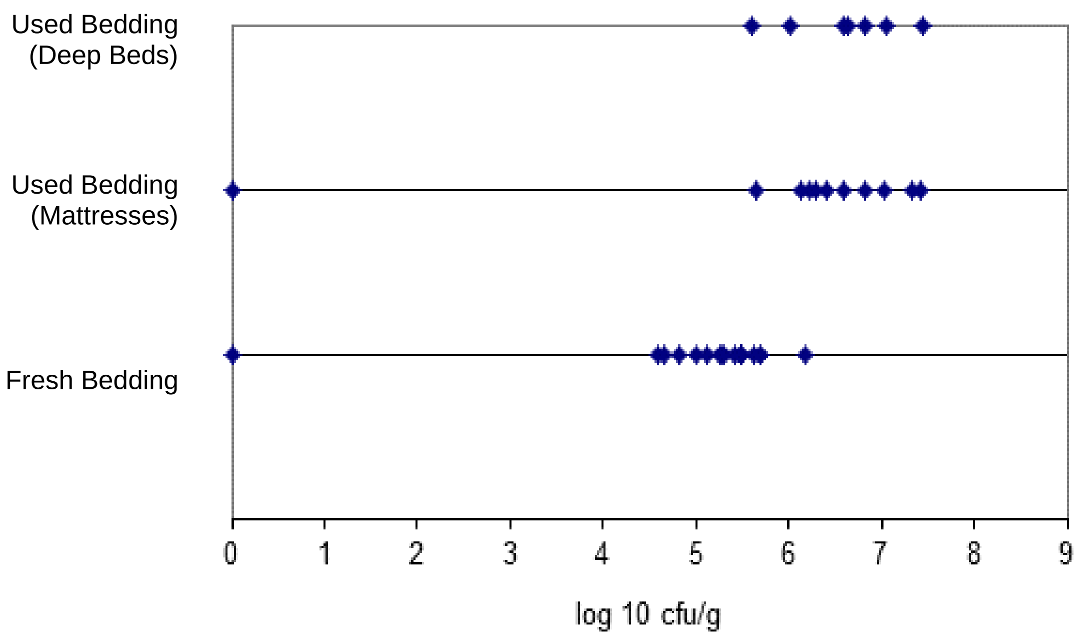
The bacterial counts for fresh material and bedding from mattresses and deep beds are illustrated in Figures 14.1 to 14.4 to allow comparison with values from the literature and other laboratory results illustrated in Figures 7.1 to 7.6.

Figure 14.1: Total bacterial count (log cfu/g) in unused RMS and used bedding from mattresses and deep beds. Samples from 16 farms.



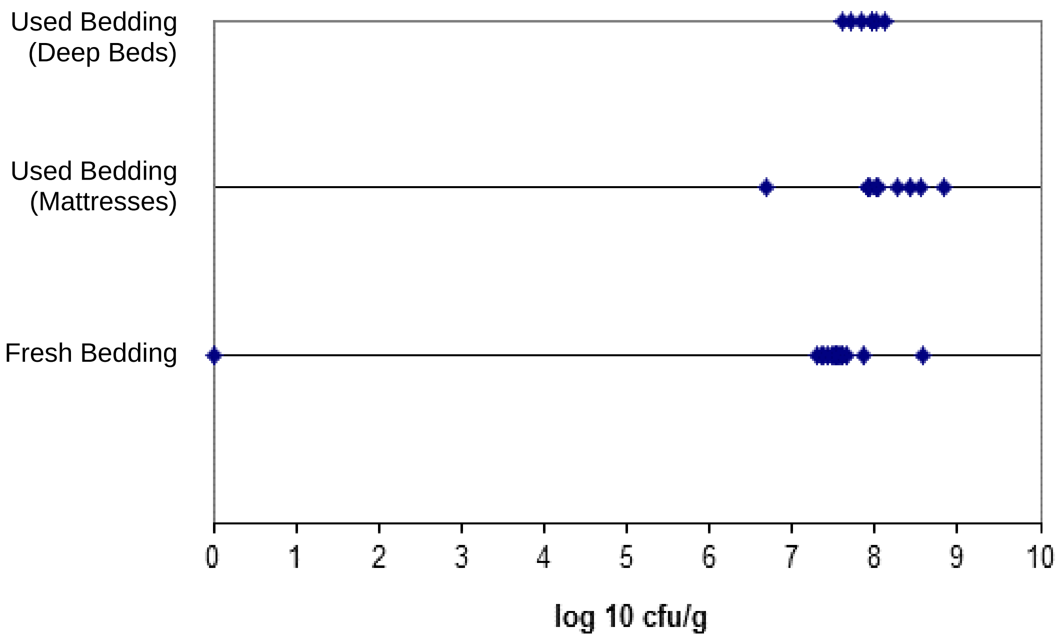
(*Zero vales indicate < 10^4 organisms/g)

Figure 14.2: Total Coliform count (log cfu/g) in unused RMS and used bedding from mattresses and deep beds. Samples from 16 farms.



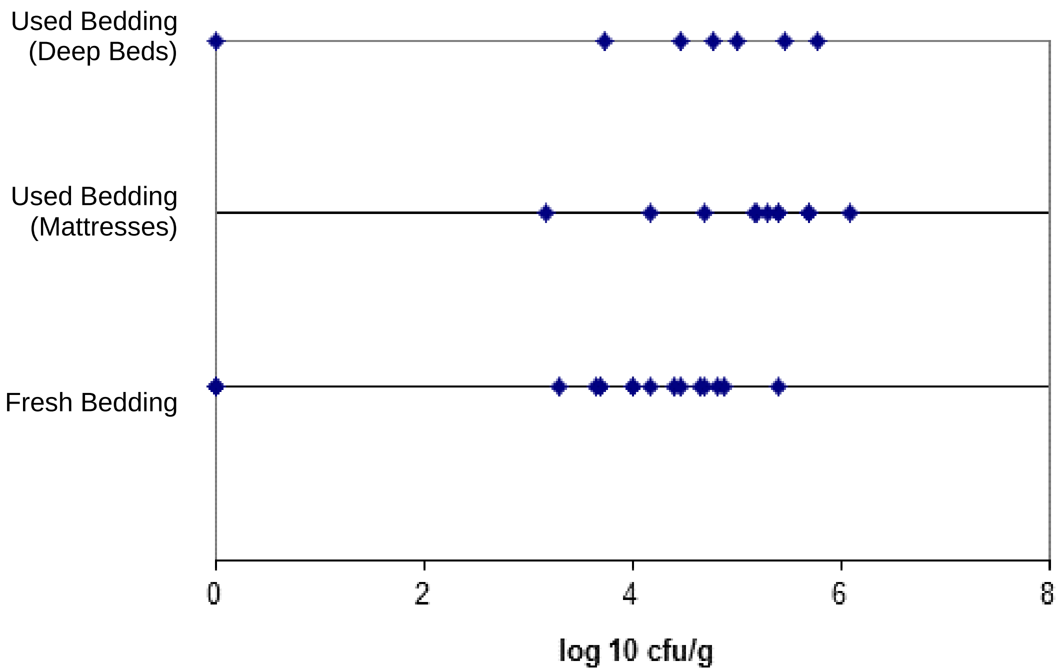
(*Zero vales indicate < 10^4 organisms/g)

Figure 14.3: Total *Streptococcus* sp. count (log cfu/g) in unused RMS and used bedding from mattresses and deep beds. Samples from 16 farms.



(*Zero vales indicate < 10^6 organisms/g)

Figure 14.4 Total Baird Parker count (log cfu/g) in unused RMS and used bedding from mattresses and deep beds. Samples from 16 farms.



(*Zero vales indicate < 10^3 organisms/g)

The counts of all organisms were significantly higher in used bedding samples than in bedding before use as outlined in Table 14.1.

Table 14.1: Bacterial load for fresh and used bedding (median cfu/g fresh weight and cfu/ml*)

	Organisms/g			**Organisms/ml**		
	Fresh	**Used**		**Fresh**	**Used**	
n	16	18		16	18	
Total Viable Count	2.80 x10^{8}	3.85 x10^{9}	$p<0.001$	8.50 x10^{7}	9.52 x10^{8}	$p<0.001$
Putative Coliform Count	2.35 x10^{5}	3.93 x10^{6}	$p<0.001$	6.87 x10^{4}	8.94 x10^{5}	$p<0.001$
Putative Streptococcus Count	3.50 x10^{7}	1.00 x10^{8}	$p<0.001$	9.91 x10^{6}	2.03 x10^{7}	$p<0.001$
Putative Staphylococcus Count	1.25 x10^{4}	1.55 x10^{5}	$p<0.01$	3.90 x10^{3}	3.35 x10^{4}	$p<0.01$

* cfu/ml were calculated using an estimate of bulk density

There were no significant differences in counts from bedding applied on mattresses compared with those from deep beds (5-12 cm deep) as outlined in Table 14.2.

Table 14.2: Bacterial load on shallow and deep beds (median cfu/g fresh weight and cfu/ml*)

	Organisms/g			**Organisms/ml**		
	Deep	**Shallow**		**Deep**	**Shallow**	
n	7	11		7	11	
Total Viable Count	3.95 x10^{9}	3.60 x10^{9}	NS	9.98 x10^{8}	9.01 x10^{8}	NS
Putative Coliform Count	4.40 x10^{6}	2.60 x 10^{6}	NS	9.41 x10^{5}	4.04 x10^{5}	NS
Putative Streptococcus Count	9.50 x10^{7}	1.05 x10^{8}	NS	1.85 x10^{7}	2.49 x10^{7}	NS
Putative Staphylococcus Count	6.00 x10^{4}	2.00 x10^{5}	NS	1.74 x10^{4}	4.14 x10^{4}	NS

* cfu/ml were calculated using an estimate of bulk density

There were numerically higher counts of organisms in samples that were collected in damp weather, though the differences were not significant, as outlined in Table 14.3. Results for both fresh and used bedding were pooled for this analysis due to insufficient numbers for a more meaningful in depth comparison.

Table 14.3: Comparison of samples taken in damp and dry weather conditions. (median cfu/g fresh weight and cfu/ml*)

	Organisms/g			Organisms/ml		
	Damp Weather	**Dry Weather**		**Damp Weather**	**Dry Weather**	
n	24	10		24	10	
Total Viable Count	1.95 $x10^9$	4.85 $x10^8$	NS	4.22 $x10^8$	1.33 $x10^8$	NS
Putative Coliform Count	1.20 $x10^6$	3.58 x 10^5	NS	2.50 $x10^5$	9.33 $x10^4$	NS
Putative Streptococcus Count	8.00 $x10^7$	3.80 $x10^7$	NS	1.50 $x10^7$	1.08 $x10^7$	NS
Putative Staphylococcus Count	5.50 $x10^4$	2.00 $x10^4$	NS	1.53 $x10^4$	5.82 $x10^3$	NS

* cfu/ml were calculated using an estimate of bulk density

There were typically, though not exclusively, numerically higher counts on bedding that had been applied for longer, though the differences were not significant, with the exception of putative *Streptococcal* counts as measured per ml. These results are outlined in Table 14.4 but as with other tables should be interpreted with care due to the impact of multiple comparisons and the small number of samples involved.

Table 14.4: Bacterial load on beds after 24 hours or >=48 hours (median cfu/g fresh weight and cfu/ml*)

	Organisms/g			Organisms/ml		
	24 hours	**>=48 hours**		**24 hours**	**>=48 hours**	
n	12	6		12	6	
Total Viable Count	3.68 $x10^9$	5.80 $x10^8$	NS	9.10 $x10^8$	9.90 $x10^8$	NS
Putative Coliform Count	2.95 $x10^6$	5.48 x 10^6	NS	6.25 $x10^5$	1.01 $x10^6$	NS
Putative Streptococcus Count	1.05 $x10^8$	8.75 $x10^7$	NS	2.79 $x10^7$	1.50 $x10^7$	$P<0.05$
Putative Staphylococcus Count	1.55 $x10^5$	1.33 $x10^5$	NS	3.35 $x10^4$	2.94 $x10^4$	NS

* cfu/ml were calculated using an estimate of bulk density

Bulk Density

The bulk density estimates for bedding before and after use, and in different beds are compared in Table 14.5. Fresh bedding had a numerically higher, but not significant, mean bulk density than used bedding, as might have been expected based on the fact that the bedding is reported to lose moisture when applied to beds. Deep beds had a mean bulk density intermediate between fresh material and material on mattresses (though differences were not significant), which is again as might be expected based on the same principles and the assumption that the material might dry out less in a deep bed.

Table 14.5 Bulk density of samples of bedding (mean and sd, g/ml) and the influence of bedding use and weather conditions at time of sampling.

Effect of bedding use	Bulk density mean	sd	
Fresh	0.28	0.035	NS
Used	0.24	0.076	
Fresh	0.28	0.035	NS
Shallow bed	0.24	0.06	
Deep bed	0.26	0.10	

14.3 Discussion and conclusions

The findings of this small survey have demonstrated a huge variation in the numbers of bacteria in RMS from different farms, both in fresh and used material. Bacterial numbers clearly increase following application of the RMS to beds, but it is unclear if this is as a result of multiplication in an aerobic environment (*cf* slurry) or as a result of contamination with fresh faeces. There is some evidence of variation due to bedding interval and climatic conditions, though both are difficult to assess on the basis of this pilot study and therefore necessarily these findings should be interpreted with care.

Comparing the samples collected with figures reported in the literature from other countries suggests that in our samples total bacterial count for fresh material was less variable, with a slightly higher median value. Total bacterial count for used bedding from the UK deep beds was at the higher end of the range found in the literature. Directly comparable figures from literature for the individual bacterial groups are limited therefore making it difficult to draw any definitive conclusions. There are few reported coliform counts in the literature for fresh solids without further processing. Harrison et al (2008) reported counts varying from 1 to 1 $x10^7$ per gram, whilst Husfeldt et al (2012) reported counts of around 1 $x10^4$ per ml. Total strep counts found here covered a similar range to those reported by others in both fresh and used material.

15. Performance review of current users

15.1 Sources of data and method of analysis

Herds that took part in the telephone questionnaire were invited to send in herd management, milk recording and health data to be used for analysis, assessment and anonymous benchmarking against a larger database of herds that have not so far used RMS as bedding for adult cows.
Of the 20 herds that fully (19) or partly (1) responded to the questionnaire, 16 provisionally agreed to their data being collated and used for this section of the scoping study. Four of the herds declined to make their herd data available to the project team. Of the 16 herds that agreed to share data, six herds did not engage with a full and routine milk recording service and were therefore discarded from this section as without robust cow, lactation and somatic cell count (SCC) data, meaningful analysis of performance would be impossible. Of the 10 remaining herds, four record with the Cattle Information Service (CIS), three with National Milk Records (NMR) and three with Quality Milk Management Services Ltd (QMMS). Four of the herds submitted data from on-farm software; one using Interherd (PAN Livestock Services, University of Reading) and three using Total Dairy (SUM-IT Computer Systems Ltd, Thame). Of the 10 herds that submitted data, either in the form of a milk recording organisation Common Data Layer (CDL) file or via on-farm software, only five reported clinical mastitis records in electronic format. The farms had been using RMS for between five and 17 months (mean 10, median 9 months).

To allow some comparisons to be made between this small subset of RMS-using herds and other dairy herds in the UK, a sample of just over 120 herds that were engaged in milk recording and which used on farm software was taken from the QMMS database and udder health parameters for these herds analysed. These herds were anonymised and benchmarked in the same manner as for the RMS herds.

All herds were benchmarked using the TotalVet© software (QMMS/SUM-IT; www.total-vet.co.uk). Parameters selected were those that encompassed udder health based on SCC and clinical mastitis data. For the SCC data, the following four parameters were used:

1. The rate of new infections in lactation (as measured by the proportion of ‘uninfected’ cows moving above a 200,000 cells/ml threshold between milk recording dates in lactation)
2. The rate of fresh calver infections (as measured by the proportion of cows with SCC result above a 200,000 cells/ml threshold at the first milk recording date in lactation (when < 30 days in milk))
3. The proportion of the herd chronically infected (i.e. more than one of the last three SCC >200,000 cells/ml)
4. The proportion of the herd infected (i.e. >200,000 cells/ml).

For clinical mastitis data (where reported), three parameters were used:

1. The clinical mastitis rate (total number of cases expressed per 100 cows per year)
2. The **dry period origin new case rate** (the rate of new clinical mastitis cases in cows less than 30 days post-calving)
3. The **lactating period origin new case rate** (the rate of new clinical mastitis cases in cows more than 30 days, but less than 306 days post-calving).
4. Figures for the month of December were included for the years 2011, 2012 and 2013 as well as the rolling 3-month average figures ending in December 2011, 2012 and 2013, to represent the period when ALL herds had been using RMS bedding for at least three months (December 2013) and comparative periods at the same time of year prior to this. All data were entered in a spreadsheet (Microsoft Excel) for further analysis.

15.2 Descriptive data

One RMS herd was omitted from the clinical mastitis analysis as clinical mastitis records were available historically but had not been updated since July 2013. One herd could not be included in historic benchmarking (2011-12) due to lack of milk recording data in 2011 but was included in data for 2012-13.

Of the herds selected from the QMMS database, 33 of the 123 were excluded from the analysis due to missing milk recording data (*i.e.* not recording every 4-6 weeks) and/or missing information in any of the three-month periods ending December 2011-13. Three herds were removed as existing RMS bedding users. Of the 87 herds with complete milk recording data in all three years that were used for SCC analysis, 58 also reported complete clinical mastitis rate data (67%). Other herds were discarded due to missing clinical mastitis data in any of the three year periods and/or reported mastitis incidence rates <5 cases per 100 cows/year (likely under-reporting).

The sample of RMS-bedded herds had a larger herd size (median 320, mean 425; range 160-981 cows) than the sample of QMMS-recorded herds (median 195, mean 227; range 33-845 cows). The sample of RMS-bedded herds also had a higher 305-day adjusted milk yield (median 9887, mean 9996; range 8524-11,425 litres) compared to the sample of QMMS-recorded herds (median 8185, mean 7972; range 4590-11,932 litres).

15.3 Data analysis - somatic cell count

Data for the RMS-bedded herds from the month of December 2011, 2012 and 2013 are shown in Tables 15.1, 15.2 and 15.3 compared to data from the QMMS database, to show the range of values for these parameters seen in other UK herds.

The averages for the selected SCC parameters for the 3-month rolling period to December in all three years across all herds encompassed a range of values that are typically seen in UK dairy herds, for the rate of new infection in lactation (between 2% and 11%; target <5%), for the fresh calver infection rate (between 4.7% and 48.7%; target <10%), for chronic cows (between 2.3% and 24.1%; target <5%) and for cows >200,000 cells/ml (between 5.2% and 31.2%; target <20%).

In all three years, the rolling 3-month average mean and median values for lactation new infections, fresh calver infections, chronic cows and cows >200,000 cells/ml were all lower for RMS-bedded herds when compared to herds from the QMMS database, with the exception of the fresh calver infection rate which was slightly higher for the period October-December 2012 in RMS bedded herds. Whilst clearly a small snapshot, this data does not provide any indication of a dramatic worsening of udder health across the small group of RMS herds studied in this short period. However there is a large variation between herds and apparent large changes year on year; these can be misleading, particularly if performance was already very good in a given herd. For example, herd 1 reduced the lactation new infection rate by 33% between the end of 2012 and the end of 2013 (6.1% down from 9.3%) whereas herd 2 appeared to get dramatically worse with an increase of 77% for the same parameter in the same period), although it can be seen that herd 2 was already achieving exceptional results in this area (5.5% up from just 3.1%).

The overall percentage change for the SCC parameters year on year in the RMS herds is summarised in Figure 15.1 below. On average, there was a trend for a slight worsening of the rate of new infection in lactation but a large decline in the fresh calver infection rate between 2012 and 2013 and reductions in both the proportion of cows >200,000 cells/ml and cows classified as chronically infected.

This can be compared with the percentage change for the SCC parameters year on year in the QMMS-recorded herds as shown in Figure 15.2 where trends are similar and therefore do not suggest improved or worsening performance for RMS-bedded herds. Interestingly, these RMS herds also saw a large decrease in the rate of infection in fresh calved cows at first test-day between 2012 and 2013.

