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2 **Are recycled manure solids an appropriate bedding material**  
3 **for dairy cattle compared to traditional materials?**

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**Abstract:**

This review explores the literature regarding the use of Recycled Manure Solids (RMS) as a bedding material for dairy cattle, in the UK. Recent papers, which used robust statistical analysis of data and were peer reviewed were accessed using commonly available search engines (Pub Med, Google Scholar and Science Direct). The effects of RMS use on cow welfare (particularly lameness and pressure lesions), milk hygiene, the environment and human health are explored. The practice of composting (whether intentional or inadvertent) to produce RMS is prohibited in the UK as the evidence for its benefits is not yet convincing and there are risks of increasing the growth of thermophilic organisms. There are benefits to cow welfare and comfort when RMS is used in cubicle housing. Some data regarding bacterial load and the risks to milk hygiene and human health are promising, in that RMS may be comparable with other bedding materials, but the issues of parlour routine and farm husbandry confound the effects of bacterial load in any chosen bedding. Research to date demonstrates that RMS may have a place in dairy cattle housing, but that the lack of studies, particularly those on a large scale, limits the data available and the ability to draw safe conclusions. There are significant uncertainties regarding associated risks to animal and human health from using recycled manure solids making it difficult to establish whether recycled solids can meet requirements and be deemed as safe to use. A structured review of literature highlighted that the management of the bedding material itself is more important especially regarding diseases and that there are substantial gaps within the research yet to be addressed.

**Introduction:**

Virtually all dairy cows at some point during production are housed, during this period the use of safe, comfortable, dry bedding is imperative for good health and animal welfare. Increased cost and a reduced availability of traditional bedding materials such as sand, straw, and wood shavings has provoked farmers to search for more accessible and sustainable options for example, recycled manure solids (Ball, 2016). The production of recycled manure solids comes from a method first established in the USA in the 1970's and is now being adopted by [some](#) UK dairy farmers (Timms,

34 2008). Physical separation of the solids from liquids in cattle manure through mechanical and  
35 gravitation force, leaves behind a solid fraction consisting of mainly undigested fibres (Leach , et al.,  
36 2015) which can then be processed to produce a suitable bedding material. The act of composting  
37 the material, permitted elsewhere, is prohibited in the UK.

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39 Livestock manures are classed as Category Two Animal By-Products, as defined by EC Regulation  
40 1069/2009 (Ball, 2016). Their use as a 'technical product', for example as animal bedding is only  
41 permitted if strict conditions are applied to minimise potential health risks (Leach , et al., 2015).  
42 Examples include only using recycled manure solids as bedding for cattle which are in the same  
43 epidemiological unit as those cattle from which it is generated and not using recycled manure solids  
44 produced from herds which are subject to official restrictions for notifiable diseases such as TB (Ball,  
45 2016). The risk of spreading disease can be particularly high in herds using recycled manure solids  
46 therefore manure from animals in quarantine, from animals which have aborted and manure from  
47 calving areas must not be used in the production of recycled manure (Ball, 2016). The production of  
48 the recycled manure solids is closely monitored and provided a sufficiently high dry matter content  
49 can be achieved, the solid fraction of manure can be considered usable as bedding, but only if it is  
50 correctly made, stored and used within twelve hours (Red Tractor Farm Assurance). The minimum  
51 dry matter recommendation is between 32-34% to minimise pathogen growth as a lower value  
52 (increased moisture) will support more rapid growth of pathogens and fail to provide a sufficiently  
53 hygienic bedding material for dairy cattle (Bradley, et al., 2014). The Red Tractor Farm Assurance  
54 defines the strict terms under which RMS may be used by farms seeking Red Tractor Assurance and  
55 these may be accessed via [https://assurance.redtractor.org.uk/contentfiles/Farmers-  
56 5409.pdf?\\_ =636262273844028704](https://assurance.redtractor.org.uk/contentfiles/Farmers-5409.pdf?_=636262273844028704)

57 Despite the accompanying risks, recycled manure solids have the potential to offer benefits to dairy  
58 units such as providing lower dust levels, thus promoting better respiratory health and reducing the  
59 transmission of pathogens via dust particles within houses (Bradley, et al., 2014), alongside a  
60 noticeable reduction in hock lesions and lameness cases (Husfeldt & Endres, 2012).