Table 15.1 Somatic cell count data parameters for Recycled Manure Solids (RMS) bedded herds with comparisons for December 2011

	Somatic Cell Count Data (December 2011)			
Herd	**% Lactation New Infection Rate (3 month rolling average)**	**% Fresh Calver Infection Rate (3 month rolling average)**	**% Chronically Infected Cows (3 month rolling average)**	**% Cows >200,000 cells/ml (3 month rolling average)**
1	7.1 (9.7)	7.7 (9.6)	11.3 (9.0)	16.80 (17.5)
2	4.3 (4.4)	0.0 (11.6)	7.9 (10.0)	11.50 (15.2)
3	5.6 (6.0)	15.3 (14.5)	9.0 (8.4)	15.10 (14.4)
4	6.6 (4.0)	7.4 (15.8)	3.8 (5.5)	11.40 (11.4)
5	7.0 (8.9)	22.4 (21.1)	12.3 (10.5)	19.90 (19.6)
6	7.9 (7.1)	29.4 (18.5)	11.1 (9.7)	19.30 (16.7)
7	15.1 (8.7)	27.3 (20.4)	16.2 (15.6)	29.10 (23.5)
8	-	-	-	-
9	11.9 (9.1)	27.3 (25.5)	8.0 (6.5)	20.30 (16.6)
10	6.4 (4.8)	14.3 (12.9)	13.9 (15.2)	20.00 (20.8)
RMS mean	**7.9 (7.0)**	**16.8 (16.7)**	**10.4 (10.0)**	**18.2 (17.3)**
RMS median	**7.0 (7.1)**	**15.3 (15.8)**	**11.1 (9.7)**	**19.3 (16.7)**
QMMS mean	**10.8 (11.2)**	**20.0 (21.6)**	**15.5 (15.4)**	**24.8 (24.8)**
QMMS median	**9.9 (10.5)**	**18.2 (20.8)**	**15.8 (15.3)**	**25.2 (25.2)**

Table 15.2 Somatic cell count data parameters for Recycled Manure Solids (RMS) bedded herds with comparisons for December 2012

	Somatic Cell Count Data (December 2012)			
Herd	**% Lactation New Infection Rate (3 month rolling average)**	**% Fresh Calver Infection Rate (3 month rolling average)**	**% Chronically Infected Cows (3 month rolling average)**	**% Cows >200,000 cells/ml (3 month rolling average)**
1	10.3 (9.3)	8.3 (13.3)	8.2 (10.3)	16.0 (17.5)
2	1.7 (3.1)	30.0 (20.5)	6.0 (7.0)	10.1 (11.8)
3	4.5 (4.5)	25.7 (19.3)	8.1 (8.4)	14.4 (12.8)
4	6.1 (6.9)	44.8 (48.7)	15.3 (13.5)	25.3 (23.6)
5	6.3 (9.3)	23.2 (20.7)	12.5 (13.0)	18.2 (21.1)
6	7.2 (7.6)	6.5 (15.4)	9.2 (10.3)	15.6 (17.8)
7	7.2 (9.7)	20.0 (9.3)	15.4 (16.8)	22.4 (24.8)
8	4.1 (4.9)	1.8 (8.7)	2.3 (2.3)	3.9 (5.2)
9	2.2 (8.7)	21.4 (23.5)	11.6 (11.4)	12.6 (19.7)
10	8.3 (7.4)	40.0 (36.4)	25.5 (24.1)	32.9 (31.2)
RMS mean	**5.8 (7.1)**	**22.2 (21.6)**	**11.4 (11.7)**	**17.1 (18.6)**
RMS median	**6.2 (7.5)**	**22.3 (19.9)**	**10.4 (10.9)**	**15.8 (18.8)**
QMMS mean	**11.0 (11.0)**	**20.5 (22.8)**	**14.9 (15.1)**	**24.1 (24.7)**
QMMS median	**10.5 (10.3)**	**20.0 (21.9)**	**14.8 (14.7)**	**24.1 (24.6)**

Table 15.3 Somatic cell count data parameters for Recycled Manure Solids (RMS) bedded herds with comparisons for December 2013

	Somatic Cell Count Data (December 2013)			
Herd	**% Lactation New Infection Rate (3 month rolling average)**	**% Fresh Calver Infection Rate (3 month rolling average)**	**% Chronically Infected Cows (3 month rolling average)**	**% Cows >200,000 cells/ml (3 month rolling average)**
1	6.3 (6.1)	3.6 (4.7)	5.2 (9.8)	12.5 (15.8)
2	6.6 (5.5)	8.3 (13.2)	8.9 (7.3)	15.5 (13.0)
3	7.9 (8.0)	18.2 (23.0)	11.2 (9.9)	18.7 (17.3)
4	6.3 (7.5)	29.4 (26.3)	16.2 (13.4)	22.6 (21.9)
5	14.7 (10.7)	22.0 (23.6)	13.5 (13.8)	25.7 (24.2)
6	5.9 (7.1)	17.6 (19.6)	8.4 (9.9)	14.3 (17.1)
7	15.0 (9.0)	17.6 (13.8)	14.0 (14.2)	27.1 (22.3)
8	3.9 (2.1)	8.5 (9.5)	6.9 (3.6)	12.9 (9.6)
9	10.5 (11.6)	50.0 (14.9)	10.8 (7.6)	18.4 (16.5)
10	6.1 (7.9)	25.0 (12.5)	19.9 (17.4)	25.5 (23.9)
RMS mean	**8.3 (7.6)**	**20.0 (16.1)**	**11.5 (10.7)**	**19.3 (18.2)**
RMS median	**6.5 (7.7)**	**17.9 (14.4)**	**11.0 (9.9)**	**18.6 (17.2)**
QMMS mean	**13.3 (11.7)**	**22.2 (20.5)**	**15.5 (14.9)**	**27.0 (25.2)**
QMMS median	**11.4 (10.3)**	**22.2 (20.0)**	**14.4 (13.9)**	**26.5 (24.2)**

Figure 15.1: Percentage change in SCC parameters between 2011-12 and 2012-13 for 10 Recycled Manure Solids (RMS) bedded herds (LPIMI = lactating period intramammary infection rate; FCIMI = Fresh Calver intramammary infection rate)

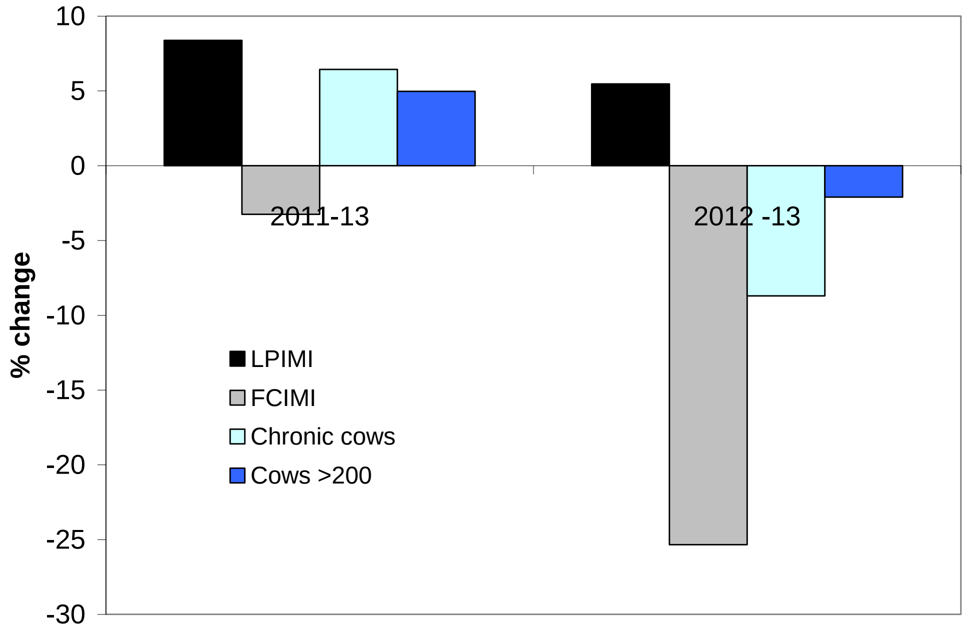
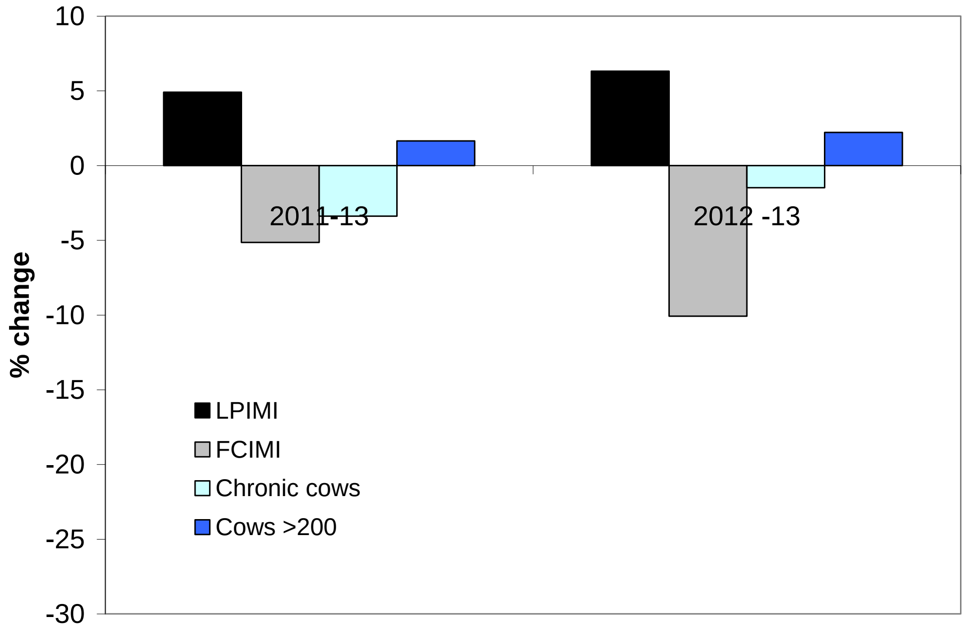


Figure 15.2: Percentage change in SCC parameters between 2011-12 and 2012-13 for 87 QMMS recorded herds (LPIMI = lactating period intramammary infection rate; FCIMI = Fresh Calver intramammary infection rate)



15.4 Data analysis - clinical mastitis

Clinical mastitis data for the RMS-bedded herds for the months of December 2011, 2012 and 2013 and the three-month rolling averages ending in these months are shown in Tables 15.4 (clinical mastitis rate), 15.5 (new cases of apparent dry period origin) and 15.6 (new cases of apparent lactating period origin). These data are compared to mean values from the QMMS database.

As seen with the somatic cell count data, values are extremely variable for the RMS herds and encompass a large range in all years. There is evidence of dramatic improvement (*e.g.* herd 1 reduced the overall clinical mastitis rate by 78% between 2012 and 2013) but also for deterioration (*e.g.* herds 3 and 5 both saw modest increases in the clinical mastitis rate between 2011 and 2013).

15.5 Overall conclusion

This small scale analysis of production and udder health data from farms which had recently converted to the use of RMS has not demonstrated any dramatic differences between performance of RMS and non RMS herds. However, the number of available datasets and the timeframe of bedding changes mean that this provisional analysis cannot hope to be either comprehensive or robust. The analysis is further hampered by the inability, in a small study such as this, to control for the host of other factors which will also influence udder health. Nevertheless, these data have not exposed any major issues or outlying effects following a short period of use of the system.

Table 15.4: Clinical mastitis rate (cases per 100 cows/year) for Recycled Manure Solids (RMS) bedded herds with comparisons from the QMMS database

	Herd					
Parameter	**1**	**3**	**5**	**7**	**9**	**QMMS Mean**
Clinical mastitis rate December 2011	62	17	32	52	na*	64.8
Clinical mastitis rate October-December 2011 (Rolling 3 month average)	59	33	32	35	na*	51.6
Clinical mastitis rate December 2012	111	32	39	35	142	50.8
Clinical mastitis rate October-December 2012 (Rolling 3 month average)	95	42	41	38	126	46.6
Clinical mastitis rate December 2013	31	49	35	49	186	39.1
Clinical mastitis rate October-December 2013 (Rolling 3 month average)	21	48	40	32	118	39.5
% change October-December 2011-13	**-64.4**	**+45.5**	**+25.0**	**-8.6**	**-**	**-23.5**
% change October-December 2012-13	**-77.9**	**+14.3**	**-2.4**	**-15.8**	**-6.4**	**-15.2**

* Herd 9 did not report clinical mastitis data in 2011

Table 15.5 Dry period origin mastitis rate (cases per 12 cows at risk; target <1 in 12 affected) for Recycled Manure Solids (RMS) bedded herds with comparisons from the QMMS database.

	Herd					
Parameter	**1**	**3**	**5**	**7**	**9**	**QMMS Mean**
Dry period rate December 2011	1.9	0.0	0.6	1.1	na*	1.4
Dry period rate October-December 2011 (Rolling 3 month average)	1.1	0.5	0.6	0.9	na*	1.1
Dry period rate December 2012	2.0	1.3	0.9	0.0	5.5	1.2
Dry period rate October-December 2012 (Rolling 3 month average)	1.4	0.7	1.1	0.7	2.4	1.1
Dry period rate December 2013	1.1	0.5	1.0	0.0	2.5	0.8
Dry period rate October-December 2013 (Rolling 3 month average)	0.8	0.8	0.7	0.1	1.8	0.9
% change October-December 2011-13	**-26.4**	**+58.0**	**+13.1**	**-84.4**	**-**	**-19.4**
% change October-December 2012-13	**-42.5**	**+9.7**	**-36.1**	**-78.8**	**-26.6**	**-21.3**

* Herd 9 did not report clinical mastitis data in 2011

Table 15.6 Lactating period origin mastitis rate (cases per 12 cows at risk; target <2 in 12 affected) for Recycled Manure Solids (RMS) bedded herds with comparisons from the QMMS database

	Herd					
Parameter	**1**	**3**	**5**	**7**	**9**	**QMMS Mean**
Lactating period rate December 2011	2.4	1.2	2.0	4.6	na*	3.7
Lactating period rate October-December 2011 (Rolling 3 month average)	2.6	2.2	1.9	2.5	na*	3.0
Lactating period rate December 2012	3.9	1.6	2.0	1.1	3.9	2.8
Lactating period rate October-December 2012 (Rolling 3 month average)	4.2	2.1	2.1	1.6	6.2	2.7
Lactating period rate December 2013	1.2	3.5	1.2	4.6	7.9	2.3
Lactating period rate October-December 2013 (Rolling 3 month average)	1.2	3.4	1.9	2.6	5.3	2.4
% change October-December 2011-13	**-52.3**	**+56.0**	**+2.7**	**+5.6**	**-**	**-18.5**
% change October-December 2012-13	**-70.4**	**+57.5**	**-9.9**	**+64.4**	**-15.7**	**-10.8**

* Herd 9 did not report clinical mastitis data in 2011

16. Gap analysis

A gap analysis has been undertaken, the findings of which are outlined in this section. Whilst there are inevitably a large number of gaps in existing knowledge an attempt has been made to limit the list to those likely to be of greatest human/animal health, welfare, environmental and economic importance in the UK situation. It should be noted at the outset that to date there is no research, and very limited farm experience, from UK conditions.

16.1 Pathogens in slurry and RMS

There is a general lack of information relating to the presence of pathogens and their survival in slurry as outlined in tables 5.1-5.3. Whilst it is probably not necessary to know the exact load and persistence for every pathogen a more thorough understanding is probably required. Key topics and areas are listed below:

- A better understanding of the presence and survival of key zoonotic and exotic notifiable pathogens is required – in particular of the viruses.
- A better understanding of the survival/multiplication of key endemic pathogens in slurry and RMS including the impact of storage before and after separation.
- A better understanding of the possible pH, dry matter and temperature range of RMS on UK farms may help assess pathogen survival. This could also help to understand reasons for time scale changes in bacterial load, and possibly how RMS conditions could be mitigated to minimise bacterial multiplication.
- Understanding of the impact of both pre and post separation treatment on RMS – including from the perspective of digesters and how this may impact exotic disease. For instance the impact of inclusion of different feedstock materials – *eg* household waste.
- Long term impact of recycling on bacterial loading/flora - slurry solids are being recycled, multiple times, without any treatment. Will pathogen concentrations increase, and if so does this matter? Will pathogen characteristics evolve to become a greater threat to cattle?
- What if any implications are there for antibiotic resistance in a "closed cycle" for manure?

16.2 Impact of the use of RMS

- Effect on air quality in buildings – there are reports of "no dust" and "no smell", but relative humidity, fine particles and air-borne pathogens have not been measured.
- Relative importance of level, and change in level, of pathogens in bedding (eg is there a critical threshold pathogen load for mastitis, or is the time of exposure also important?)
- An understanding of both the short, medium and longer term animal health implications of the use of RMS as bedding. Particularly with respect to mastitis and Johne's Disease. Direct evidence of consequence is completely lacking for all diseases other than mastitis.
- The impact of different bedding materials on bulk milk quality both at the farm level and subsequently at the milk purchaser level should large numbers of farms take up the use of RMS.

16.3 Management of RMS

Much of our existing knowledge on the use of RMS as bedding seems to have been acquired through experience and anecdote rather than rigorous scientific study. Management of RMS should be further investigated to address the following issues:

- Determine the evidence for the critical DM content for application to beds being 35% DM
- The best approach to minimise pathogen survival and multiplication in RMS once applied to the bed. *eg* optimum frequency of replenishing bedding in deep bedded cubicles as varying experiences are reported anecdotally and in the literature.
- What is the relative importance of pre-existing flora in RMS compared to that freshly added by animals after bedding applied – this would allow a better evaluation of the impact of RMS use compared to other bedding materials. This should encompass the impact of use of a 'sterile material' and the impact of the presence of non-pathogenic bacteria.
- Farmers report RMS dries out in the cubicles with cow heat and exposure to air - how dry does RMS get once applied as bedding in UK conditions, and is this sufficient to control the bacterial count?
- The impact of diet on RMS - *eg* do higher concentrate diets result in the presence of more coliforms in RMS.

16.4 Risk pathways

- Does RMS increase or decrease the risk of livestock feed contamination with pathogens, (eg via common handling machinery or transfer via wildlife)

16.5 Economics

- Some farmers are projecting cost savings with RMS of up to 1ppl – a better understanding of the potential cost benefit of the use of RMS is required.

16.6 Other issues

- A better understanding of UK consumers' and milk buyers' views on use of RMS as bedding and how best to mitigate any negative perceptions.

DairyCo

REFERENCES

Adamski, M., K. Glowacka, R. Kupczynski, and A. Benski. 2011. Analysis of the possibility of various litter beddings application with special consideration of cattle manure separate. Acta Scientiarum Polonorum – Zootechnica 10(4):5-12.

Adhikari, N., H. E. Bonaiuto, and A. B. Lichtenwalner. 2013. Short communication: Dairy bedding type affects survival of Prototheca in vitro. Journal of Dairy Science 96(12):7739-7742.

Amon, B., V. Kryvoruchko, T. Amon, and S. Zechmeister-Boltenstern. 2006. Methane, nitrous oxide and ammonia emissions during storage and after application of dairy cattle slurry and influence of slurry treatment. Agriculture Ecosystems & Environment 112(2-3):153-162.

Amon, M., M. Dobeic, T. H. Misselbrook, B. F. Pain, V. R. Phillips, and R. W. Sneath. 1995. A farm scale study on the use of de-odorase(r) for reducing odor and ammontiam emissions from intensive fattening piggeries Bioresource Technology 51(2-3):163-169.

Avery, B. A. Synge, and A. Moore. 2004. Levels of zoonotic agents in British livestock manures. Letters in Applied Microbiology 39(2):207-214.

Barker Z.E., J.R. Amory, J.L. Wright, R.W. Blowey and L.E. Green (2007) Management factors associated with impaired locomotion in dairy cows in England and Wales. Journal of Dairy Science 90: 3270-3327.

Beudert, B., Do¨hler, H., Aldag, R., 1988. Ammoniakverluste aus mitWasser verdu¨nnter Rindergu¨lle im Modellversuch. In: VDLUFA (Ed.), VDLUFA-Schriftenreihe No. 28, pp. 1355–1364.

Bishop, J. R., A. B. Bodine, and J. J. Janzen. 1980. Effect of ambient environments on survival of selected bacterial populations in dairy waste solids. Journal of Dairy Science 63(4):523-525.

Blowey, R., J. Wookey, L. Russell, and R. Goss. 2013. Dried manure solids as a bedding material for dairy cows. Veterinary Record 173(4):99.

Bøtner, A. and G. J. Belsham. 2012. Virus survival in slurry: Analysis of the stability of foot-and-mouth disease, classical swine fever, bovine viral diarrhoea and swine influenza viruses. Veterinary Microbiology 157(1-2):41-49.

Bonhotal, J., M. Schwarz, and S. M. Stehman. 2011. How Mycobacterium avium paratuberculosis is affected by the composting process. Trends in Animal and Veterinary Sciences 2(1):5-10.

Bramley, A. J. and F. K. Neave. 1975. Studies on the control of coliform mastitis in dairy cows. Br. Vet. J. 131:160-169.

Breen, J. E., M. J. Green, and A. J. Bradley. 2009. Quarter and cow risk factors associated with the occurrence of clinical mastitis in dairy cows in the United Kingdom. Journal of Dairy Science 92(6):2551-2561.

Buelow, Kenn. 2008. How to make digested manure solids work in the Midwest. Proceedings of the National Mastitis Council 47th Annual Meeting. January 20-23, 2008. New Orleans, Louisiana.

Capion, N., M. Boye, C. Ekstrom, K. Dupont, and T. K. Jensen. 2013. A study into digital dermatitis transmission and bacterial associated pathological changes involved in the disease. Open Journal of Veterinary Medicine 3(2):192-198.

Carroll, E. J. and D. E. Jasper. 1978. Distribution of Enterobaceriaceae in recycled manure bedding on Calfornia dairies. Journal of Dairy Science 61(10):1498-1508.

Cempirkova, R. and M. Soch. 2007. The analysis of real microbiological risks for dissociated slurry. Agricultura Tropica et Subtropica 40(4):164-170.

Chase-Topping,M J, I Handel, M Bartlomiej, M Bankowski, D Nicholas, D Juleff, D Gibson, S J Cox, M A Windsor, E Reid, C Doel, R Howey, P V Barnett, M EJ Woolhouse and B Charleston 2013. Understanding foot-and-mouth disease virus transmission biology: identification of the indicators of infectiousness. Veterinary Research 44:46.

Chee-Sandford, J. C., R. I. Aminov, I. J. Krapac, N. Garriguez-Jeanjean, and R. I. Mackie. 2001. Occurrence and diversity of tetracycline resistance genes in lagoons and groundwater underlying two swine production facilities. Applied and Environmental Microbiology 67(4):1494-1502.

Dean, G. S., S. G. Rhodes, M. Coad, A. O. Whelan, P. J. Cockle, D. J. Clifford, R. G. Hewinson, and H. M. Vordermeier. 2005. Minimum infective dose of Mycobacterium bovis in cattle. Infection and Immunity 73(10):6467-6471.

Defra (2010) Fertiliser Manual (RB209) 8th Edition. The Stationery Office.

Dixon, B., L. Parrington, A. Cook, K. Pintar, F. Pollari, D. Kelton, and J. Farber. 2011. The potential for zoonotic transmission of Giardia duodenalis and Cryptosporidium spp. from beef and dairy cattle in Ontario, Canada. Veterinary Parasitology 175(1/2):20-26.

Driehuis, F., Rademaker, J.L.W., Hoolwerf, J.D., Lucas-van den Bos, H.R., & Wells-Bennik, M.H.J. (2010) Onderzoek naar sporen van Clostridium tyrobutyricum, Clostridium beijerinckii en Paenibacillus in melk, kuilvoer en koemest en verbetering van de bepalingsmethode van boterzuurbacteriesporen. NIZO-Rapport E2010-070.

Dreihus, F., L. van den Bos, and M.H.J Wells-Bennik,. 2012. Risks of microbial contaminants of bedding materials: compost, cattle manure solids, horse dung and bedded pack barns. NIZO Report. NIZO Food Research BV, Ede, The Netherlands.

F. Driehuis, E. Lucas-van den Bos, M.H.J. Wells-Bennik (2013) Risks of the use of cattle manure solids as bedding material for milk quality: Bacillus cereus and butyric acid bacteria spores. NIZO-Rapport E 2013/180

Eisenberg, SWF, R Chuchaisangrata, M Nielena and A P Koetsa 2013 Relationship between presence of cows with milk positive for Mycobacterium avium subsp. paratuberculosis-specific antibody by ELISA and viable M. avium subsp. paratuberculosis in dust in cattle barns. Appl. Environ. Microbiol. 79 (18) 5458-5464 .

Endres, Marcia. Use of recycled 'fiber' bedding in freestall barns. Published in Dairy Star February 5, 2010

Endres, Marcia. Overview of Trends in Use of Manure Solids and Compost Bedded Packs. Proceedings of the National Mastitis Council 47th Annual Meeting. January 20-23, 2008. New Orleans, Louisiana

Evstigneeva, A. S., T. Y. Ul'yanova, and I. V. Tarasevich. 2007. The survival of Coxiella burnetii in soils. Eurasian Soil Sc. 40(5):565-568.

Evans, N. J., J. M. Brown, R. D. Murray, B. Getty, R. J. Birtles, C. A. Hart, and S. D. Carter. 2010. Characterization of Novel Bovine Gastrointestinal Tract Treponema Isolates and Comparison with Bovine Digital Dermatitis Treponemes. Applied and Environmental Microbiology 77(1):138-147.

Evans, N. J., J. M. Brown, R. D. Murray, B. Getty, R. J. Birtles, C. A. Hart, and S. D. Carter. 2011. Characterization of Novel Bovine Gastrointestinal Tract Treponema Isolates and Comparison with Bovine Digital Dermatitis Treponemes. Applied and Environmental Microbiology 77(1):138-147.

Evans, N. J., D. Timofte, D. R. Isherwood, J. M. Brown, J. M. Williams, K. Sherlock, M. J. Lehane, R. D. Murray, R. J. Birtles, C. A. Hart, and S. D. Carter. 2012. Host and environmental reservoirs of infection for bovine digital dermatitis treponemes. Veterinary Microbiology 156(1-2):102-109.

Fairchild, T. P., B. J. Mc Arthur, J. H. Moore, and W. E. Hylton. 1982. Coliform counts in various bedding materials. Journal of Dairy Science 65:1029-1035.

Fangueiro, D., J. Coutinho, D. Chadwick, N. Moreira, and H. Trindade. 2008. Effect of Cattle Slurry Separation on Greenhouse Gas and Ammonia Emissions during Storage. Journal of environmental quality 37(6):2322-2331.

Fayer, R. 1980. Epidemiology of protozoan infections: The coccidia. Veterinary Parasitology 6(1–3):75-103.

Feiken, M. and W. van Laarhoven. 2012. Verslag van een praktijkonderzoek naar het gebruik van vaste fractie uit gescheiden mest als boxbeddingsmateriaal in ligboxen voor melkvee (Report of a practical study on the use of the solid fraction of separated manure as bedding in cubicles for dairy cattle) (In Dutch). Valacon Dairy.

Fine, A.E, C A Bolin, J C. Gardiner,4 and J B. Kaneene 2011 A study of the persistence of Mycobacterium bovis in the environment under natural weather conditions in Michigan, USA. Vet Med Int. 2011; 2011: 765430. Published online Apr 26, 2011. doi: 10.4061/2011/765430

Finn, S., J. C. D. Hinton, P. McClure, A. Amezquita, M. Martins, and S. Fanning. 2013. Phenotypic Characterization of Salmonella Isolated from Food Production Environments Associated with Low-Water Activity Foods. Journal of Food Protection 76(9):1488-1499.

Flachowsky, G. and A. Hennig. 1990. Composition and digestibility of untreated and chemically treated animal excreta for ruminants - a review. Biological Wastes 31(1):17-36.

Franz, E. 2007. Ecology and risk assessment of E. coli O157:H7 and Salmonella Typhimurium in the primary production chain of lettuce. Page 216. Wageningen Universiteit (Wageningen University), Wageningen.

Fulwider, W. K., T. Grandin, D. J. Garrick, T. E. Engle, W. D. Lamm, N. L. Dalsted, and B. E. Rollin. 2007. Influence of free-stall base on tarsal joint lesions and hygiene in dairy cows. Journal of Dairy Science 90(7):3559-3566.

Godden, S., R. Bey, K. Lorch, R. Farnsworth, and P. Rapnicki. 2008. Ability of organic and inorganic bedding materials to promote growth of rnvironmental bacteria. Journal of Dairy Science 91(1):151-159.

Gooch, R C., J. Hogan, N. Glazier, and R. Noble. 2006. Use of post-digested separated manure solids as freestall bedding: a case study. Pages 151-160 in Proc. NMC Annual Meeting Proceedings.

Green, M. 2013. Dried manure solids as a bedding material for dairy cows. Veterinary Record. 172(26):690-691.

Grewal, S. K., S. Rajeev, S. Sreevatsan, and F. C. Michel, Jr. 2006. Persistence of Mycobacterium avium subsp. paratuberculosis and other zoonotic pathogens during simulated composting, manure packing, and liquid storage of dairy manure. Applied and Environmental Microbiology; 2006. 72(1):565-574

Guatteo, R., F. Beaudeau, M. Berri, A. Rodolakis, A. Joly ,and H. Seegers (2007). Shedding routes of Coxiella burnetii in dairy cows: implications for detection and control. Veterinary Research 37, 827-833.

Harrison, E., J. Bonhotal, M. Schwarz. 2008. Using manure solids as bedding. Cornell Waste Management Institute. Ithaca, NY. (http://cwmi.css.cornell.edu/bedding.htm)

Hartley, L. 2013. Potential benefits and risks of green bedding. Farmers Guardian 23 Nov 2013 p 21.

Hippen, A, A. Garcia, W. Hammink, L. Smith (2007) Comfort and hygiene of dairy cows lying on bedding: limestone vs. separated solids Proc 6th International Dairy housing Conference, Minneapolis. pp27 – 33

Hjorth, M., K. V. Christensen, M. L. Christensen, and S. G. Sommer (2010), Solid-liquid separation of animal slurry in theory and practice. A review, Agronomy for Sustainable Development, 30(1), 153-180

Hogan, J. and K. L. Smith. 2012. Managing Environmental Mastitis. Veterinary Clinics of North America-Food Animal Practice 28(2):217

Hogan, J. S., V. L. Bogacz, L. M. Thompson, S. Romig, P. S. Schoenberger, W. P. Weiss, and K. L. Smith. 1999. Bacterial counts associated with sawdust and recycled manure bedding treated with commercial conditioners. Journal of Dairy Science 82(8):1690-1695.

Hogan, J. S., K. L. Smith, K. H. Hoblet, D. A. Todhunter, P. S. Schoenberger, W. D. Hueston, D. E. Pritchard, G. L. Bowman, L. E. Heider, B. L. Brockett, and H. R. Conrad. 1989. Bacterial counts in bedding materials used on nine commercial dairies. Journal of Dairy Science 72(1):250-258.

House, H 2012 Bedding alternatives http://www.omafra.gov.on.ca/english/livestock/dairy/facts/info_beddingalternative.htm accessed 1 March 2014

Husfeldt, A. W. and M. I. Endres. 2012. Association between stall surface and some animal welfare measurements in freestall dairy herds using recycled manure solids for bedding. Journal of Dairy Science 95(10):5626-5634.

Husfeldt, A. W., M. I. Endres, J. A. Salfer, and K. A. Janni. 2012. Management and characteristics of recycled manure solids used for bedding in Midwest freestall dairy herds. Journal of Dairy Science 95(4):2195-2203.

Hutchison, M. L., F. A. Nicholson, K. Smith, W. C. Keevil, and T. Moore. 2000. A study of on-farm manure application to agricultural land and an assessment of the risk of pathogen transfer into the food chain. In MAFF report FS2526. Ministry of Agriculture, Fisheries and Food, London UK.

Hutchison, M. L., L. D. Walters, S. M. Avery, B. A. Synge, and A. Moore. 2004. Levels of zoonotic agents in British livestock manures. Letters in Applied Microbiology 39(2):207-214.

Ibekwe, A. M. and C. M. Grieve. 2003. Detection and quantification of Escherichia coli O157:H7 in environmental samples by real-time PCR. Journal of Applied Microbiology 94(3):421-431.

Karatzas, K. A. G., M. A. Webber, L. J. V. Piddockl, M. J. Woodward, and T. J. Humphrey. 2006. Disinfectants and multiple antibiotic resistance in Salmonella enterica serovar typhimuriurn strain SL1344. Abstracts of the General Meeting of the American Society for Microbiology 106:9-9.

Kearney, T. E., M. J. Larkin, J. P. Frost, and P. N. Levett. 1993. Survival of pathogenic bacteria during mesophilic anaerobic digestion of animal waste. Journal of Applied Bacteriology 75(3):215-219.

Kearney, T. E., M. J. Larkin, and P. N. Levett. 1993. The effect of slurry storage and anaerobic digestion on survival of pathogenic bacteria. Journal of Applied Bacteriology 74(1):86-93.

Kersh, G. J., K. A. Fitzpatrick, J. S. Self, R. A. Priestley, A. J. Kelly, R. R. Lash, N. Marsden-Haug, R. J. Nett, A. Bjork, R. F. Massung, and A. D. Anderson. 2013. Presence and persistence of Coxiella burnetii in the environments of goat farms associated with a Q fever outbreak. Appl Environ Microbiol 79(5):1697-1703.

Keys, J. E., L. W. Smith, and B. T. Weinland. 1976. Response of dairy cattle given a free choice of free stall location and 3 bedding materials. Journal of Dairy Science 59(6):1157-1162.

Kramer J. M. & Gilbert R.J. 1989. Bacillus cereus and other Bacillus species. Pp 21-70 in Foodborne Bacterial Pathogens. M.P. Doyle, Ed Marcel Dekker, New York.

Kristula, M. A., W. Rogers, J. S. Hogan, and M. Sabo. 2005. Comparison of bacteria populations in clean and recycled sand used for bedding in dairy facilities. Journal of Dairy Science 88(12):4317-4325.

Leggett HC, C. C., West SA. 2012 doi:10.1371/journal.ppat.1002512. Mechanisms of Pathogenesis, Infective Dose and Virulence in Human Parasites. PLoS Pathogens 8(2):: e1002512.

Liebsich, A., S. Olbriche, M. Deppe (1985). Survival of *P. ovis, P cuniculi, C bovis* when separated from the host animal. Deutsche Tierarztliche Wochenschrift 92, 165-204.

Rentdorff, R. C. 1954. The experimental transmission of human protozoan parasites. II. Giardia lamblia cysts given in capsules. . American Journal of Hygiene 59:209-220.

Lombard, J. E., C. B. Tucker, M. A. G. von Keyserlingk, C. A. Kopral, and D. M. Weary. 2010. Associations between cow hygiene, hock injuries, and free stall usage on US dairy farms. Journal of Dairy Science 93(10):4668-4676.

Lopez-Benavides, M. G., J. H. Williamson, and R. T. Cursons. 2005. Associations between Streptococus uberis populations on farm races and climatic conditions during a twelve-month period. Pages 153-156 in Proc. New Zealand Society of Animal Production.

Magnusson, M., A. Christiansson, and B. Svensson. 2007. Bacillus cereus spores during housing of dairy cows: Factors affecting contamination of raw milk. Journal of Dairy Science 90(6):2745-2754.

Magnusson, M., B. Svensson, C. Kolstrup, and A. Christiansson. 2007. Bacillus cereus in free-stall bedding. Journal of Dairy Science 90(12):5473-5482.

Marques, S., E. Silva, J. Carvalheira, and G. Thompson. 2010. In Vitro Susceptibility of Prototheca to pH and Salt Concentration. Mycopathologia 169(4):297-302.

McCarthy, G., P. G. Lawlor, M. Gutierrez, and G. E. Gardiner. 2013. Assessing the biosafety risks of pig manure for use as a feedstock for composting. Science of The Total Environment 463-464:712-719.

Menzies, F. D. and S. D. Neill. 2000. Cattle-to-cattle transmission of bovine tuberculosis. Veterinary Journal 160:92-106.

Meyer, D. J., L. Timms, L. Moody, and R. Burns. 2007. Recycling digested manure solids for dairies. in Sixth International Dairy Housing Conference Proceedings. Minneapolis.

Misselbrook, T. H. and J. M. Powell. 2005. Influence of bedding material on ammonia emissions from cattle excreta. Journal of Dairy Science 88(12):4304-4312.

Mohaibes, M. and H. Heinonen-Tanski. 2004. Aerobic thermophilic treatment of farm slurry and food wastes. Bioresource Technology 95(3):245-254.

Monteith, H. D., E. E. Shannon, and J. B. Derbyshire. 1986. The inactivation of a bovine enterovirus and a bovine parvovirus in cattle manure by anaerobic digestion, heat treatment, gamma irradiation, ensilage and composting. J. Hyg. 97:175.

Neill, S.D., J. Hanna, J.J, O_Brien, R.M. McCracken, R.M., 1988.Excretion of Mycobacterium bovis by experimentally infected cattle. Veterinary Record 123, 340–343.

NRAES (1992) On Farm Compost Handbook" (http://watershedbmps.com/wp-content/uploads/2012/03/01744_FarmCompost.pdf)

DairyCo

Ostrum, P. 2008 Sand and recycled manure: Headaches and train wrecks in the Northeast. Proceedings of the National Mastitis Council 47th Annual Meeting. January 20-23, 2008. New Orleans, Louisiana.

Paduch, J. H., E. Mohr, and V. Kromker. 2013. The association between bedding material and the bacterial counts of Staphylococcus aureus, Streptococcus uberis and coliform bacteria on teat skin and in teat canals in lactating dairy cattle. Journal of Dairy Research 80(2):159-164.

Peeler, E. J., M. J. Green, J. L. Fitzpatrick, K. L. Morgan, and L. E. Green. 2000. Risk factors associated with clinical mastitis in low somatic cell count British dairy herds. Journal of Dairy Science 83(11):2464-2472.

Pell, A. N. 1997. Manure and microbes: Public and animal health problem? Journal of Dairy Science 80(10):2673-2681.

Pronto, J. and K. Gooch. 2009. Anaerobic Digestion at Noblehurst Farms, Inc.: Case Study. Cornell University.

Ramirez-Villaescusa, A. M., G. F. Medley, S. Mason, and L. E. Green. 2010. Risk factors for herd breakdown with bovine tuberculosis in 148 cattle herds in the south west of England. Preventive Veterinary Medicine 95(3/4):224-230.

Reithmeier, P., W. Schaeren, M. Schallibaum, and K. Friedli. 2004. Bacterial load of several lying area surfaces in cubicle housing systems on dairy farms and its influence on milk quality. Milchwissenschaft-Milk Science International 59(1-2):20-24.

Rendos, J. J., R. J. Eberhart, and E. M. Kesler. 1975. Microbial Populations of Teat Ends of Dairy Cows, and Bedding Materials1. Journal of dairy science 58(10):1492-1500.

Rentdorff, R. C. 1954. The experimental transmission of human protozoan parasites. II. Giardia lamblia cysts given in capsules. . American Journal of Hygiene 59:209-220.

Sarre, C., K. De Bleecker, P. Deprez, B. Levecke, J. Charlier, J. Vercruysse, and E. Claerebout. 2012. Risk factors for Psoroptes ovis mange on Belgian Blue farms in Northern Belgium. Veterinary Parasitology 190(1-2):216-221.

Schwartz, M., J. Bonhotal, and A. E. Staehr. 2010. Use of Dried Manure Solids as Bedding For Dairy Cows and “How frequently should stalls be refreshed with new bedding”: Case Study. Cornell Waste Management Institute. Department of Crop & Soil Sciences Rice Hall • Ithaca, NY 14853.

Schwartz, M., J. Bonhotal, and E. Staehr. 2011. How frequently should stalls be refreshed with new bedding? . Pages 57-58 in Progressive Dairyman. Vol. 1.

Sharma, R., F. J. Larney, J. Chen, L. J. Yanke, M. Morrison, E. Topp, T. A. McAllister, and Z. Yu. 2009. Selected antimicrobial resistance during composting of manure from cattle administered sub-therapeutic antimicrobials. Journal of environmental quality 38(2):567-575.

Sheff, B. and T. VanAken. 2009. Options for Post Digestion Management of Effluent and Solids. 2009 Bioenergy Engineering Conference.

Smith, K. and J. Hogan. 2006. Bedding counts in manure solids. Pages 161-167 in Proc. National Mastitis Council Annual Meeting.

Sommer, S. G., Friis, E., Bach, A. and Schjorring, J.K. 1997. Ammonia volatilization from pig slurry applied with trail hoses or broad-spread to winter wheat: Effects of crop developmental stage, microclimate, and leaf ammonia absorption. Journal of Environmental Quality 26:1153–1160.

Sorter, D., Kester, H and Hogan, J. 2014. Bacterial counts in recycled manure bedding replaced daily or deep packed in free-stalls. Proc. National Mastitis Annual Meeting 2014. Fort Worth, Texas.

Srivastava, R. and E. Lund. 1980. The stability of bovine parvovirus and its possible use as an indicator for the persistence of enteric viruses. Water Research 14(8):1017-1021.

Stokes, J.,E., 2011. Investigating novel and existing methods of preventing, detecting and treating digital dermatitis in cattle. PhD Thesis, University of Bristol.

Timms, L. 2008 a. Preliminary evaluation of separated manure solids characteristics at a New York dairy. In Iowa State University Animal Industry Report. Vol. A.S. Leaflet R2318.

Timms, L. 2008b. Characteristics and use of separated manure solids (following composting) for dairy freestall bedding, and effects on animal health and performance in an Iowa dairy herd. In Animal Industry Report. Vol. AS 654.

Timms, L. 2008c. Characteristics and use of separated manure solids (following composting) for dairy freestall bedding, and effects on animal health and performance in an Iowa dairy herd. In Iowa State University Animal Industry Report. Vol. A.S. Leaflet R2322.