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62 Along with the production of the bedding material, the management of both the bedding itself and  
63 cattle during milking is also of utmost importance to maintain good herd health (Rowbotham &  
64 Ruegg, 2015). Cattle housing should be well ventilated regardless of the bedding material but  
65 particularly when using recycled manure solids and adequate drainage should be installed to ensure  
66 a drier environment to discourage pathogen growth (Bradley, et al., 2014). Weather conditions can  
67 also have a profound effect on the dry matter content of the recycled manure therefore it should be

68 stored indoors before being used as bedding; the need for appropriate buildings for storage should  
69 be considered before farmers attempt to adopt the use of recycled manure solids (Timms, 2008).  
70 This analysis of peer reviewed literature summarises the potential opportunities and challenges  
71 presented by recycled manure solids as a potential source of bedding material.

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### 73 **Methodology:**

74 Initially, several publication search engines were used to give a comprehensive view of the literature  
75 on recycled manure solids deemed appropriate to be used in this review. Many papers were  
76 returned which concentrated on certain major topics, namely diseases such as Johne's disease and  
77 Bovine Tuberculosis and cow welfare. The search criteria were subsequently refined to limit the  
78 literature to papers addressing these topics.

79

80 Databases searched were PubMed, Science Direct and Google Scholar (being commonly used search  
81 engines, available to readers) and search terms included 'recycled manure solids', 'Johne's disease'  
82 'green bedding' 'bovine tuberculosis' 'bacteria' and combinations thereof. A summary of the  
83 keywords used and papers returned is shown in table 1a.

84

85 As shown a large number of papers were returned which prompted concise refining. Duplicate  
86 papers were discarded, as were those not relevant to the UK dairy industry, those not scientifically  
87 proven and those published more than 10 years ago.

88 Additional search refinements included refining to recent papers and those from higher impact  
89 factor journals in the field of veterinary and dairy publications, to return a sensible number of papers  
90 to be read and analysed. The papers returned from each search determined the keywords used for  
91 the next search by highlighting which topics had the largest availability of literature and should  
92 therefore be investigated further. Detailed repeatable searches are listed in Appendix 1 (tables 1-  
93 27). All papers were critically reviewed; papers used within this review were considered scientifically  
94 relevant and their main conclusions are documented. Conflicting findings are included to identify  
95 potential areas of additional research.

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97

98 **Results:**

99 The flow diagram (Figure 1) shows how the literature was screened and the evidence each paper  
100 provided is listed in tables 1-27.

101 **Discussion:**

102 **Cow comfort and welfare:**

103 Cows can spend between 12 and 14 hours resting in cubicles between milking sessions therefore  
104 providing a comfortable and clean place for them to rest is imperative (Rowbotham & Ruegg, 2015).  
105 Recycled manure solids are described as soft, easily deformed and non-abrasive, all which can be  
106 described as beneficial traits (Harrison, et al., 2008). Decreased cow comfort when lying down and  
107 resting can be associated with increased lameness as the cows spend less time lying down and more  
108 time standing or using the cubicles incorrectly. Given that lameness is one of the greatest animal  
109 welfare concerns in the dairy industry there should be continual efforts made to improve cow  
110 comfort (Husfeldt & Endres, 2012).