Todhunter, D.A., Smith, K.L., & Hogan, J.S. (1995). Environmental streptococcal intramammary infections of the bovine mammary gland. Journal of Dairy Science, 78:2366-2374.

Tucker, C. B., D. M. Weary, M. A. G. von Keyserlingk, and K. A. Beauchemin. 2009. Cow comfort in tie-stalls: Increased depth of shavings or straw bedding increases lying time. Journal of Dairy Science 92(6):2684-2690.

van Gastelen, S., B. Westerlaan, D. J. Houwers, and F. J. C. M. van Eerdenburg. 2011. A study on cow comfort and risk for lameness and mastitis in relation to different types of bedding materials. Journal of Dairy Science 94(10):4878-4888.

Wang, L., K. R. Mankin, and G. L. Marchin. 2004. Survival of fecal bacteria in dairy cow manure. Vol. 47(4) American Society of Agricultural Engineers, St Joseph.

Watabe, M., J. R. Rao, T. A. Stewart, J. Xu, B. C. Millar, L. Xiao, C. J. Lowery, J. S. G. Dooley, and J. E. Moore. 2003. Prevalence of bacterial faecal pathogens in separated and unseparated stored pig slurry. Letters in Applied Microbiology 36(4):208-212.

Weary, D. M. and I. Taszkun. 2000. Hock lesions and free-stall design. Journal of Dairy Science 83(4):697-702.

Webber, M. A., K. A. Karatzas, L. P. Randall, N. G. Coldham, T. J. Humphrey, M. J. Woodward, and L. J. V. Piddock. 2007. Biocide Resistance in Salmonella enterica Serovar Typhimurium. Abstracts of the Interscience Conference on Antimicrobial Agents and Chemotherapy 47:87-87.

Whitehead, R. N., T. W. Overton, C. L. Kemp, and M. A. Webber. 2011. Exposure of Salmonella enterica Serovar Typhimurium to High Level Biocide Challenge Can Select Multidrug Resistant Mutants in a Single Step. Plos One 6(7).

Woolhouse and B Charleston 2013. Understanding foot-and-mouth disease virus transmission biology: identification of the indicators of infectiousness. Veterinary Research 44:46.

Zadoks, R. N., H. M. Griffiths, M. A. Munoz, C. Ahlstrom, G. J. Bennett, E. Thomas, and Y. H. Schukken. 2011. Sources of Klebsiella and Raoultella species on dairy farms: Be careful where you walk. Journal of Dairy Science 94(2):1045-1051.

Zambriski, J. A., D. V. Nydam, Z. J. Wilcox, D. D. Bowman, H. O. Mohammed, and J. L. Liotta. 2013. Cryptosporidium parvum: determination of ID50 and the dose-response relationship in experimentally challenged dairy calves. Veterinary Parasitology 197(1/2):104-112.

Zähner, M., J. Schmidtko, S. Schrade, W. Schaeren, and S. Otten. 2009. Alternative Einstreumaterialien in Liegeboxen. Bautagung Raumberg-Gumpenstein 2009:33-38.

DairyCo

Zehner, M. M., R. J. Farnsworth, R. D. Appleman, K. Larntz, and J. A. Springer. 1986. Growth of environmental mastitis pathogens in various bedding materials. Journal of Dairy Science 69:1932-1941.

Zdanowicz, M., J. A. Shelford, C. B. Tucker, D. M. Weary, and M. A. G. von Keyserlingk. 2004. Bacterial populations on teat ends of dairy cows housed in free stalls and bedded with either sand or sawdust. Journal of Dairy Science 87(6):1694-1701.

Zucker, B. A., S. Trojan, and W. Muller. 2000. Airborne gram-negative bacterial flora in animal houses. Journal of Veterinary Medicine Series B-Infectious Diseases and Veterinary Public Health 47(1):37-46.

APPENDICES

1. List of parties contacted for information
2. Information on technology
3. Complete Pathogen Table
4. Tables indicating availability of published information
5. Main literature review
6. Experiences from other countries
7. Tables of risk questions
8. Availability of information to carry out risk assessment

APPENDIX 1: LIST OF PARTIES CONTACTED

Contact	Company	Country (UK unless otherwise stated)
UK consultants and veterinarians		
Neil Blackburn	Kite Consulting	
John Allen	Kite Consulting	
David Levick	Kite Consulting	
Paul Macer	Kite Consulting	
Max Sealy	Farm Consultancy Group	
William Waterfield	Farm Consultancy Group	
Chris Coxon	Farm Consultancy Group	
Jonathan Statham	Vet/BCVA	
Roger Blowey	Vet	
European Veterinarians		
Nathalie Bareille		France
Sarne Devlieghe		Belgium
Andrew Biggs		
Dimitrio Herrera		Spain
Martina Hoedemaker		Germany
Reglindis Huber		Germany
Jørgen Katholm		Denmark
Volker Kroemker		Denmark
Theo Lam		Netherlands
Paolo Moroni		Italy
Luís Pinho		Portugal
Francis Serieys		France
Jantijn Swinkels		Netherlands
Stakeholder group and other stakeholder contacts		
Amanda Ball	Dairy Co	
Brenda Foster	AHVLA	
Christina Papadopoulou	**Defra**	
Daniel Berner	Press Technology	
David Alvis	Independent Consultant	
David Clarke	Red Tractor	
David Cooke	Genus	
David Herbert	Wyvern Business Support Ltd	
David Wenner	GEA	
George Jamieson	NFU Scotland	
Guda Van der Burgt	Defra	
Ian Powell	Dairy Group	
Jenny Gibbons	DairyCo	
John Sharkey	Cow Care Systems	
Luke Ryder	NFU	
Paul Honeyman	AHVLA	
Peter Dawson	DairyUK	
Pinder Gill	Defra	
Ray Keatinge	Dairy Co	
Rob Jackson	Spreadwise	
Tim Hamilton	Kraiburg linked to GEA	
Vicky Porteus	Arla Foods	

Contact	Company	Country (UK unless otherwise stated)
Rob Newberry	NFU	
Widening network		
Martin Squires	The Green Veterinary Surgery	
Dyfrig Williams BVSc MRCVS	Wern Vets	
Joep Driessen	Cow signals user	Netherlands
Thomas Gill	Promar	
Dave Roberts	SRUC	
Jimmy Goldie	SAC Consulting	
Laurence Smith	ORC	
Esther Willems	Merck	
David H Black BVM&S DBR MRCVS	Paragon Veterinary Group	
Researchers		
Willem Koops	Dutch Milk Levy Board	Netherlands
Koos Verloop	WUR	Netherlands
Willem van Laarhoven	Valacon Dairy	Netherlands
Frank Driehuis	NIZO Food Research BV	Netherlands
Ole Kristensen	Knowledge Centre for Agriculture	Denmark
Morten Lindgaard Jensen	Videncentret for Landbrug	Denmark
Marcia Endres	Department of Animal Science,University of Minnesota	USA
Leo Timms		USA
Mary Schwarz	Cornell Waste Management Institute	USA
Prof E Wellington	University of Warwick	
Machinery manufacturers and distributors		
Adrian Tindall	Bauer	
Melzer head office	Bauer	
Tim Hudson	CH4e Limited	
John Hird	Storth Machinery	
David Wenner	GEA Farm Technologies	
Chris Sage	Spreadwise Ltd	
Howard Chantry	Greencrop Irrigation	
Christiane Bürkle	NOCK	Germany
Peter Blackwell	Redlynch Agricultural Engineering Ltd	
Edwin Baker	Tramspread (linked to NOCK)	
Terry Baker	Tramspread	
	CE Projects	
	NC Engineering	
Matthew Moore	Shield Agriculture	
Roger Craig	Shield Agriculture	
	DariTech	

Contact	Company	Country (UK unless otherwise stated)
Tim Hamilton	Kitt Agri UK	
Giles Russell	Midland Slurry Systems Ltd	

APPENDIX 2: INFORMATION ON MACHINERY

Table A2.1: Summary of slurry separating machinery suitable for preparing material for bedding

MANUFACTURER	MODEL	Mode of operation	DM of solids produced	DISTRIBUTOR	Numbers in use in UK
SEPARATORS					
FAN (a subsidiary of Bauer)	3.3-780	Screw Press	max 36%	Spreadwise	The most common. Reported to be about 30 in October 2013
DARITECH	DT 4	Roller Press used with DT360 or DT-X (DTeXternal Separator--adaptable to any type of roller press)	max 35%	Kitt Agri Ltd	One - farmer contacted and interviewed
WAM (WAMGROUP waste water separators)	SEPCOM 260	Screw Press	max 36%	Greencrop Irrigation, Redlynch	One farmer just installing 2/10/13. Not willing to be interviewed
EYS	600 HD 800HD	Screw Press	max 600- 38%, 800- 36%	Storth Machinery	Apparently 6 on farm Oct 2013 but no contacts forthcoming
HOULE	Xpress	Cascading Roller Press	max 34% with modular configuration	GEA Farm technologies	We have not been able to locate any
	Xscrew	Screw Press	not given	GEA Farm technologies	We have not been able to locate any
NOCK	SP254/I	Screw Press	not given	Tramspread	None in the UK yet 27/9/13
CONDITIONING UNITS					
FAN (a subsidiary of Bauer)	Bedding Recovery Unit	FAN screw press separator plus insulated compost drum drier	at least 44%	Tramspread are distributers of the Nock Slurry Separator and FAN Bedding Recovery Unit (a Press Screw Separator) that includes an aerobic process that sanitises and dries the solids.	1 FAN BRU in UK. Farmer has been interviewed
DARITECH	Bedding Master	Heat Composting unit	not given		We are not aware of any units in the UK

DairyCo

Brochures of relevant technology can be found at the following links, accessed 17/2/14

FAN separator

http://www.spreadwise.com/FAN%20Separator%20product%20brief.pdf

Daritech – roller press

http://www.daritech.com/categories/manure/separation/DT%20Roller%20Press/RollerPress_Brochure.pdf

WAM separator

http://pdf.directindustry.com/pdf/wamgroup-spa/animal-waste-separator-sepcom/29492-172503.html

http://www.wam.be/Vast_vloeistofafscheiding_van_afval/SEPCOM_Solids_Liquid_Separator.html

EYS Separator

http://www.storthmachinery.co.uk/Slurry-Products-Blog/storth-s-eys-screw-press-separators.html

http://www.storthmachinery.co.uk/Slurry-Products/screw-press-separators.html

Houle Xpress

www.gea-farmtechnologies.com/Images/XPress_LowRes_CA_247643_tcm278-97173.pdf

NOCK separator

http://www.tramspread.co.uk/separators.html

FAN Bedding Recovery Unit

http://www.bauer-technics.com/en/103.bedding-recovery-unit

http://www.tramspread.co.uk/separators2.html

The Bedding Recovery Unit allows further processing after physical separation. It has a drum which heat treats up to 65 °C producing dry matter above 40%.

Contributions from machinery manufacturers

Information from Bauer, manufacturers of the FAN Screw Press and Bedding Recovery Unit

Slurry separators separate out the undigestible fibre in the diet so the higher the digestibility of the diet the lower the amount of solid fraction. Certainly the diet and volume of water, yards and parlour washings being collected affect the operation of the separators and the DM of the bedding produced, but weights and pressure on the machine can be adjusted in order to produce the target DM product.

Most reception pits are fitted with a mixer to present the separator with a consistent input material, which is important for the formation of a consistent output product.

Operations are set on automatic timers for mixing and separation.

Screw presses are best described as a screw auger that forces slurry between a stainless steel through which the liquid passes. Screen maintenance is recommended by monthly removal and power washing. (The EYS Green bedding separator has a reverse auger mode that operates as a self cleaning mechanism).

Current recommendations for DM content come from Bauer experience over hundreds of sites. On the continent generally they look for over 32% DM. Once the DM content exceeds 34%, management of the material on the beds is considered less crucial than when the initial DM content is under 34%

Adrian Tindall, Bauer.

Figure A2.1: FAN screw press

Information regarding the Sepcom Green Bedding machine from Greencrop

Greencrop are the official importer of the Sepcom range of slurry separators, and are delighted to be able to offer the new Sepcom 250 green bedding separator, manufactured by the Italian WAM Group.

The new Sepcom 250 green bedding separator is designed to produce a recycled bedding material from the separated slurry. The benefits of this system give the cows better comfort in the cubicle and help to reduce mastitis levels in the heard, while also reducing bedding costs, The Sepcom 250 has a lower electrical demand than other machines, even though it is fitted with an 9.2kw motor, due to its larger screen area and lower power requirement. The Sepcom 250 will produce bedding with a dry matter content of 33-37 per cent.

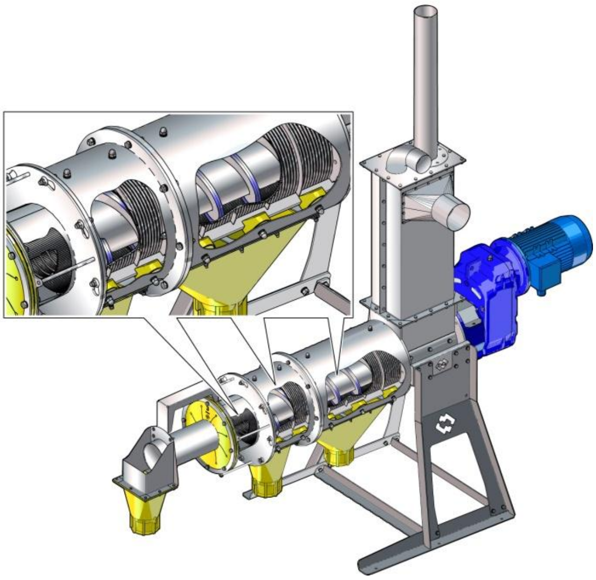
It is fitted with a polymer auger as standard, which has proved itself on other Sepcom separators for its cleaning ability during use. As well as significant advantages in keeping the screens cleaner it aids a higher degree of separation than a steel screw system. The final part of the separation is by a screen mounted in the centre of the solid core, this allows the moisture from the inside of the solids out through the centre, thus not trying to squeeze all of the liquid to the outside

We have found that the green bedding cannot be spread to a depth of more than 75mm, as this then starts to heat up. Also depending on the type of mattress, the bedding can slide off the back easier, so this will determine the depth of bedding. The average depth is around 25 and 50mm. We have also found that the bedding must be used within 24hrs of being produced.

We have one Sepcom unit working in the UK, but the customer is reluctant to be identified as a user of green bedding. Other units are working in France and Italy, 8 in Switzerland and 2 in the Czech Republic.

Howard Chantry
UK Sales Manager
Greencrop Irrigation

Figure A2.2: Sepcom separator



Information on the Daritech Roller Press distributed by Kitt Agri UK.

The Roller press process does not involve any applied pressure, the fibre is initially lifted out of the slurry and then passes through rollers so is not subjected to any pressure as in the screw press. This has two benefits - i) far less electrical power required (a report of 30% of the power used with a previous screw press on one farm) ii) the fibre remains more intact with the roller press and as a consequence cows have even cleaner coats.

In the USA there is a wide variation in slurry that feeds the separators, and hence in the product used as bedding, including variation in its DM. There is also variation in the depth and amount applied. There is no one formula.

Daritech experience in the USA is that the DM of the separated product may not be as critical or important as is claimed by other machinery manufacturers. In USA the material is used for bedding at 30 - 32% DM and this machinery manufacturer does not consider there is any advantage of it being drier. Some anecdotal evidence from the UK is that material at 30%DM out of separator reached 35% after a few hours and 80% DM on beds after a week or more.

Tim Hamilton Kitt Agri UK

Figure A2.3: Daritech Rollerpress

Table A2.2: General guidelines given by machine manufacturers/distributors: guidelines and rationale compared

Guidance	Rationale	Evidence
The material produced needs to be 35% DM	Higher DM content will support less pathogen growth	Evidence for general principle – hard to find evidence for the precise cut-off point – mainly based on field experience
The consistency of slurry presented to the separator is important, and should be consistent.	Action of press depends on the incoming material and consistent action is needed to produce material of consistent dry matter	Experience: farmers reporting problems if slurry is too thick, or not well mixed
The material should not be stored in a heap, but used immediately	Anaerobic conditions will support undesirable microbial growth, generate heat and contribute further to microbial growth	Evidence for general principle. When stored (for how long? In what conditions?) the material does become hot
The material could be spread out thinly to dry further	Evaporation faster from a thinner layer. Aim is to continue to reduce moisture content during use	One farmer was spreading it out in a shed to depth of 6 inches for 24 hours
The material will dry out further once on cubicle beds, if applied in relatively thin layers	Evaporation faster from a thinner layer. Aim is to continue to reduce moisture content during use	Anecdotal evidence, and some figures from van Laanhoven (2012)
The beds need to be well managed – twice daily removal of faeces and wet material	There is organic matter to support microbial growth. Removing further microbial input and moisture will reduce this risk. (important for all bedding)	General principle. Farmer experiences
??what is the best frequency of replenishing? Varying practices are reported		One paper suggests less frequent application is better
Suggested best practice ideas		
The material should be used in well-ventilated, buildings	The material contains more moisture than many bedding materials and there will be evaporation from it as it dries out.	Farmer comment that old buildings are not ideal
The material should not be used in situations with exposure to rainfall	The material can absorb a lot of moisture, so could become heavily saturated if rained on.	Two farmers in high rainfall areas have had some mastitis/scc issues when using the bedding

DairyCo

APPENDIX 3: THE EXHAUSTIVE LIST OF PATHOGENS INITIALLY CONSIDERED
The full references can be found in the reference list provided in the main report. Where it is suggested there is likely to be a 'high' pathogen load and no reference is provided, either this is based on biological plausibility or the pathogen is part of some generic group such as 'coliforms'.

Shortlist	Pathogen	Zoonotic	Likely load in slurry	Reference
Viruses				
	Rinderpest virus	N	Nil	
	Foot and mouth disease virus	N	Nil unless outbreak	Botner 2012
Y	*Bovine Viral Diarrhoea virus*	N	High	Botner 2012
	Bovine Herpes virus 1	N		
	Bovine Herpes virus 2	N		
	Bovine Papilloma virus	N		
	Vesicular stomatitis virus	N		
	Rotavirus	?	High	Hutchison 2000; Pell 1997
	Coronavirus	N	High	
	Respiratory syntical virus	N		
	Parainfluenza virus	N		
	Calici-like virus	N	High	
	Astrovirus	N	High	Pell 1997
	Breda virus	N	High	
	Reovirus	N	High	
	Adenovirus	N	High	Pell 1997
	Enterovirus	N	High	Pell 1997
	Rhinvirus	N		
	Infuenza virus	Y		
Viruses (continued)				
	Cow pox virus	Y		
	Bluetongue virus	N		
	Schmallenberg virus	N		
	Bovine leukosis virus	N		
	Bovine immunodeficiency virus	N		
	Bovine parvovirus	N	High	Pell 1997
	Rift Valley Fever virus	N		Pell 1997
Gram positive bacteria				
Y	*Streptococcus uberis*	N	High	Blowey 2013; Husfeldt 2012
	Coagulase negative staphylococi	N	High	Blowey 2013; Husfeldt 2012
Y	*S. aureus*	Y	High	Blowey 2013; Husfeldt 2012

DairyCo

Shortlist	Pathogen	Zoonotic	Likely load in slurry	Reference
Y	*S. agalactiae*	N		
Y	*S. dysgalactiae*	N		
	Mycobacterium bovis	Y	Variable	Ramirez-Villaescusa 2010
Y	*Streptococcus* spp	Y	High	Blowey 2013; Husfeldt 2012; Hutchison 2000
	Trueperella pyogenes	N		
	Bacillus spp	N	High	Husfeldt 2012; Pell 1997
Y	*Mycobacterium avium subsp. paratuberculosis*	?	High	Grewal 2006; Cempirkova 2007
Gram positive bacteria (continued)				
Y	*Clostridium* spp	N	High	Heinonen-Tanski, Helvi 2006
	Erysipelothrix	Y	High	Huchison 2000; Pell 1997
Y	*Listeria monocytogenes*	Y	High	Cempirkova 2007; Pell 1997; Hutchison 2000
	Aerococcus spp	N		
	Micrococcus spp	N		
	Bacillus anthracis	Y		
	Enterococcus faecium	Y but can be commensal	High	
Gram negative bacteria				
Y	*E. coli*	Y	High	Husfeldt 2012; Blowey 2013; Cempirkova 2007; Hutchison 2000;
	Corynebacterium bovis	N		
Y	*Proteus* spp	N	High	Husfeldt 2012; Blowey 2013; Cempirkova 2007; Hutchison 2000;
Y	*Pseudomonas* spp	N	High	Husfeldt 2012; Blowey 2013; Cempirkova 2007; Hutchison 2000;
Y	*E. coli 0157*	Y	High	Cempirkova 2007; Franz 2007; Ibekwe 2003
Y	*Salmonella* spp	Y	High	Hutchison 2000; Pell 1997;
Gram negative bacteria (continued)				
Y	*Campylobacter* spp	Y	High	Cempirkova 2007; Franz 2007; Pell

Shortlist	Pathogen	Zoonotic	Likely load in slurry	Reference
				1997; Hutchison 2000; Inglis et al 2010
	Fusobacterium necrophorum	N		
Y	*Treponema* spp	N	High	Capion 2013
	Dichelobacter nodosus	N		
	Spirochaetes	N	High	
	Leptospira spp	Y	High	Pell 1997
Y	*Klebsiella* spp	N	High	
Y	*Yernsinia* spp	Y	High	Husfeldt 2012; Blowey 2013; Cempirkova 2007; Hutchison 2000; Pell 1997, Guan & Holley, 2003
	Pasteurella spp	N		Hutchison 2000; Pell 1997; Franz
	Acinetobacter spp	N		
	Neisseria spp	N		
	Chlamydia spp	N		
	Actinobacillus lignierеii	N		
	Haemophilus spp	N		
	Aeromonas spp	N		
	Alcaligenes spp	N		
	Citrobacter spp	N		
	Prevotella melaninogenicus	N		
	Rickettsia spp	N		
Gram negative bacteria (continued)				
	Coxiella burnetii	Y	Moderate unless reproductive materials included	Guatteo et al 2007
	Brucella spp	Y		
Mollicutes				
	Mycoplasma spp	N		
	Ureaplasma spp	N		
Parasites				
Y	*Eimeria* spp	N	High	
	Yeast spp	N		
Y	*Crytosporidium* spp	Y	High	Dixon 2011; Hutchison 2000; Pell 1997; Cempirkova 2007
	Giardia spp	Y	High	Dixon 2011; Hutchison 2000;

Shortlist	Pathogen	Zoonotic	Likely load in slurry	Reference
				Pell 1997; Cempirkova 2007
	Fasciola Hepatica	Y		
Y	*Dictyocaulus* spp	N		
	Ostertagia spp	N		
	Stephanurus dentatus	N		
	Bunostomum phlebotomum	N		
	Haemonchus palcei	N		
	Schistosoma spp	N		
	Paramphistomum spp	N		
	Neospora caninum	N		
Parasites (continued)				
	Toxoplasma gondii	Y		
	Sarcocystis spp	Y		
	Trichomonas fetus	N		
	Ascaris suum	N		
	Strongyloides spp	N		
	Psoroptes ovis	N		
Fungi				
	Aspergillus spp	N		
	Trichophyton verrucosum	Y		
	Absidia spp	N		
	Entomopthora spp	N		
	Mortierella spp	N		
	Mucor spp	N		
	Rhizopus spp	N		
	Rhinosporidium spp	N		
Y	*Candida* spp	N		
	Histoplasma spp	N		
Y	*Prototheca* spp	N	High	Adhikari 2013

DairyCo

APPENDIX 4: TABLES INDICATING AVAILABILITY OF INFORMATION RELATING TO RMS

Table A4.1: Summary of references with information on bacteriology and mastitis related to RMS comparable to that currently used in the UK (ie approx 35% DM, not composted, used in cubicles) The full list of references can be found in the reference list provided in the main report.

Author & country	Location	Bacteria on fresh bedding (units reported)	Bacteria on used bedding (units reported)	Bacteria on teats (swabs)	Bacteria in milk	Clinical mastitis/SCC
Husfeldt et al 2012 USA *	38 commercial farms	cfu/ml	cfu/ml			
Adamski 2011 Poland	University Farm	descriptive				A few months' observations, no concerns
Zehner et al 2009 Switzerland	Swiss farms	cfu/g			Yes	
Zehner 1986 USA *	Laboratory	cfu/g				
Harrison et al 2008, and Schwarz et al 2010	Farms NW USA	log 10 cfu/ml	log 10 cfu/ml	at 3 times of year	Quarter and bulk milk samples	Incidence of mastitis and abnormal SCC
Harrison et al, 2008 USA Cobleskill	Cobleskill Institute Farm	cfu/ml in tables, cfu/g DM in graphs	cfu/ml in tables, cfu/g DM in graphs			
Hippen et al 2007 USA	University Farm	log 10 cfu graphs			yes graph	
Hogan et al 1989 USA *	Commercial dairies		cfu log10/g DM		2 samples/lactn and clinical cases	IMI from clinical cases
Sorter & Hogan USA	??		log cfu/g DM			
Husfeldt & Endres 2012 USA*	Commercial dairy farms					Incidence

* Peer reviewed

Table A4.2: Papers and reports with bacteriology from RMS bedding equivalent to UK (separated with no further processing)

Author	RMS AS UK	Bact on fresh bedding (units reported)	Bact on used bedding (units reported)	Time series of sampling	Bacterial categories
Husfeldt, Endres, Salfer, Janni 2012*	Mech screw press separation of raw manure (n =9) 27% DM before use	300g collected, 50 cm3 tested	300g just before addition of more bedding		Total, *Bacillus* spp, Environmental *Streptococci*, *Stapylococci*, coliforms
Blowey 2013	yes	yes			Numbers on10 g fresh bedding
Biggs 2013	One of these acid treated	yes			
Zehner et al 2009*	"solids from separated manure" 3 farms	yes			For compost and separated manure solids; *Enterococci*, Enterobacteriacae and prop acid bacteria
Harrison et al, 2008 and Schwarz et al 2010	some	log 10 cfu/ml	log 10 cfu/ml	seasonal comparisons	*Streptococcus* spp, *Staphylococcus* spp, *E. coli*, *Klebsiella* spp, *Enterobacter* spp, *Proteus* spp, Gram negative bacteria, Gram positive bacteria, *Corynebacterium* spp, Molds, MAP
Feiken & van Laarhoven 2012	yes	log10/g	log10/g	Days 1,3,6 or 1,6, or 1,7	Total plate count, thermophile and mesophile spore formers, aerobic psychotroph spore formers, *Bacillus cereus*, anaerobic spore-formers, *Streptococci*, *Klebsiella* spp, *E. coli*
Schwarz et al 2010	y1	yes	yes	days 0,1,2,5,6,7	Coliforms, *Klebsiella* spp, *E. coli*
Timms 2008a	1 (but not used as bedding)	log cfu/g			Total, gram -ve , Coliform, Environmental *Streptococci*
Timms 2008b	1	cfu/g	cfu/g	monthly for a year	Total, gram -ve , Coliform, Environmental *Streptococci*, MAP, *Salmonella* spp

* Peer reviewed

Table A4.3: Papers and reports with information on the physical and chemical properties of separated manure solids before and after use as bedding

			Before use							After use					
Author	**Date**	**RMS AS UK**	**DM**	**pH**	**NDF**	**Chem. comp.**	**Fine part.**	**Organic matter**	**Absorbency**	**DM**	**pH**	**NDF**	**Chem comp.**	**Fine part.**	**Organic matter**
Adamski	2011		Y												
Biggs	2013	Y	Y	Y											
Fairchild*	1982		Y	Y						Y	Y				
Feiken & van Laarhoven	2012	Y	Y							Y					
Gooch et al	2006		Y							Y					
Harrison et al	2008		Y	Y		Y		Y		Y	Y		Y		Y
Harrison et al	2010	Y	Y				Y	Y		Y				Y	Y
Hogan et al *	1999		Y	Y						Y	Y				
Husfeldt, Endres, Salfer, Janni*	2012	Y	Y	Y	Y	Y				Y	Y	Y	Y		
Kristula et al*	2005		Y				Y	Y		Y				Y	Y
Misselbrook & Powell*	2005								Y						
Pronto & Gooch	2009		Y	Y		Y		Y							
Schwarz et al	2010	Y	Y				Y			Y				Y	
Timms a	2008	Y	Y												
Timms b	2008	Y	Y							Y					
Timms c	2008		Y							Y					
Zehner*	1986		Y												

DM – dry matter; NDF – neutral detergent fibre; Chem. Comp. – chemical composition; Fine part. – fine particles
* Peer reviewed

Table A4.4 Papers and reports with information on cow health and welfare using RMS bedding

Author	Date	Country	RMS AS UK	Cow clean-liness	Lame-ness	Hocks	Lying times or index	Time to lie down	Cow prefer-ences	Herd turnover	Involunt-ary culls	SCC	Mastitis
Adamski	2011	Poland							Y				
Feiken & van Laarhoven	2012	Netherlands	Y	Y		Y	Y					Y	Y
Gooch et al	2006	USA											
Harrison et al	2008 2010	USA	Y									Y	
Hogan et al *	1989	USA											Y
Husfeldt & Endres *	2012	USA	Y	Y	Y	Y							Y
Keys et al *	1976	USA					Y		Y				
Lombard et al *	2010	USA		Y		Y	Y						
Meyer et al Timms b	2007	USA	Y	Y	Y		Y	Y			Y		Y
Ostrum et al	2008	USA	Y	Y			Y			Y	Y		Y
Schwarz et al	2010	USA	Y										Y
Van Gastelen et al	2011	Netherlands		Y		Y	Y	Y					
Zehner et al	2009	Switzerland	Y			Y							

* Peer reviewed

APPENDIX 5: MAIN LITERATURE REVIEW

This section constitutes a narrative review of the literature directly referring to use of separated RMS as bedding to cattle, largely peer reviewed.

Overview of papers and reports covering use of separated manure solids as bedding in the scientific literature

1. Introduction

This section of the report gives an overview of key peer reviewed papers, conference papers and reports that refer specifically to the use of physically separated manure solids as bedding for dairy cattle, to indicate the availability of directly applicable information. It focuses mainly on the use of physically separated manure solids without further processing, since this is the product currently most widely in use in the UK. In other sections of the report, a broader range of literature which provides conceptual information that is transferable to individual aspects, risks and benefits of using separated manure solids as cattle bedding is referred to. Table 1 indicates the availability of peer reviewed papers directly relating to the use of separated manure solids as bedding. Appendix 4 summarises the content of some of the studies covered in this section (and others) in tabular form.

Table 1 Availability of peer reviewed papers relating to recycled manure solids in the context of use as a bedding material for dairy cattle.

Description of "manure solids"	**No of papers**
Material definitely comparable to UK physically separated	9
Material likely to be comparable to UK physically separated but not clearly described	3
Unspecified "dairy waste solids"	5
Drum composted dairy waste solids	8
Windrow composted dairy waste solids	6
Digested dairy waste	12
Total number of published papers with some reference to Recycled Manure Solids in the context of use as a bedding material	32
Groupings are not mutually exclusive as papers may include more than one type of material	

1.1 Definitions/distinctions of types of recycled manure bedding

In order to focus the literature review, some definitions and boundaries are needed. A search for "recycled manure" casts a wide net, covering a range of methods of processing livestock waste materials. Reports are inconsistent in terms used to describe bedding materials prepared by "recycling manure". It is important to be aware that there are a number of processes which can be applied in the recycling, and the manure may be subject to one or more of these processes. The processes undergone will affect the properties of the material. Clearly distinct processing methods are:

PHYSICAL SEPARATION of liquid slurry

producing “fresh” or “separated” manure solids. Sometimes referred to as “raw” or “green” manure solids, but the term “green bedding” is not used exclusively for this type.
COMPOSTING – of separated solids, or digested solids
- producing “composted manure solids” – defined here as a result of undergoing an aerobic process which generates heat (aerobic conditions being maintained by the introduction of air, usually by frequent turning or disturbance of the material).
ANAEROBIC DIGESTION
producing “digested manure” – defined here as undergoing anaerobic digestion. Unseparated slurry, the solid fraction or the liquid fraction may be used as digester feedstock, with or without supplementary materials. After digestion, the digestate may be further separated, or composted, before use as bedding: “digested manure solids”..
HEAT TREATMENT
producing “heat treated manure solids” – subjected to some external source of heat generated by an energy supply rather than by bacterial activity during composting.
AIR DRYING is a term also found in the literature. This is assumed to mean a process in which forcing air over or through a material, or moving the material by blowing it, increases the rate of evaporation of moisture, but is rarely clearly defined.
Two or more of these processes may be applied before the material is used for bedding. It is important to be aware of the range of processing that is possible, when reading the literature, comparing materials, information and experiences, and transferring concepts.

NB in this introductory focussed review we do not consider the use of “Compost bedded packs”. These provide a deep bed of an organic material (usually sawdust) which is cultivated daily to introduce air. Some principles on which these are based may be referred to in the section on mitigation of risks or effects of housing, but no published papers have been found which refer to use of recycled manure solids in compost bedded packs. There is an anecdotal report of the use of dried manure solids in this way in Spain, in a region with 250 days sunshine per year (D Herrerro, personal communication)

2. Production of bedding material from manure solids

The concept of using “dairy waste solids” as a bedding material developed in the US in the 1970’s. The rise in numbers of housed dairy herds of expanding size increased the scale of waste produced in the form of manure. **Separating the solid and liquid fractions** made handling the materials easier. Menear and Smith (1973) termed the simplest physical separation of solid particles and liquid “dewatering”, and pointed out that this is seldom a complete separation. They reported on composition of material originating from cattle manure following passage through a screw press separator, experimenting with different pressures and flow rates. At the initial setting selected for further measurements, manure entering at 18% DM was dried to 22.4% DM (an increase of 25%) on one passage through the machine. A second passage increased the DM to 27%. It was considered that a similar result might be achieved with a single passage at lower flow rates.
The opportunity for re-using the solid fraction as **bedding material** was explored. The earliest reference found to the use of “recycled manure bedding” in the English language peer reviewed scientific literature is from Keys et al (1976) in America, who studied the occupation of cubicles bedded with “Dewatered manure solids” (29% DM), “Dehydrated manure solids” (81% DM), and sawdust, by cows given free choice between the three types. The next chronological reference is the work of Carroll and Jasper (1978) who described the use of manure solids as bedding on three Californian dairies. The scenarios (see box) are not directly comparable to the current UK situation, since the preparation included composting the material, and the climate was far hotter and drier. * Composting was

introduced in view of the bacterial load of the material. The risk of mastitis from environmental pathogens was recognised, and has been the main focus of the majority of work on RMS, beginning with that of Carroll and Jasper (1978). These authors followed in detail the development of bacterial populations during the composting process. In 2008, Timms (2008a) reported that although material from the solid fraction of manure had been used in the Western United States for over 30 years, this was mainly in “dry lot” dairies in hot dry areas, where high temperatures and low humidity made it easy to maintain the material at a high dry matter content (figures not specified), it had not been successfully used in other regions of the US. At this time, interest was growing in using solid material extracted from the product of anaerobic digestion of manure as bedding, as a way of offsetting the cost of digestion equipment (Timms, 2008). The temperature of the digester is critical since some mesophilic digesters (running at 30 – 38^{o}C) may cause some pathogens to proliferate (Tulloch, personal communication). A wide variety of combinations of the processes of separation, digestion and composting are now practised in the USA (Timms, 2008 a,b,c). Interest in bedding from manure solids has recently grown in Europe (Zaehner et al, 2009; Driehuis, 2012; Feiken & van Laarhoven, 2012). Some farms are incorporating composting (eg in the Netherlands; Driehuis, 2012; Feiken & van Laarhoven, 2012) but this is not currently used in the UK. To date, to our knowledge, no UK farmers are using digestate as a bedding source.

2.1 Physical characteristics of bedding and changes with use

Harrison et al (2008) and Husfeldt et al (2012) describe the differences in physical characteristics between bedding produced by separation, digestion and composting of manure solids. Harrison et al (2008) provide some data on moisture content, organic matter and particle size in used and unused materials and found a range of values within and between types, across farms. Dry matter content of the unused material ranged from 27 to 36%. The “fresh solids” figure was 27 – 33%. Samples taken from the beds show that with use the DM content of the RMS products increases, with the evaporation of moisture as a result of heat from the cow, reaching 40 to 61% DM (40 – 51% for separated solids). Feiken and Van Laarhoven (2012) reported similar figures from the Netherlands. Interestingly, there was no change in the organic matter content of RMS before and after use.

3. Animal health impact

The majority of work investigating the effects of RMS on cow health relates to udder health. As well as mastitis pathogens, levels of *Mycobacterium avium ssp paratuberculosis* (MAP) (Meyer et al, 2007) and *Salmonella* spp (Timms, 2008) have been studied. Despite this heavy emphasis on mastitis, it is interesting to note the opinion of Smith and Hogan (2006) in a non-peer reviewed article: “The potential to recycle mastitis pathogens is of little concern given the fact that the cows themselves are producing huge numbers of coliforms and environmental *Streptococci*/*Enterococci* on a daily basis “. This belief has not resulted in research work on other pathogens, presumably because of the difficulties and expense of culturing organisms other than the common mastitis pathogens. Screening for MAP (Meyer et al, 2007, Harrison et al, 2008;Timms 2008b) and *Salmonella* spp (Meyer et al, 2007;Timms 2008b) in initial slurry source material (Meyer et al, 2007), and bedding prior to use (Harrison et al, 2008; Meyer et al, 2007) has been carried out. Timms (2008) found only one sample positive for *Salmonella* spp among 100 samples taken across three herds.. Although all three herds had MAP in fresh manure, over 90% of digestate samples tested negative for MAP. Pronto and Gooch (2009) provide further evidence that digestion can considerably reduce the load of MAP. Harrison et al (2008) also found relatively few positive samples, although MAP was found to be able to survive digestion and composting.

3.1 Bacterial populations of RMS bedding material

Mastitis pathogens

Early on in the use of RMS bedding, a potential risk to **udder health** was recognised (because of the presence of organic matter largely derived from faecal material, and potentially pathogenic microorganisms) and Carrol & Jasper (1978) give the first reference to **bacteriology**. Their paper provides some information on the bacterial population of freshly separated manure solids, indicating the presence of *E. coli*, *Klebsiella* spp and *Enterobacter* spp. However, the material underwent further processing before being used for bedding. Composting was seen as a possible way of mitigating the risk, by increasing the temperature to a level at which pathogens would not survive. The main conclusion of this paper was that coliforms were present in the separated solids, but composting reduced coliform counts to zero, or close to zero, so that the material was considered safe for bedding. However, it was noted that with suitable conditions of temperature and moisture, when the bedding was used in stalls, coliform numbers could soon increase. Whether this was from a residual population or from further input was not determined. Subsequent papers have provided further evidence for the presence of high levels of coliforms in freshly separated manure solids (eg Timms, 2008a,b; Harrison et al, 2008), their reduction by composting (Timms, 2008c), and the rapid increase in population once the bedding is in use (Timms 2008 a,b; Harrison et al, 2008, Feiken & Van Laarhoven, 2012). Several papers have included comparisons with other bedding materials (eg Harrison et al, 2008; Zaehner et al, 2009). In agreement with Harrison et al (2008), results from Feiken & Van Laarhoven (2012) showed high concentrations of potential mastitis-causing organisms in “fresh” RMS bedding material, which increased with use in the first few days and then plateaued. Zaehner (1986) carried out laboratory studies to provide growth curves for *Klebsiella* spp and *S. uberis* on various bedding types including "recycled dried manure" in lab conditions and came to the conclusion that high bacterial counts in barns are influenced by factors other than type of bedding, but did not identify these factors.

Other pathogens

There are very few papers which report on pathogens other than mastitis pathogens in RMS. The only references found have been to *Mycobacterium avium ssp paratuberculosis* (MAP), responsible for Johne’s Disease (Meyer et al, 2007; Harrison et al, 2008, Timms 2008b; Pronto & Gooch, 2009), and *Salmonella* spp (Meyer et al, 2007; Timms 2008b). From Harrison’s small sample of farms, it appeared that untreated separated solids do not necessarily contain high levels of MAP, but that the pathogen is not necessarily destroyed by digestion or composting. To minimise the risk of transmission it was suggested that RMS should not be used to bed youngstock. Pronto and Gooch (2009) and Timms (2008b) provide some evidence that digestion can considerably reduce the load of MAP.

.The report of Kearney et al (1993) on digestion of slurry from beef cattle covers some further pathogens, although not in the context of using the material as bedding. These authors determined that with mesophilic anaerobic digestion, for *E. coli*, *Salmonella typhimurium* and *Yersinia enterocolitica*, the time taken to reduce the population by 90% (T90) ranged from 0.7 to 0.9 d during batch digestion and 1.1 to 2.5 d during semi-continuous digestion. *Listeria monocytogenes* had a significantly higher mean T90 value during semi-continuous digestion (35.7 d) than batch digestion (12.3 d). Anaerobic digestion had little effect in reducing the viable numbers of *Campylobacter jejuni*.

3.1.1 Implications of these bacterial levels

Bacteriology was further investigated by Bishop et al (1980 and 1981), with comparisons of bacterial populations on bedding and cows’ teats, and in milk, but again using composted

RMS material. Bishop et al (1981) used their findings to challenge the suggestion of Bramley & Neave (1975) * that the new infection rate of coliform mastitis was increased with levels in the bedding exceeding 10^6 cfu/g wet weight of bedding, on the basis that their bedding materials with *E. coli* counts above this level were not associated with higher coliform **levels in milk** than in cows kept on the mats where sampling with swabs indicated a lower *E. coli* population, though it is unclear how such a comparison was validated and statement substantiated.