111

112 Cow comfort can be measured by looking at cow preference, standing and lying behaviour and  
113 looking at the prevalence of lameness and hock lesions. A study conducted in upper Midwest US  
114 looking at 34 dairy farms with herds ranging from 130 to 3,700 lactating Holstein cows using  
115 recycled manure solids investigated the effect of bedding material on locomotion scores. The  
116 cattle's locomotion was scored out of five, with score one (normal) being used for cows standing and  
117 walking normally with a level back, to score three (moderately lame) for cows standing and walking  
118 with an arched back and short strides with one or more legs, to score five (severely lame) for cattle  
119 with pronounced arching of the back, reluctance to move with almost complete weight transfer off  
120 the affected limb (Sprecher, et al., 1997). The results demonstrated that lameness prevalence was  
121 significantly lower in deep-bedded freestalls (14.4%) compared to freestalls with mattresses (19.8%)  
122 and severe lameness prevalence (when cows had a locomotion score equal to or above 4) was also  
123 significantly higher in mattress freestalls (5.9%) compared to deep bedded free stalls (3.6%). Cows  
124 bedded on deep bedded recycled manure solids also had a statistically significant lower prevalence  
125 of hock lesions (49.4% versus 67.3% for cows on mattresses) (Husfeldt & Endres, 2012). Lameness is  
126 a multifactorial problem and confounding factors such as a breed lameness prevalence should be  
127 considered; the study only used Holstein dairy cattle therefore the effect of genetic makeup as a  
128 confounding variable is possibly reduced and the lameness prevalence is more attributable to the  
129 type of bedding material; however, the wide genetic base of the Holstein does cause there to be  
130 genetic variation within a herd of one breed and the influence of genetics cannot be dismissed.  
131 Deeper bedding is therefore a way of reducing lameness and hock lesions in dairy cattle. The

132 increased costs and reduced availability of other bedding materials such as sand and sawdust often  
133 deters farmers from applying copious amounts of bedding. Recycled manure solids are freely  
134 available as a raw material encouraging a more liberal application to mats and mattresses hence  
135 achieving a deeper bed; however, considerable investment in machinery and possibly storage is  
136 required for the processing of the “free” resource and these costs should be weighed against the  
137 “saving” of not buying in sand or sawdust or straw. The study’s results highlight the fact the choice  
138 of recycled bedding materials does not overcome the problem but the reduction in prevalence of  
139 lameness and hock lesions is a successful starting point.

140

#### 141 **Cleanliness:**

142 Another aspect of cow comfort and welfare that has been considered is cow cleanliness. This was  
143 particularly investigated in a study conducted by Hippen *et al.* (2007) which compared the hygiene  
144 and comfort of dairy cows bedded on dolomite limestone versus those on recycled manure solids on  
145 mattresses. The study involved four pens using 104 cows and fresh bedding was applied every two  
146 days, there was a noted improvement in cow cleanliness (cows measured on average 1.4 out of 2 on  
147 the AHDB cleanliness scoring system compared to cows scoring an average of 2 when bedded on  
148 limestone) and a decrease in hock lesions when using recycled manure solids was also discovered in  
149 this study. These conclusions were supported in another study by Timms (2008) which also claimed  
150 that cow comfort, cleanliness and feet and leg health were “excellent” on bedded manure solids.  
151 Although the appearance of cows looking clean sometimes does not correspond to an absence of  
152 pathogenic microorganisms, a study by Zadoks (2011 cited by Bradley, *et al.*, 2014) claimed that  
153 bacterial counts are lower when there is a reduced faecal burden and increased cleanliness of the  
154 legs.

155

#### 156 **Disease:**

157 Studies of the bacterial load of recycled manure solids are often conflicting, with results highlighting  
158 areas that need more exploration before conclusions can be drawn. It is supposed that freshly  
159 separated manure solids contain relatively high levels of pathogenic microorganisms, especially if  
160 there was a large microorganism burden in the slurry before separation (Bradley, *et al.*, 2014).  
161 Harrison *et al.*, (2008) however found that certain pathogens such as *Escherichia coli* were not found  
162 in recycled solids after they had undergone treatment (in this study composting) prior to being used  
163 as bedding but significantly higher levels were found in the bedding after use. This highlights the  
164 possibility that bacterial levels in used bedding are more likely to be a result of bacteria in the fresh  
165 manure of the animal, how well the stalls are cleaned along with how frequently the bedding is