3.2 Effects of treatment and processing on health risks of manure solids

Although the bacterial load of the initial faecal material feeding into RMS is likely to be high, various stages of processing will alter this.

3.2.1 Physical separation

No reports on the microbial population of raw cattle slurry before and after separation have been found although there are reports on reductions in pig slurry. Physical separation of pig slurry using a centrifugal mechanism resulted in a solid fraction with a ten-fold reduction in *E. coli* and *Enterococci* compared with the initial material (McCarthy et al, 2013). Watabe et al (2003) demonstrated a marked reduction in the prevalence of *Campylobacter* spp and *Salmonella* spp in the solids component of pig slurry separated using a perforated drum screen. An American case study showed that liquid-solid separation of cattle manure digestate resulted in a reduction in the faecal coliform counts from 4000 mpn (most probable number)/g in the whole digestate to 1000 mpn/g in the solid fraction (Pronto & Gooch, 2009). Separation of anaerobically digested pig manure using a belt separator resulted in a numerical reduction in total bacterial numbers, but did not achieve a significant reduction in any specific microorganisms identified in the initial manure.

3.2.2 Effect of change in dry matter content

Many of the practical recommendations for use of RMS are based on the assumption that a reduction in dry matter content will reduce the viability of pathogenic organisms, but there is little peer reviewed work on the direct effect of RMS DM content on pathogen levels. This advice appears to be based on a very general principle. However, it has been pointed out by one researcher in the field of RMS use (van Laarhoven, personal communication) that there is evidence from Magnusson et al (2007) that the reduction in available water capacity needs to be considerable to restrict microbial growth reliably. There is some evidence that *Salmonella* spp. can survive heat better under higher DM conditions (Finn et al 2014).

3.2.3 Change in temperature and composting

Bishop et al (1981) found that bacterial counts decreased in dairy waste solids composted over 14 days and considered the material suitable for bedding. Later work by Husfeldt et al (2012) from a larger survey confirmed this. However, although coliform counts were reduced to zero after composting manure waste, with use they multiplied again, under suitable conditions of moisture and temperature (Carrol and Jasper (1978). These authors did not determine whether this was through survival or external contamination. (NB This was in California and the composted solids were spread “to dry” in a pen inhabited by yearling heifers before being used for cow bedding). Several others report no detectable coliforms in composted material pre-use (e.g Timms, 2008c), but a rapid increase following use (Harrison et al, 2008; Feiken & van Laarhoven, 2012). Although composting unseparated manure in an experimental windrow reaching 55 ^{o}C was effective in reducing MAP to undetectable levels within five days (Bonhotal et al, 2011), Harrison et al (2008) found that composting on farm did not always prevent recovery of MAP at very low levels from separated manure solids. It should be noted that neither composting nor commercial drying (for which machinery is available, heating to 70-75^{o}C) reaches the temperature of 83^{o}C which is needed for optimum microbial control.

3.2.4 Manure solids from anaerobic digestion

There are several reports of the effect on pathogen populations in this type of bedding, which will be dependent on the feedstock and temperature in the digester (Meyer et al, 2007; Timms et al, 2008b; Tulloch et al, 2009). There is a wider body of literature for this processing, relating to manure digestion for energy production in addition to operations utilising the material as bedding, but this is not exhaustively reviewed here. In general bacterial levels are considerably reduced and coliforms often undetectable after digestion (Meyer et al, 2007; Tulloch et al, 2009). However, the temperature in the digester is critical: mesophilic digesters running at temperatures of 30 to 38^{o}C can, theoretically, and in anecdotal experience (Tulloch, personal communication) increase bacterial numbers. With this material, as with others, levels of contamination again increase very rapidly once it is in place on beds. (Meyer et al, 2007; Harrison et al, 2008; Tulloch et al, 2009). Perhaps surprisingly, even mesophilic anaerobic digestion resulted in a significant reduction in the MAP counts of manure from 4000 cfu/g to 50-100 cfu/g (Pronto & Gooch 2009). It is possible that detection methods were not particularly sensitive, since Bonhotal et al (2011) found that, using PCR, MAP could be detected in composted unseparated manure samples which tested negative by culture methods. *E. coli*, *Salmonella typhimurium* and *Yersinia enterocolitica* can be reduced by 90% in 1-3 days of mesophilic anaerobic digestion, *Listeria monocytogenes* in 12-36 days depending on the type of digester. However, aerobic digestion had little effect in reducing the viable numbers of *Campylobacter jejuni* (Kearney et al, 1993).

3.3 Evidence of impact on animal health

As already indicated, the majority of work investigating the effects of RMS on cow health relates to udder health.

3.3.1 Udder health

Findings related to the influence on clinical and subclinical mastitis levels vary in outcome and in quality and type of evidence. In a general overview at the American National Mastitis Conference (NMC) Smith and Hogan (2006) referred to “an elevated incidence of environmental mastitis in many herds that utilize manure solids as bedding (with no numerical evidence provided), and suggested that the material was “a significant risk factor for exposure to environmental pathogens that cause mastitis in dairy herds” However, they pointed out that this was the case for most organic bedding materials. According to Timms (2007a), also in the USA, “an elevated incidence of environmental mastitis” is experienced in some herds using separated manure solids, but “some research shows manure solids can be an appropriate bedding if dried and managed properly”.

There are case studies which report problems attributed to the use of RMS and others where no detrimental effects of changing to RMS are reported. At the National Mastitis Council in 2008 three case studies relating to RMS were presented. Locatelli et al (2008) reported from a large Italian farm where bacterial levels in bedding from separated manure always exceeded 10^{6} cfu/g, with increases during storage. Levels were particularly high during hot and humid weather which corresponded with increased incidence of *E. coli* and *Klebsiella* spp mastitis. In contrast, Buelow (2008) reported from two American farms and failed to find a correlation between bacterial counts in bedding and clinical or subclinical mastitis. Thirdly, Ostrum et al (2008) reported on an unsuccessful experience in New York State upon changing from recycled sand to separated manure solids that were left to heat in a pile, being used within three weeks. On the manure solids, cows were 2.1 times more likely to suffer clinical mastitis, which was 1.3 more times likely to be caused by *Klebsiella* spp, than on the sand system. A small telephone survey of farmers in upper mid-west USA indicated that those using digested manure solids were able to keep bulk milk somatic cell counts (bmSCC) consistently below 250,000 cells/ml while those using separated solids bmSCC exceeded 450,000 cells/ml (Endres et al, 2008). On 34 farms, that included nine using raw solids, with 21 using digestate, and 4 composted material, the average bmSCC was 274,000 cells/ml (+/- 98,000 cells/ml) Husfeldt and Endres (2012). The RMS farms in the study more frequently culled cows for mastitis than the national population of farms did, with mastitis being given as the most common cause of culling, compared with infertility for the national population. Timms (2008b) gives examples of 3 farms using digested and composted solids, where bmSCC fluctuated around 250,000-420,000 cells/ml, 250,000-420,000 cells/ml and 110,000- 480,000 cells/ml respectively, in the first year of using RMS.

Harrison et al (2008) followed the bmSCC patterns of nine farms that converted to RMS (of varying types including fresh, composted and digested) and found that some increased and some decreased after conversion. An attempt was made to compare the change in bulk milk SCC over a seven year period on these farms with the whole state population; these authors' analysis indicated that bmSCC was increasing more rapidly on the RMS farms than in the whole state population, but, since the bedding types in the whole state were not know they were reluctant to draw conclusions. The general conclusion was that there was no consistent impact on SCC of the use of RMS, and an effect on clinical mastitis could not be clearly demonstrated.

Although the concentration of *Klebsiella* spp was higher in RMS than in sawdust, no increased incidence of *Klebsiella* spp-related mastitis or total cases of clinical mastitis was found in three herds converting to RMS, in The Netherlands (Feiken and Van Laarhoven, 2012) (although there are anecdotal reports of some *Klebsiella* spp outbreaks in herds using RMS in the Netherlands).

3.3.2 Other health issues

No detailed studies on any issues apart from udder health have been found. Although MAP and salmonella have been enumerated in bedding samples, no information on the impact on disease has been associated with this. During a two year study of three farms converting to RMS in the Netherlands (comparing the year prior to RMS use with the first year of use), there was no evidence of increased veterinary problems (Feiken & van Laarhoven, 2012). References to effects on lameness are covered in the following section on cow comfort.

3.4 Cow comfort

Seven papers have reported on comfort and welfare aspects of recycled manure solids.

The two published papers reporting cow preferences for recycled manure solids give contrasting results. Keys et al (1976) compared the amount of time cows spent **lying** on a choice of stalls with "Dewatered manure solids" (29% DM), "Dehydrated manure solids" (81% DM), and sawdust at 10 cm depths, finding by far the shortest proportion of time spent lying on the dewatered solids (9 cows with choice between 27 stalls). They speculated that the DM content of the material influenced the cows' choice, since times on sawdust and dehydrated solids were similar. Yet, cows have shown preference for cubicles bedded with "manure separates" (processing undefined) compared to those with straw, sand and sawdust (Adamski, 2011). In a comparison of RMS, straw, sawdust and compost bedded cubicles, cows were no less likely to lie down on RMS (Feiken & van Laarhoven, 2012).

The only published figures for **lameness** on RMS bedding (of various types) report a 95% confidence interval of 13-16% prevalence for deep beds, and 18-22% for mats (Husfeldt & Endres (2012). These figures are relatively similar to those reported in Minnesota by Wells et al (1993) and lower than those reported by vonKeyserlingk et al (2012) for a number of American states, so do not give rise to major concerns for this group of farms as a whole.

From a single within-farm comparison of cows on sand and RMS, Harrison et al (2008) reported a significantly higher level of lameness in the sand group, in cows of lactation 4 and over. However, given the knowledge of build up of chronic lameness over time, this might not be a fair comparison if current lameness status was not a factor considered in allocation of cows to bedding treatments. Timms (2008) commented that “foot and leg health improved” with the introduction of composted RMS but gave no specific information on either the previous bedding material or the absolute levels of lameness. Adamski (2011) commented that the hooves of cattle housed on RMS were dry, which is likely to be beneficial for foot health. Hippen et al (2007) in a conference paper reported no difference in lameness in cows in freestalls bedded with RMS and dolomitic limestone, but conclude that a period of one month on each treatment in a “switchback” design was a relatively short period in which to detect changes.

One American 4000 cow farm which changed from sand to DMS experienced an increase in foot and leg injuries, attributed to the loss of sand particles that had improved grip in the alleyways (Ostrum et al, 2008).

The **hock lesion** prevalence of 45-53% for deep beds and 63-72% for mattresses reported by Husfeldt & Endres (2012), and 41% on deep RMS beds by Zaehner et al (2011) suggests that the material, as used on these farms, does not overcome the problem of hock lesions, although these prevalences are lower than some reported for mats and sawdust (Weary & Taszkun, 2000; Fulwider et al, 2006). Perhaps surprisingly, given the qualities of the material, these figures are higher than those reported by Weary & Taszkun, (2000), and Fulwider et al (2006) for cows on deep sand. Husfeldt & Endres considered that this might be as a result of the RMS being more easily compressed than sand and more likely to expose the “heelstone” of the cubicle bed, to come into contact with the cow. Again, perhaps surprisingly, Lombard et al (2010) reported a higher prevalence of severe hock lesions in cows bedded on dry or composted RMS compared with sand, straw and sawdust, in a study of 491 dairies. Thus it appears that although RMS has advantages for hocks over mats with or without sawdust or straw (Zaehner et al, 2011), or dolomitic limestone (Hippen et al, 2007), it does not protect totally against hock lesions, at least in some circumstances.

Cow **cleanliness** was assessed in a comparison including RMS by Hippen et al, (2007) who reported a trend for cleaner cows than on dolomitic limestone. Timms (2007) reported an “improvement” in cleanliness on RMS from a previous, unspecified bedding material. Feiken & vanLaarhoven, (2012) found cows on RMS to be slightly more dirty than those bedded on sawdust and wheat straw, but cleaner than those on compost.

4. Bedding management

There are a relatively small number of studies which provide information on aspects of management of RMS bedding.

4.1 Storage of material

In general the current UK advice is that separated bedding material should be used immediately, to avoid heating and causing conditions that encourage growth of pathogens. One paper with conflicting findings refers to solids recovered from digested manure: Gooch et al (2006) measured lower levels of environmental mastitis pathogens from digested material that had been “stockpiled” (for an unspecified time) compared with freshly separated digestate.

Sharkey et al (2010) report on the use of “SOP C COW”, a commercial powder that “combats replication of environmental pathogenic bacteria”, on separated heat-treated RMS when it was stored in a pile. *Streptococci* reduced over seven days equally in both treated and untreated material while the decline in *Klebsiella* spp occurred more rapidly and was more marked with the treatment.

Small increases in DM content achieved by blowing the material or storing it under cover did not result in any difference in bacterial population (Husfeldt et al 2012),.
One large Iowa dairy discontinued use of digested and composted RMS due to variability of the material in the absence of undercover composting and storage facilities (Timms, 2008c).

4.2 Types of beds where RMS is used

The earliest use of dried manure solids was in open feed lots in the Western USA (Timms, 2008a), but this is not comparable to the conditions and practices prevailing in the UK. RMS may be used as a thin layer on cubicle mats, or as a deeper layer, the former reaching a higher DM content (Harrison et al, 2008; Husfeldt et al, 2012). As would be expected, the deeper layer was found to provide better cow comfort and lower incidence of hock lesions (Husfeldt & Endres, 2012). On some American farms, deep beds are regularly cultivated mechanically so that the composting process continues during, as well as prior to use (Timms, 2008c). No published reports on the use of RMS in loose housing have been found.

4.3 Attempts to reduce bacterial load when bedding is in use

4.3.1 Conditioners

The addition of “conditioners” to alter the pH of bedding materials is sometimes recommended for control of microbial populations. However, effects are usually short-lived, in the range of 24- 48 hours (Hippen et al 2007). Hogan et al (1999) included RMS as a substrate in an experiment testing the effect of “bedding conditioners” aiming to reduce bacterial load. Specifically for “raw” RMS, these authors reported that, although both acid and alkali conditioners reduced bacterial populations in unused material, only the alkali conditioner and hydrated lime inhibited bacteria in used bedding, and only for one day; use of an acid conditioner had little effect on bacteria in bedding. Feiken and van Laarhoven (2012) added lime and a proprietary alkali conditioner to RMS and found that the resulting pH change was not sufficient to alter the bacterial population effectively.

4.3.2 Frequency of bedding

In general, frequent bedding with any material is recommended for maintaining good cow hygiene. This is based on the fact that pathogen levels rise during 24-48 hours after fresh bedding of many types is applied to cubicles (Gooch et al, 2006; Harrison et al, 2008). Gooch et al (2006) advocated frequent bedding for digestate solids. However, several authors report that pathogen levels reach a plateau or even peak at 24-48 hours after fresh material has been applied, when various types of RMS are used. Schwarz et al (2010) found lower pathogen levels when stalls were bedded weekly compared with daily. With the capacity of RMS to dry out further when applied to beds in thin layers (Gooch et al, 2006, Feiken & van Laarhoven, 2012) there might be some argument for less frequent addition, to maintain a lower DM content. Schwarz et al (2010) compared daily and weekly addition of RMS to deep bedded stalls, on two commercial farms. It was concluded that daily bedding did not necessarily improve bacterial levels, milk quality or mastitis, compared with weekly bedding. The number of mastitis events on each farm was very low (1.35 and 3.5% prevalence in the whole herd over the period studied respectively) and unrelated to bedding frequency. However, Feiken & van Laarhoven (2012) considered that the main advantage of the material drying out in the cubicle beds, from an initial 29-31 % DM to between 45 and 62 % was that it was less likely to stick to the cows and contaminate milk; bacterial numbers were not reduced. The change in DM content was not considered sufficient to restrict bacterial development, based on the findings of Magnusson et al (2007). Sorter et al (2014) reported a tenfold reduction in Klebsiella counts as a result of completely replacing all bedding from the back third of deep bedded stalls daily.

5. Does RMS-based bedding present any greater bacterial risk than other bedding types?

Zehner et al (1986) concluded from laboratory studies that high bacterial counts in bedding were influenced by factors other than the type of bedding. Smith and Hogan (2006) commented that RMS was “a significant risk factor for exposure to environmental pathogens that cause mastitis in dairy herds” but pointed out that this was the case for most organic bedding materials. Harrison et al (2008) came to the conclusion that the management of bedding was more important in controlling microbial populations than the type of bedding per se, since bacterial numbers on different bedding types on the same farm converged very quickly.

6. Food quality

The main concern for food quality related to RMS identified to date is the risk of elevated levels of spore forming bacteria (eg *Bacillus cereus*), yeasts and moulds in composted material. In The Netherlands use of separated RMS is growing, as is the use of compost from a variety of source materials (including treated municipal bio-waste and horse manure). With concerns about new risks for food quality and safety and animal health, two reports have been published recently with a large emphasis on the influence of bedding on spore-forming bacteria and implications for product quality (Driehus, 2012; Feiken & van Laarhoven, 2012). Findings relevant to the use of raw separated manure solids were the higher concentrations of spores of *Bacillus cereus* and butyric acid bacteria in RMS than in sawdust, suggesting an increased risk of food spoilage, although the levels of these specific spores in milk were not quantified for dried manure bedding (Driehus et al, 2012). It is likely that levels in milk will be elevated, since in farms bedding with composted materials, higher levels of mesophilic and thermophilic spore-forming bacteria in bedding were reflected in higher levels of their spores in bulk tank milk. Zähner et al (2009) also expressed some reservations about the suitability of RMS as a bedding material for cheese producing farms, because of levels of aerobic mesophiles in the milk (5800 to 7200 cfu/ml, depending on farm and season).

7. Human health

There is little direct research relating use of RMS to human health. None of the surveys have asked about effects on staff. Driehus et al (2012) outlined the theoretical risk that pathogens transmitted in faeces, including zoonotic organisms, could accumulate in cattle manure solids with repeated recycling, leading to a higher infection pressure, but had no evidence to show whether this occurred in practice.

8. Conclusions

In summary, the peer reviewed literature includes no papers on the UK use of RMS, and a limited number that refer to the type of separated solids, with no further processing, that are currently in use in the UK. Most papers refer to work with composted or digested material, which will have different initial microbiology and this should be borne in mind when extrapolating results. The climatic conditions of many locations of published papers also differ from those in the UK.

There is a lack of information on the effects of physical separation on the microbiology of cattle slurry. The microbiology of the bedding material has been relatively well studied at the level of groups of bacteria, and demonstrates that there is quite a high bacterial load, although similarly high levels can be found in other types of “fresh” bedding in some circumstances. However, the difference between bacterial load on different types of bedding material narrows rapidly with use. Lack of standardisation in sampling methods (particularly for used bedding) and units used for reporting, restrict the extent to which the results of studies can be compared directly. There is no information on organisms other than bacteria.

In terms of management of the bedding material, there is little scientific support for the anecdotally recommended figures quoted for optimum dry matter of the initial material; studies have shown that this alters rapidly with use. This could be taken to suggest that the initial dry matter is immaterial, but since practical experience indicates that there can be udder health problems with wetter “fresh” bedding, this area might be worthy of further investigation. Scientific evidence for optimum management, eg in terms of bedding frequency, aeration and replacement, is limited and sometimes conflicting.

The literature gives less evidence for the scale of absolute welfare benefits specifically attributable to RMS than might be expected from anecdotal reports, but there are definitely advantages in terms of comfort compared with abrasive materials on mattresses.

There is relatively little information on cattle health consequences. The only disease studied in depth has been mastitis and only Harrison et al (2008) in an unpublished report, have attempted to evaluate all stages of the complete pathway from bedding bacteriology to clinical or subclinical outcomes. Epidemiological studies have been relatively small and control groups difficult to define. There have been some small controlled trials using the bedding indicating varying effects on udder health but these necessarily provide information only on short term effects. We have found no reports in the peer reviewed literature or conference proceedings on youngstock health, diseases other than mastitis, or the effect of RMS used for dry cows.

No papers have reported on ultimate consequences for human health although the risk of higher levels of spore forming bacteria in milk has been mentioned.

In terms of environmental influence, the potential for release of higher levels of ammonia than other bedding materials identified in the laboratory has not been translated into a large impact, according to an unpublished study in farm housing conditions.

Thus one must draw the conclusion that there is still a great deal that is unknown about the optimum management, risks and likely impact of RMS used as bedding for dairy cattle.

References

Adamski, M., K. Glowacka, R. Kupczynski, and A. Benski. 2011. Analysis of the possibility of various litter beddings application with special consideration of cattle manure separate. Acta Scientiarum Polonorum - Zootechnica 10(4):5-12.

Bishop, J. R., A. B. Bodine, and J. J. Janzen. 1980. Effect of ambient environments on survival of selected bacterial populations in dairy waste solids. Journal of Dairy Science 63(4):523-525.

Bishop, J. R., J. J. Janzen, A. B. Bodine, C. A. Caldwell, and D. W. Johnson. 1981. Dry waste solids as a possible source of bedding. Journal of Dairy Science 64(4):706-711.

Bonhotal, J., M. Schwarz, and S. M. Stehman. 2011. How Mycobacterium avium paratuberculosis is affected by the composting process. Trends in Animal and Veterinary Sciences 2(1):5-10.

Bramley, A. J. and F. Neave. 1975. Studies on the control of Coliform mastitis in dairy cows. British Veterinary Journal 131:160-169.

Buelow, Kenn. 2008. How to make digested manure solids work in the Midwest. Proceedings of the National Mastitis Council 47th Annual Meeting. January 20-23, 2008. New Orleans

Carroll, E. J. and D. E. Jasper. 1978. Distribution of Enterobaceriaceae in recycled manure bedding on Calfornia dairies. Journal of Dairy Science 61(10):1498-1508.

Driehuis, F., Rademaker, J.L.W., Hoolwerf, J.D., Lucas-van den Bos, H.R., & Wells-Bennik, M.H.J. 2010. Onderzoek naar sporen van Clostridium tyrobutyricum, Clostridium beijerinckii en Paenibacillus in melk, kuilvoer en koemest en verbetering van de bepalingsmethode van boterzuurbacteriesporen. NIZO-Rapport E2010-070.

Dreihus, F., L. van den Bos, and M.H.J Wells-Bennik. 2012. Risks of microbial contaminants of bedding materials: compost, cattle manure solids, horse dung and bedded pack barns. NIZO Report. NIZO Food Research BV, Ede, The Netherlands.

Endres, M. I. 2008. Overview of trends in use of manure solids and compost bedded packs. Pages 136-142 in National Mastitis Conference Annual Meeting Proceedings.

Feiken, M. and W. van Laarhoven. 2012. Verslag van een praktijkonderzoek naar het gebruik van vaste fractie uit gescheiden mest als boxbeddingsmateriaal in ligboxen voor melkvee (Report of a practical study on the use of the solid fraction of separated manure as bedding in cubicles for dairy cattle) (In Dutch). Valacon Dairy.

Finn, S., J. C. D. Hinton, P. McClure, A. Amezquita, M. Martins, and S. Fanning. 2013. Phenotypic characterization of Salmonella isolated from food production environments associated with low-water activity foods. Journal of Food Protection 76(9):1488-1499.

Fulwider, W., T. Grandin, D. Lamm, N. Dalsted, D. Garrick, and B. Rollin. 2006. Hock lesion and hygiene score by stall bed type in commercial US dairy cows. Journal of Animal Science 84:411-411.

Harrison, E., J. Bonhotal, M. Schwarz. 2008. Using manure solids as bedding. Cornell Waste Management Institute. Ithaca, NY. (http://cwmi.css.cornell.edu/bedding.htm

Hogan, J. S., V. L. Bogacz, L. M. Thompson, S. Romig, P. S. Schoenberger, W. P.Weiss, and K. L. Smith. 1999. Bacterial counts associated with sawdust and recycled manure bedding treated with commercial conditioners. Journal of Dairy Science 82(8):1690-1695.

Husfeldt, A. W. and M. I. Endres. 2012. Association between stall surface and some animal welfare measurements in freestall dairy herds using recycled manure solids for bedding. Journal of Dairy Science 95(10):5626-5634.

Husfeldt, A. W., M. I. Endres, J. A. Salfer, and K. A. Janni. 2012. Management and characteristics of recycled manure solids used for bedding in Midwest freestall dairy herds. Journal of Dairy Science 95(4):2195-2203.

Kearney, T. E., M. J. Larkin, and P. N. Levett. 1993. The effect of slurry storage and anaerobic digestion on survival of pathogenic bacteria. The Journal of applied bacteriology 74(1):86-93.

Keys, J. E., L. W. Smith, and B. T. Weinland. 1976. Response of dairy cattle given a free choice of free stall location and 3 bedding materials. Journal of Dairy Science 59(6):1157-1162.

Locatelli, C., L. Scaccabarozzi, A. Casula, F. Gorrieri, A. Harouna, P. Moroni (2008), Manure solids bedding as a source of clinical environmental mastitis. Proc. National Mastitis Council.

Lombard, J. E., C. B. Tucker, M. A. G. von Keyserlingk, C. A. Kopral, and D. M. Weary. 2010. Associations between cow hygiene, hock injuries, and free stall usage on US dairy farms. Journal of Dairy Science 93(10):4668-4676.

Magnusson, M., B. Svensson, C. Kolstrup, and A. Christiansson. 2007. Bacillus cereus in free-stall bedding. Journal of Dairy Science 90(12):5473-5482.

McCarthy, G., P. G. Lawlor, L. Coffey, T. Nolan, M. Gutierrez, and G. E. Gardiner. 2011. An assessment of pathogen removal during composting of the separated solid fraction of pig manure. Bioresource Technology 102(19):9059-9067.

Menear, J R and L W Smith (1973) Dairy cattle manure liquid: solid separation with a screw press. Journal of Animal Science, 36:788-791.

Meyer, D. J., L. Timms, L. Moody, and R. Burns. 2007. Recycling digested manure solids for dairies. in Sixth International Dairy Housing Conference Proceedings. Minneapolis.

Ostrum, P. 2008 Sand and Recycled Manure: Headaches and Train Wrecks in the Northeast. Proceedings of the National Mastitis Council 47th Annual Meeting. January 20-23, 2008. New Orleans, Louisiana.

Pronto, J. and K. Gooch. 2009. Anaerobic Digestion at Noblehurst Farms, Inc.: Case Study. Cornell University.

Schwartz, M., J. Bonhotal, and A. E. Staehr. 2010. Use of Dried Manure Solids as Bedding For Dairy Cows and “How frequently should stalls be refreshed with new bedding”: Case Study. Cornell Waste Management Institute. Department of Crop & Soil Sciences Rice Hall • Ithaca, NY 14853.

Smith L and J Hogan 2006. Bedding counts in manure. Proc. National Mastitis Council. 161-167.

Sorter, D. and J. Hogan. 2013. Klebsiella species counts in bedding of recycled manure solids. IDF Newsletter.

Sorter, D., Kester, H and Hogan, J. 2014. Bacterial counts in recycled manure bedding replaced daily or deep packed in free-stalls. Proc. National Mastitis Annual Meeting 2014. Fort Worth, Texas.

Timms, L. 2008 a. Preliminary evaluation onf separated manure solids characteristics at a New York dairy. in Iowa State University Animal Industry Report. Vol. A.S. Leaflet R2318.

Timms, L. 2008 b. Characteristics and use of separated manure solids (following composting) for dairy freestall bedding, and effects on animal health and performance in an Iowa dairy herd. in Animal Industry Report. Vol. AS 654.

Timms, L. 2008c. Characteristics and use of separated manure solids (following composting) for dairy freestall bedding, and effects on animal health and performance in an Iowa dairy herd. in Iowa State University Animal Industry Report. Vol. A.S. Leaflet R2322.

Tulloch, J., N. O'Boyle, and S. PM. 2009. An investigation into the coliform growth of digested manure solids on a large commercial Michigan dairy. in Proc. Association of American Bovine Practitioners, Omaha, Nebraska.

Tulloch, J., Personal Communication.

von Keyserlingk, M. A., A. Barrientos, K. Ito, E. Galo, and D. M. Weary. 2012. Benchmarking cow comfort on North American freestall dairies: lameness, leg injuries, lying time, facility design, and management for high-producing Holstein dairy cows. J Dairy Sci 95(12):7399-7408.

Watabe, M., J. R. Rao, T. A. Stewart, J. Xu, B. C. Millar, L. Xiao, C. J. Lowery, J. S. G. Dooley, and J. E. Moore. 2003. Prevalence of bacterial faecal pathogens in separated and unseparated stored pig slurry. Letters in Applied Microbiology 36(4):208-212.

Wells, S. J., A. M. Trent, W. E. Marsh, and R. A. Robinson. 1993. Prevalence and severity of lameness in lactating dairy cows in a sample of Minnesota and Wisconsin herds. Journal of the American Veterinary Medical Association 202(1):78-82.

Zähner, M., J. Schmidtko, S. Schrade, W. Schaeren, and S. Otten. 2009. Alternative Einstreumaterialien in Liegeboxen. Bautagung Raumberg-Gumpenstein 2009:33-38.

Zehner, M. M., R. J. Farnsworth, R. D. Appleman, K. Larntz, and J. A. Springer. 1986. Growth of environmental mastitis pathogens in various bedding materials. Journal of Dairy Science 69:1932-1941.

APPENDIX 6: INTERNATIONAL EXPERIENCES

Experiences and anecdotal evidence from a variety of countries have been obtained from contacts made throughout the project. These are summarised here. It should be remembered that climatic conditions and dairy farming systems are rather different in many of these countries from those in the UK.

Denmark

In Denmark the use of RMS is relatively new, and not fully approved by the competent authorities. Around 40 farms in Denmark are using fresh RMS in cubicles, both on mattresses and on deep beds. The typical preparation for RMS in Denmark is with a screw press (*eg* from Vincent (http://www.vincentcorp.com/)), achieving 35-40% DM. No farmers are currently using further drying technology. Neither is there composting of RMS - this would need special approval, because it is not legally permitted to leave the solid lying without a cover more than 24 hours due to impact on ammonia emissions.

The Food and Veterinary Authorities have accepted the practice, with the caveat that no manure from young stock must be recycled, only cow manure. This was decided as it will to some extent ensure a balance with the flora normally found in the adult housing environment. The general opinion of farmers is of very clean cows and extremely good hocks. However, environmental laws require that farms need to comply with a maximum ammonia emission level, to keep their environmental licence. To allow use of recycled manure solid in the cubicles the environmental office requires that this level does not exceed the maximum approved level. Work is currently being carried out by Jensen *et al* at VIDENCENTRET FOR LANDBRUG, testing the ammonia emission levels from the solid, at first in the laboratory and then in a cubicle barn. These ammonia tests showed emissions were higher than the experimental baseline of emissions from straw by 70g ammonia per cubicle per year. However, when compared with the “standard” value assumed for emissions from cattle housed with slatted floor, the experimental values measured from straw and manure solids respectively were only 0.09% higher and 0.64% higher than the theoretical standard, as outlined in the table A6.1 below.

If the ammonia level is converted to nitrogen emissions, the increase in emissions per cow per year as a result of converting from straw to solids will be 57g. This is unlikely to be measurable, and is of a lower order than changes that can be made by altering protein content of the diet. However, until the Environment Office have given feedback on whether these levels are acceptable without some other ammonia reducing equipment, it is unknown whether permission to use RMS will continue in the future. It is possible that permission will be granted at a local municipal level and currently the local authorities are more concerned with factors affecting animal welfare than with ammonia emissions.

Table A6.1: Measurements of ammonia emissions in cubicle accommodation

Bedding material	Measured ammonia emission mg NH_3/cubicle/h	Measured ammonia emission g NH_3/cubicle/year	Standard ammonia-emission g NH_3/cow/year*	Further emission of ammonia measured in experiment compared with standard per cow per year %
Manure solid	9.3	81.6	12.76	0.64
Straw	1.3	11.9	12.76	0.09
Difference	8.0	69.7	0	0.55

* **theoretical value assuming cows on slatted floors**

There have been some problems with severe *Klebsiella* spp mastitis outbreaks on 3 farms. There is some evidence that farms which carry out acidification of their manure (to reduce ammonia emissions) are more prone to such problems, although no firm data are available on this. The acid makes it difficult to use lime or hydrated calcium to give high pH in the bedding material to reduce bacterial growth. There is also anecdotal evidence of sudden deaths due to *Pseudomonas* spp mastitis on a farm using RMS.

Jorgen Katholm

Morten Lindgaard Jensen

VIDENCENTRET FOR LANDBRUG

Agro Food Park 15, Skejby, DK 8200 Århus N

www.vfl.dk

Japan

The use of RMS for bedding dairy cows was seen during a visit to a Japanese dairy farm prior to the IDF conference (personal communication R. Keatinge, DairyCo). The recovered bedding was composted for two and a half months before being reused, with added sawdust as part of the composting process. The composted material was spread in a layer under cover, and turned mechanically to dry out further. Around 30% of the material was reused as bedding; the rest was available as compost to local rice farmers, in exchange for straw.

The Netherlands

High sawdust prices have meant that RMS is increasingly used in The Netherlands. Use of the material at the farm of production is permitted. One rough estimation based on separator sales is that it is used on 400 farms, while another respondent estimated there were 1000 users of the material (a mobile separator may service several farms - see below).

Technology and processing to produce bedding

There are several makes of separator in use in the Netherlands. The first was the Sepcom, there are also “Dodo”, Delaval, DR and Bauer models. There needs to be fibre in the material for the press to work. It may be necessary to put in a “plug” of straw initially to give enough fibre for resistance to build up. The slurry needs to be well mixed so that fibres are well distributed through it. It is more difficult to press if there is less structure, but, equally, if it is too stiff, it may be necessary to add some water. Some farmers have their own separators while others use a contractor who brings a mobile machine and separates enough for a month or so. This is compacted and covered with a plastic sheet. No fermentation occurs since there is no sugar for fermentation but the preservation through exclusion of air seems to result in a relatively stable product. The temperature rises to 75°C for 3-4 days, then falls to 50-55°C. Materials dried to 70-75°C may have reduced microbial populations for 1-2 days, but after this time the advantage is lost. Therefore, researchers consider that this expensive process is not considered worthwhile, except perhaps when initially creating deep beds (see below).

Simply covering without excluding air results in a temperature rise, without anaerobic conditions, and favours the growth of *Bacillus* spp. The bacterial activity during storage breaks down the organic material and the material becomes lumpy, and lumps need to be broken down before use, so storage just under plastic without compacting is not recommended. Composting by building heaps and turning them has been tried, but only 70°C was reached. This did not reduce the total bacterial population, just altered the balance of pathogens present.

DM content

Bedding material starting "fresh" between 29% to 36% DM has been used. One researcher considers that the DM content around this range is not critical (van Laarhoven, personal communication). On the beds, the bedding dries out to reach a DM of 35% in winter and 45% in summer, with no significant effect on bacterial count. However, there is a general opinion that reaching a certain DM content at the time of separation is advisable. Values from 32% to 35 % have been advocated.

Creating deep beds

To create new deep beds, farmers add layers once a week until the required depth is reached. Suggested addition rate is 70 to 100 litres per cubicle per week (approx 25 kg fresh manure fibre). When the ventilation in the building is poor, it takes longer to dry the material. Good ventilation is always important and advice is NEVER to fill up the bed in just one session.

Bed management

It is considered unnecessary to disturb the beds (no raking as in the Spanish approach), as the material remains soft and loose enough to provide comfort. ("Cultivation" of compost beds in the US is carried out because of the physical properties of the compost – the compaction that occurs- rather than in order to alter bacterial populations).

Various types of additive to alter the pH once on the beds have been tried, but none gives a long-lasting effect. Similarly, use by the cow and contact with the lower layers means that the bacterial population in fresh bedding rises again quickly and within 2-3 days the level in upper layers is the same as in the lower layers.

Cow comfort and health

The majority of farmers have positive reports of use. The product is considered to be beneficial for cow comfort and overall not detrimental to udder health if the material and beds are properly managed. However, there are examples of problems:

Two veterinarians have reported "numerous *Klebsiella* spp and *E. coli* mastitis outbreaks related to the use of RMS". Their impression is that it can be a source of environmental mastitis on some farms, whilst it is not in others. This is not surprising since infection pressure is not the only factor affecting mastitis. Success factors are reputed to be reaching at least 32% DM of the separated material, and good ventilation in the housing.

Ongoing research

There is ongoing research by NIZO and Valacon-Dairy into the technical and economic aspects (and public image) of using the solid fraction as a bedding (Dreihuis, 2012; Feiken & van Laarhoven, 2012). This includes the risks to the quality of the milk.

With thanks to:
Joep Driessen
Jantijn Swinkels
Hans Miltenburg.
Willem van Laarhoven

Poland

Following an early publication on the preference of cows for RMS bedding, no further research has been carried out; this material is not popular in Poland.

Maciej Adamski [maciej.adamski@up.wroc.pl]
Instytut Hodowli Zwierząt (Institute of Animal Breeding)
Uniwersitet Przyrodniczy (University of Natural Sciences)
Wroclav

Portugal

There is no legislation or entities working on this subject currently in Portugal and therefore there are no restrictions on its use. We received a report from one dairy where fresh cow

manure is used as bedding. This is a herd of 500 lactating cows kept in pens with different beddings (sawdust, straw, fresh manure) according to their level of production or state of lactation. Fresh cow manures separated using a Bauer press is used as bedding for cubicles with rubber mattresses and also used to be put in cubicles 25cm deep. Since January 2013, due to a high incidence of environmental mastitis (mainly *E. coli*, *Enterobacter* spp and *Klebsiella* spp) in the deep bedded cubicles, the procedure has been changed and fresh cow manure is only used as bedding for the rubber mattress cubicles. The temperature at the surface and deep in the bedding when used in 25cm boxes was constant and optimal for microbial growth. The farm experience is that when manure is compressed and used in the same day for bedding it does not increase the mastitis incidence when compared to using nothing on the rubber mattress. The machinery manufacturer explained that the manure should not be used in beds after the first day of production.
The maintenance procedure includes scraping the cubicles twice or thrice a day according to the number of milkings per day and replacement every other day, with addition of lime.
The cows that lie on this type of bedding (manure and mattress) seem to do very well in terms of well-being, with few hock lesions and an udder and legs hygiene score mainly of 2 in a scale of 4.

Luis Andre Pinho

luisandrepinho@gmail.com

Spain

There are no regulations with respect to the use of RMS as bedding in Spain. We received a report on three large dairies (>500 cows) who have been using fresh manure to bed cubicles for about 18 months. They saw the idea in the US and came back enthusiastic about the reduction in labour and costs.
After separation, the solid part remains for a week in a layer to get it dryer, before use (the region has 250 days of sun per year). One of these farms has mattresses in the cubicles, which they cover these to about ‘2 fingers’ depth. Two farms use it in deep beds where the depth is approx 10cm. On all farms faeces and dirty bedding are removed daily. Cubicles are filled twice per month. If the manure is too wet, sawdust or lime may be mixed in just before bedding is applied to beds. In winter time, with rainy weather, lime or sawdust may be added directly on the cubicle. There is not a “gold standard” or measurement of dry matter content, judgement is based on farmer’s perception. In the deep beds the bedding is “tilled” twice per week with a home made tool joined to the tractor in order to add oxygen to the bedding and compost it.
Cows are dirtier than they were when cubicles were daily bedded with new sawdust, but surprisingly new intramammary infection rate is currently lower than before in those three farms and also they have reduced the monthly mastitis rate. At the farm with mattresses, there has been a dramatic reduction in hock lesions. Farmers are saving around 50% of bedding material cost and labour costs are also reduced.

Demetrio Herrera
Q-LLET SLP

Switzerland

A research project has been carried out comparing financial, labour and cow comfort aspects of different bedding types for cubicles, including RMS - see link below. We have not had any communication regarding the extent or nature of RMS use in commercial Swiss farms

Michael Zähner, Janet Schmidtko, Sabine Schrade, Walter Schaeren, Sonja Otten Alternative Einstreumaterialien in Liegeboxen. In: Bautagung "Technik in der Rinderhaltung, Emissionen, Rahmenbedingungen für die Schweinehaltung". Publ. Lehr- und

Forschungsanstalt für Landwirtschaft, Raumberg-Gumpenstein. 27. und 28. Mai , 2009, 33-38.

USA

The USA is the country where RMS is most widely used for bedding.

Use of RMS in Minnesota - Conversation with Marcia Endres, University of Minnesota 10/12/13 (joint author of papers by Husfeldt et al 2012)

Use of manure solids for bedding in the US

The majority of dairy farmers in California use RMS for bedding. The material dries well in the hot dry conditions. There is less mastitis in cows bedded on RMS in California than in Minnesota, where the climate is damper and it is harder to make the material work well.

Technology and processing

The FAN Bedding Recovery Unit is quite commonly used in USA. The Daritech is apparently selling well in Canada. This is claimed to reach a higher DM product than the FAN, and this is attractive. (no Daritech machines were in place in the farms in the Husfeldt papers).

In the mid-west, RMS leaves the separator at approx 30% DM and dry to at least 50% once on the beds. 60% is preferable and can be achieved, depending on weather and building designs and bed management. Some farms use the material direct, others compost it further *eg* for 7-10 days on a concrete floor under a “hooped barn” with daily turning. Some pass it through a digester before composting. Composting to 50-60 deg C is considered to kill bacteria, but the introduction of air regularly is important. Composting is accelerated in machines that “tumble” the material. Turning is necessary - if the product is just piled and not moved the material becomes anaerobic, and bacterial numbers increase. Despite low numbers of coliforms in composted material, the numbers rise again within 2 days. Therefore Endres questions the value of composting.