166 changed. Harrison *et al.*, (2008), along with showing that composting reduced bacterial numbers in  
167 recycled manure solids (apart from *Klebsiella* which was able to survive), also compared other  
168 commercial bedding materials and demonstrated that sometimes even the commercial materials  
169 can contain a relatively high bacterial load and can reach similar levels of environmental mastitis  
170 pathogens as recycled manure solids when being used as bedding. Recycled manure solids contain a  
171 high pathogen load for a consistent period of time compared to commercial bedding materials which  
172 have a reduced pathogen load when first applied to the stalls but can rapidly exhibit similar  
173 pathogen levels after time. This provides an area of potential investigation exploring whether the  
174 steep increase in pathogen numbers seen in commercial beddings presents a bigger challenge to  
175 teat ends than the more stable level of pathogens which may be seen in some recycled solids.  
176 However, there will be variation in pathogen loads between farms and with seasonal/daily variations  
177 in weather which have not been investigated as confounding factors.

178

179 The literature investigating pathogens other than mastitis pathogens in recycled manure is limited.  
180 There have been some studies investigating *Mycobacterium avium* spp *paratuberculosis* (MAP),  
181 responsible for Johne's Disease but more studies are needed before conclusions can be made. MAP  
182 is shed in faeces therefore there is the possibility that using recycled manure solids can spread  
183 Johne's disease if the bacteria remains viable. There is every chance this could happen as the  
184 pathogen is not always killed by composting, separation or drum composting (Gooch, et al., 2006).  
185 Bonhotal *et al.*, (2011) provided conflicting evidence that composting unseparated manure to  
186 temperatures of 55°C was effective in reducing MAP to undetectable levels within five days. A study  
187 was conducted investigating MAP survival further and results showed after composting for three  
188 days at 55°C there was no evidence of *Escherichia coli*, *Salmonella* and *Listeria monocytogenes* in the  
189 bedding even when it was present prior to composting. MAP was detected on day zero of  
190 composting but was undetectable on day three and day seven (Grewal, et al., 2006). The study  
191 however did identify MAP DNA on day 56 in all methods of treating the manure. With these  
192 conflicting results in mind it should be suggested that recycled manure solids should not be used for  
193 bedding in calves as they may be more inclined to eat it than adult cows (Harrison, et al., 2008).  
194 Considering the study's findings and the knowledge of high risk of transmission in early life, recycled  
195 manure solids should also not be used where cows are kept for the late dry period or for calving to  
196 minimise the chance of Johne's disease transmission to young stock (Leach , et al., 2015).

197

198 **Clinical Mastitis:**

199 Mastitis is considered the most economically important disease seen in dairy cattle and is a very  
200 common problem farmers have to deal with (Rowbotham & Ruegg, 2016b). The pathogens that  
201 cause mastitis can be categorized as environmental or contagious depending on their primary  
202 reservoir and their point of exposure (Smith & Hogan, 2006). Contagious mastitis pathogens are  
203 often picked up during the milking process when the teats of healthy cattle are infected with  
204 pathogens from infected teats by either defective milking machines, inappropriate hygiene practices  
205 or the presence of carrier cows within the herd. The prevalence of contagious mastitis within herds  
206 is seen to be decreasing due to incorporation of good milking hygiene and the selective culling of  
207 chronically infected cows. (Rowbotham & Ruegg, 2016b).