Cell counts and mastitis

Unpublished data from the survey of 38 Midwest (including Minnesota) dairy operations showed that, although farms can keep at or below the US cell count limit (700,000 cells/ml) there are more cases of clinical mastitis in herds with RMS than with sand. Data suggests twice as many cases, although the majority are not fatal. However, mortality due to *E. coli* mastitis was 15% for the RMS farms, compared with other published figures of 8% for sand bedded herds.

The median SCC for the 38 herds in the Husfeldt study was 275, lowest 120. There was seasonal variation, as with other bedding materials, with higher SCC in summer months. Marcia considers that it is difficult to achieve a SCC <150,000 cells/ml when utilising RMS.

Marcia gave a recent anecdotal report of SCC increasing with a change to RMS, reducing again on reversion to sawdust.

Risk mitigation: Bed management

The frequency of addition of material to the beds is considered important. Most farmers add fresh material 3 times a week. It is thought that with daily additions the material does not dry out enough, and is more likely to support bacterial growth.

Risk mitigation: Teat preparation

Marcia considers that teat preparation is particularly important with RMS, and may be neglected or reduced because teats look clean. This may contribute to cell count/ mastitis problems on RMS farms. A study of teat preparation and its association with problems on RMS farms could be revealing.

Other diseases

RMS in the study was tested for MAP and only tested positive on 4/45 farms. This was a surprise, as MAP is known to be prevalent. No other diseases have been investigated or monitored for the effect of RMS use.

Public image

Apparently the public image of recycled fibre" as bedding in the US is quite good – producers give tours to the public, who like the idea of recycling.

Experiences with digestate - John Tulloch.

Many US farms now use the solid product resulting from anaerobic digestion of manure as free stall bedding. This has the advantage of improved cow comfort and availability on site. However concerns have been raised about the relationship of this bedding to udder health and milk quality. Some farms use this technology with a low incidence of coliform mastitis and excellent milk quality; while others experience high levels and poor milk quality. Some anecdotal experience suggests that output from mesophilic digesters can cause problems since the operating temperature favours more pathogenic organisms, while the product from thermophilic digesters is "safer".

APPENDIX 7: A SUMMARY OF KEY RISK QUESTIONS, AND THEIR PERCEIVED IMPORTANCE, INCLUDING A NOTE OF THE INFORMATION NEEDED TO ASSESS THE RISK. THE AVAILABILITY OF THIS INFORMATION IS SUMMARISED IN APPENDIX 8.

A7.1 Risk Question: What is the risk to adult cow health of the use of RMS?

Hazards:	Pathogens – those in slurry that survive the processing and storage Physically damaging properties – none identified to date, but some unknown areas. Users report "no dust" but are there other effects on air quality eg humidity? Ammonia – some emerging evidence of slightly higher release than from straw beds, but at a level that is difficult to measure.
Release assessment	Based on knowledge of individual pathogens in slurry, their environmental requirements relative to the conditions in slurry, and processed solids, and the bed created by using the solids. Also on knowledge of physical properties of the material and its effect on the environment in the housing. Unknown possibility of feed contamination via indirect routes – use of equipment? Wildlife vectors?
Exposure assessment:	The most frequently considered exposure pathway is via teat canal. Legs and feet are reported to be cleaner. No reports of ingestion of bedding by adult animals. Possibility of ingestion by self-grooming, but no information on this. The effect of reduced dust should reduce this risk. The probability of increased risk of feed contamination is unknown, but should be minimal if best practice followed. Inhalation- No information on properties of the air when using this bedding, other than anecdotal reports of "no dust".
Consequence assessment:	Quantitative information on links between pathogen levels in bedding and clinical disease is only available for mastitis and this is limited. Assumptions are that higher pathogen load on bedding increases the risk of intramammary infection. A threshold level of 10^5 to 10^6 cfu/g for coliforms is often quoted but this is not from a very broad evidence base and figures are not available for all pathogens Quantifying risk of infection would require knowledge of infective dose for all pathogens, and, for respiratory conditions, more information about effects on air humidity and ammonia For other diseases, no direct information on disease outcomes as a result of RMS use is available.

OVERVIEW: Whilst there is some knowledge with respect to the risk to adult bovine health from the use of RMS as bedding, this is far from complete and there are significant gaps. Further research is unlikely to 'fill' these gaps even in the medium term as the consequences of changed exposure could be quite protracted. However, a pragmatic approach might be that in fact the use of RMS has many similarities with existing management practices, where cattle are in constant contact with fresh manure and slurry, and therefore there is unlikely to be a large impact of the change.

A7.2 Risk Question: What is the risk to youngstock health of the use of RMS?

Hazards:	Pathogens – those in slurry that survive the processing and storage. Physical properties –there are reports of “no dust”, which should be beneficial, but the effects on air humidity in buildings are not known. One anecdotal report that the bedding becomes very wet when used for young calves on milk and is not suitable for this age group. Ammonia – some emerging evidence of slightly higher release than from straw beds, but at a level that is difficult to measure.
Release assessment	Based on knowledge of individual pathogens in slurry, their environmental requirements relative to the conditions in slurry, and processed solids, and the bed created by using the solids. Further information on the effect on air quality required.
Exposure assessment:	Legs and feet are reported to be cleaner. No reports of ingestion by young animals but the material has been infrequently used for youngstock. Possibility of contact with higher atmospheric humidity - not quantified. Use of RMS from adult cows would increase contact of calves with adult pathogens (*eg* MAP).
Consequence assessment:	Pneumonia and enteric diseases can have serious consequences for calves. Recycling slurry from one age group to another will have the implications of contact with an unfamiliar microbial population. If MAP is present in the herd, this is a particular concern for young animals.

OVERVIEW: Whilst there are still significant deficits with respect to our knowledge in the area of youngstock health, it is perhaps possible to make clearer extrapolations than for adult cattle, which therefore necessarily preclude certain practices. For examples, whilst not directly quantifiable, our knowledge of Johne’s Disease epidemiology means that, in the absence of clear evidence to the contrary, it would be unwise to recycle manure from adults to youngstock or to use RMS as bedding in calving areas.

A7.3 Risk Question: What is the risk to farm workers' health of the use of RMS?

Hazards:	Pathogens: Those zoonotic pathogens in slurry that survive the processing and storage. Physically damaging properties: none identified - dust reported to be much lower than for many other bedding materials. Smell reported to "disappear within a few hours". Ammonia release possibly slightly higher than from straw beds.
Release assessment	Based on knowledge of individual pathogens in slurry, their environmental requirements relative to the conditions in slurry, and processed solids, and the bed created by using the solids. Ammonia - some emerging evidence of slightly higher release than from straw beds, but at a level that is difficult to measure.
Exposure assessment:	Oral route - No difference in contact expected compared with other bedding materials Physical contact: Possibly more exposure to slurry based materials than previously, although most parts of the process are mechanised and independent of the use of RMS as bedding. Inhalation – no information on the effect of preparing the bedding (*eg* effects of stirring slurry – possible distribution of pathogens or fine particles in aerosols/droplets), or of the bedding on air quality in buildings, apart from anecdotal reports of "little or no dust".
Consequence assessment:	Occupation-related disease. Depends on pathogen exceeding minimum infective dose (limited information for many organisms) and vulnerability of subject (age, immuno-status).

OVERVIEW: It is perhaps possible to make a more definitive assessment of this risk question, albeit that one would have to make assumptions about potential changes in the number and characteristics of pathogens present in RMS over time (antibiotic resistance is considered elsewhere). Here we consider only the direct impact from the use of RMS as bedding, not that associated with the process of separation of solids from slurry per se, which may occur for reasons other than producing bedding.

There are likely to be both decreased and increased hazards associated with the use of RMS as bedding. The environment is reported as being less dusty which will have clear benefits both in terms of the risk of dust, but also probably the aerosolisation of pathogens which may be subsequently inhaled. However, increased levels of ammonia may compromise the mucociliary apparatus.

There is no direct published evidence of the human health consequences of use of RMS available. There are no anecdotal reports of human health problems.

As with any other bedding materials and close contact with cattle, good personal hygiene and suitable PPE should mitigate any risks.

A7.4 Risk Question: What is the risk to consumers' health of the use of RMS? (pasteurised and unpasteurised products need to be considered separately)

Hazards:	Those zoonotic pathogens in slurry that survive the processing and storage, and use on the beds, and enter milk. Consider separately those that do and do not survive pasteurisation.
Release assessment	Based on knowledge of individual pathogens likely to survive in the bed created by using the solids AND be transferred to milk (and survive pasteurisation and/or any further processing).
Exposure assessment:	Oral route.
Consequence assessment:	Food-borne disease. Depends on pathogen exceeding minimum infective dose (limited information for many organisms) and vulnerability of consumer (age, immuno-status).

OVERVIEW: Pasteurised and unpasteurised milk and milk products will carry different levels of risk, with pasteurisation mitigating most potential increases in risk. Some exceptions could be *B. cereus* and MAP, both of which are relatively resistant to heat at normal pasteurisation temperatures. Any 'breakdown' in the pasteurisation process could have more significant consequences, but this would be as a result of a failure in a control process rather than because of the use of RMS as bedding *per se*.

There is no published direct evidence of the consequences for consumer health.

A sensible strategy would seem to be to insist on pasteurisation of all milk originating from premises on which RMS is used as bedding until evidence proves otherwise. Consumption of raw milk on farm should be discouraged, but even more so in these circumstances.

DairyCo

A7.5 Risk Question: What is the risk to milk quality of the use of RMS?

Hazards:	Those food spoilage micro-organisms that survive in the bedding and reach the milk. Mostly likely are coliforms, thermophilic spore-forming bacteria eg *Bacillus cereus*, yeasts and fungi. Consider separately those that do and do not survive pasteurisation.
Release assessment	Based on knowledge of individual pathogens likely to survive in the bed created by using the solids AND be transferred to milk (and survive pasteurisation and/or further processing).
Consequence assessment:	Consequences for food spoilage/keeping qualities, particularly for specialist and artisan cheeses, but also potentially for fresh pasteurised milk

OVERVIEW: There is some evidence of an increase in the numbers of psychrotrophic and thermoduric bacteria in bulk milk originating from farms using RMS bedding, though no definitive causal link has been established. *Bacillus* spp in particular have been highlighted; these are of particular interest because whilst vegetative forms are relatively easily killed by heat treatment the same is not true of spores, some of which easily escape at normal pasteurisation temperatures (some species will also survive temperatures in excess of 120^{o}C).

This has the potential to impact keeping quality of dairy products and needs to be considered. Some mitigation may be possible by improved pre-milking teat preparation. This area may be of increased importance in small producer-processor units where all (or a large proportion) of the milk is originating from premises where RMS is utilised.

A7.6 Risk Question: What is the risk to the environment of the use of RMS?

Hazards:	Ammonia, nitrates, greenhouse gas emissions
Release assessment	Effects on ammonia release relative to other methods of manure handling – some information available on separation compared with other methods, but none on use of RMS Effects on nitrate leaching from separated slurry compared with whole slurry – some information available Effects on greenhouse gas emissions as a result of slurry separation – some information available, but not specifically in the case of using solids as bedding. Reduction of long distance transport of imported bedding materials will reduce carbon emissions.
Consequence assessment:	Pollution of ground and surface water and greenhouse gas emissions

OVERVIEW: There are potential risks and benefits of the use of RMS from an environmental perspective. In a more comprehensive assessment it would be necessary to investigate further the implications of RMS use as bedding as distinct from those of slurry separation per se, which already occurs for other reasons.

A7.7 Risk Question: What is the risk of increasing antimicrobial resistance of the use of RMS?

Hazards:	Antibiotic resistant micro-organisms and genetic elements
Release assessment	Maintaining micro-organisms in a "closed cycle" by recycling manure might increase the likelihood of resistant organisms multiplying and new resistance developing. Incorporation of milk or excreta from treated animals or disinfectants in slurry used for bedding might increase the risk of resistant micro-organisms or genetic material
Exposure assessment:	Transfer of resistant populations and genetic material within and outside the farm microbiome both via direct contact and via food.
Consequence assessment:	Increasing population of antibiotic resistant pathogens, with potentially serious consequences for animal and human health

OVERVIEW: There is an increasing body of research and evidence exploring the fate and mobility of antimicrobial resistant pathogens and genetic elements. What needs to be established is whether the use of RMS as bedding, or aspects of its preparation (*ie* source materials) increases the prevalence of antimicrobial resistant organisms or genetic material in the farm microbiome.

APPENDIX 8: SUMMARY OF AVAILABILITY OF INFORMATION NEEDED TO CARRY OUT RISK ASSESSMENTS FOR THE USE OF RMS AS BEDDING.

Boundaries of the provision of information for risk assessment.

This part of the study was limited to considering bedding material produced by screw press or roller separators, since this is the current UK practice. The effects of further heating and composting were considered as possible mitigation measures.

Hazards identified.

For animal health, the **potential** hazards associated with use of the bedding material are:
Pathogens:
those that are found in slurry, will survive removal of moisture to approx 35% DM, and could potentially cause infection of cattle through the following routes:

1) Intramammary - via the streak canal
2) Contact with skin (particularly digital dermatitis)
3) Respiratory - pathogens carried on dust particles.
4) Ingestion - the oral route
5) Reproductive – via the reproductive tract and navel

Chemical agents – ammonia
Physical agents – dust, abrasive particles
For human health, the hazards potentially associated with use of the bedding material are:
Pathogens: those that are zoonotic, are found in slurry, and
a) could cause infection of humans through handling or working in the environment where the bedding is produced and used.
b) survive processing of bedding, are transmitted to unpasteurised milk and milk products
c) survive processing of the bedding, could be transmitted to milk/milk products and survive pasteurisation.
Chemical agents – ammonia
Physical agents – dust particles - levels in the environment when bedding is used

For food quality:

Micro-organisms responsible for food spoilage that are present in slurry, survive the separation and could contaminate milk products.

For antibiotic resistance:

Genetic material that conveys antibiotic resistance

Availability of information on the hazards is shown below

Animal pathogens	See Table 5.1 – 5.4
Zoonotic pathogens	See Table 5.5..
Ammonia	See Section 9.1 Ammonia emissions
Dust	See Section 4 Table 4.10 Benefits of bedding from survey
Abrasive particles	See Section 4 Table 4.10 Benefits of bedding from survey
Food spoilage organisms	See Table 5.3 and literature review Section 6
Genetic material conveying antibiotic resistance	Section 5.5

Release assessment

We have defined the release stage as the presence of organisms in the processed material as it is applied to the beds. Sources of this information include some published papers and grey literature (Appendix 4 Table A4.1; Section 7) and information from samples collected as part of our survey (Section 14). Published work has concentrated almost exclusively on mastitis pathogens. Therefore for many other pathogens this information can only be based upon knowledge of the conditions of survival (Table 5.3).
For ammonia and dust the information needed is levels in the environment when bedding is used. Only two sources of information on ammonia have been found (Section 9). No measurements of dust particles have been found but the farmer survey consensus is that dust levels are far lower than when using straw, sawdust, shavings, gypsum and lime.
For genetic material, the information needed is levels of organisms with resistance to antimicrobials and of and genetic material able to convey this property. This is very detailed information. A small amount specifically related to RMS is available (Section 8.5).

Exposure assessment

For livestock we have defined the exposure stage as the stage when cattle come into physical contact with the bedding material. When considering information needed to assess exposure risks we consider the bedding material once it has been applied to the beds.
For farm workers we have defined the exposure stage as beginning with preparation and handling of the bedding material (slurry is handled anyway, even if not used for bedding).
For consumers we have defined the exposure stage as coming into contact with food products produced from animals housed on RMS.

Information required to assess livestock exposure

For pathogens – load on bedding (Section 7 and Section 14), changes as the bedding is used (Section 7 and Section 14), transmission route (Table 5.4 and Section 5.4.1), housing system and conditions in buildings (Survey in Section 4 and literature and "grey literature" Section 9).
For ammonia and dust – release rates and removal rates – dependent on ventilation. Very limited information on ammonia; anecdotal information on dust. (See Section 9).

Information required to assess human exposure in farm workers:

Pathogen load in fresh material (Sections 7 and 14), on bedding (Section 7 and 14) , transmission route (Table 5.5), transfer to air via spores or aerosols; personal protection and hygiene measures.
Ammonia and dust – as above.

Information required to assess human exposure in consumers

Transmission of pathogens from bedding to milk (Section 5.4.3 and Appendix 4 Table A4.1). Survival of organisms in foodstuffs (very dependent on processing). No information directly related to RMS bedding has been found.

Information required to assess exposure to food spoilage organisms:

Minimum damaging contamination level. Some information on the presence of food spoilage organisms in milk in relation to bedding material is given in Section 5.4.4 and Section 6 of literature review.

Information required to assess exposure to antibiotic resistant genetic material:
Relevant information for evaluating this step would include an understanding of the contact between micro-organisms in the slurry being recycled and others in the farm micro-biome. Also understanding of methods of transfer of resistant populations and genetic material within and outside the farm microbiome both via direct contact and via food. This is an area where the underlying concepts are complex.
A critical issue here might be the effect of the “closed cycle” of slurry from storage to housing, rather than the traditional use of slurry and manure involving return to the land, since this affects which organisms will come into contact with each other and with animals. (Section 8.5)

Consequence assessment

Information required to assess consequences of exposure to animal pathogens:

Minimum infective dose (limited information -Table 5.4) and relationship with time of exposure through the route(s) that bedding provides **– gap area.**
Susceptibility of different animal age groups. (could only be based on existing general knowledge of the diseases; no specific information on consequences of RMS bedding for different age groups).
In fact there is no disease consequence information specifically relating to RMS use, with the exception of mastitis and this is limited – see Section 8.2. **– gap area.**

Information required to assess consequences of exposure to zoonotic pathogens:

Minimum infective dose and likely concentration in food – highly dependent on processing, mainly pasteurisation. Limited information on minimum infective dose – Table 5.5.
Disease consequences are considered grouped by transmission pathways in Section 5.4.2. There is no information available that specifically and directly links use of RMS and human health issues.

Information required to assess consequences of exposure to food spoilage organisms:

Minimum damaging contamination level. The reports providing some information on levels of sporeforming bacteria in milk specifically related to RMS use (Section 8.4) did not assess the consequences.

Information required to assess consequences of exposure to genetic material with resistance to antibiotics:

Levels of resistant organisms in situations where RMS is used, and implications for disease control.
The limited amount of information available is given in section 5.5. This relates to slurry not to RMS per se.

GAP ANALYSIS

For most hazards, there are gaps in the information needed for certain stages of the risk assessment. *eg* there is a relatively large amount of information on the levels of pathogens in bedding (and these are very variable) but little strong published evidence on the effect on levels of mastitis. By and large, the greatest gaps are at the stage of consequence assessment. In many cases there is no information directly about the effect of RMS on disease outcomes; it would only be possible to estimate risks based on an understanding of conditions required for pathogen survival, translated to conditions in the bedding, combined with a theoretical understanding of the infection pathways. In many cases there is no information on minimum infective dose.

The gaps are presented in more detail in Section 14 Gap analysis.

Table A8.1: Summarising steps of CAC and OIE frameworks for risk assessment

Hazard Identification	Hazard characterisation	Release assessment	Exposure assessment	Risk characterisation /estimation	Consequence assessment
CAC	CAC		CAC	CAC	CAC
Agent with potential to cause an adverse health effect	Nature of adverse health effect with dose-response information if available		Qual. or quant. evaluation of likely intake of hazards via food or other routes	Qual. or quant. estimate including uncertainty of prob. of occurrence. and severity. of potential health effects	”Risk management should take into account the economic consequences”
OIE as above		OIE: describes biological pathways necessary for release into a particular environement –(ie in slurry and survive processing)-, and estimate of the probability thereof, and how these might change as a result of certain actions/measures	OIE: biological pathways necessary for exposure of humans and animals to the hazard and the probability of this occurring	OIE Uses the term risk estimation.	OIE Describes a causal relationship between specific exposures to a bioogical agent and the conseq’s. – health, economic, environmental. Describes the consequences and estimates the probability of them occurring.

In this study we have aimed to show the information that is available to allow these assessments to be made. However, it was not within our remit to carry out a complete and comprehensive risk assessment and indeed the scoping study has shown that insufficient information is available to conduct a quantitative risk assessment of the practice of using recycled manure solids as bedding material for dairy cows.

DairyCo
Agriculture and Horticulture Development Board
Stoneleigh Park
Kenilworth
Warwickshire
CV8 2TL

T: 024 7669 2051
E: info@dairyco.ahdb.org.uk

www.dairyco.org.uk

DairyCo is a division of the Agriculture and Horticulture Development Board