208

209 Environmental mastitis pathogens are prevalent in the cow's housing environment and exposure can  
210 occur when teats encounter these micro-organisms either through bedding or in the manure itself.  
211 Teats can be in contact with bedding material for 40-65% of the day, therefore keeping  
212 environmental pathogens in the bedding to a minimum is imperative (Rowbotham & Ruegg, 2016a).  
213 Many studies have been conducted investigating the prevalence of environmental pathogens such  
214 as *Streptococcus* spp, Coliform bacteria and *Klebsiella* spp within different bedding materials.  
215 Rowbotham and Ruegg (2016b) concluded that large numbers of *Streptococci* species were  
216 recovered from all bedding types in all seasons however were greatest in shallow bedded recycled  
217 manure solids and recycled sand and least in deep bedded recycled manure. Total counts of gram  
218 negative Coliform bacteria and *Klebsiella* spp were greatest in deep bedded manure solids and least  
219 in new sand as expected. The study therefore displayed there was not a single bedding material that  
220 provided low levels of all mastitis pathogens indicating there is a risk of environmental pathogen  
221 contamination present with any bedding. The incidence rate of mastitis was also studied in the  
222 population of cows to try and determine if there was a correlation between pathogen load in the  
223 bedding and clinical cases of mastitis. The low prevalence of clinical mastitis detected in this study  
224 however could not be attributed to bedding materials as the population was made up of  
225 primiparous cattle and therefore not characteristic of cows on commercial dairy farms. Primiparous  
226 cows are known to have a lower risk of both clinical and subclinical mastitis and can withstand a  
227 greater exposure to environmental pathogens (Rowbotham & [Ruegg2016a](#)), the study therefore  
228 highlighted that recycled manure solids can be used in this population with a minimal effect on  
229 udder health.

230

231 As bedding can be a reservoir for bacterial growth and can create a heightened issue for teat  
232 exposure to environmental pathogens (Godden, et al., 2008), many studies have been conducted to



233 investigate whether certain techniques could reduce bacterial load within recycled manure solids.  
234 The ability of composting to effectively reduce numbers of Coliform bacteria has been discovered in  
235 many studies (Carroll & Jasper, 1978; Cole & Hogan, 2016). Cole and Hogan (2016), also discovered  
236 that composting for four weeks reduces counts of gram negative bacteria and *Streptococcal* counts  
237 associated with environmental mastitis. Bishop *et al.*, (1981) conducted a study which further  
238 supported this conclusion as results showed bacterial counts decreased in dairy waste solids by  
239 composting over 14 days. This study also attempted to detect a direct relationship between bacterial  
240 load within bedding and bacterial count on teats and within the milk. When comparing recycled  
241 manure to rubber mats, there was no statistically significant difference in bacterial counts on teats  
242 or in milk between the two types of bedding thus indicating there is no relationship between  
243 microflora in bedding and microflora on teats and in milk. More recent studies conducted have  
244 supported Bishop *et al.*, (1981) and have discovered the high level of bacteria seen in recycled  
245 manure solids does not correspond to an increased incidence of mastitis, teat end bacteria count or  
246 increased cell count in milk (Driehuis, et al., 2012). Driehuis, *et al.*, (2012) also highlighted that once  
247 in the cubicles, pathogen concentrations increase in a relatively short space of time, independent of  
248 the bedding material therefore there is no evidence to highlight an increased risk of mastitis when  
249 using recycled manure solids provided they are composted and managed correctly. However, the  
250 practice of composting is currently not permitted in the UK as there is a risk of selection for  
251 thermophilic organisms which are associated with milk and milk product spoilage, therefore the  
252 perceived benefits of the process are not yet applicable in the UK.

253

#### 254 **Somatic Cell Count:**

255 Bulk milk somatic cell count is associated with intramammary infections and can be used to  
256 determine premium payments by milk purchasers (Rowbotham & Ruegg, 2015). It is therefore  
257 important to consider any potential effects of using recycled manure solids on somatic cell count.  
258 The consensus after analysing numerous studies is that using recycled manure solids is not  
259 associated with an increased somatic cell count and that bacterial levels within bedding do not  
260 correspond to more animals presenting with an increased cell count (Harrison, et al., 2008; Hippen,  
261 et al., 2007; Timms, 2008). Studies also highlighted that although bedding bacterial counts were  
262 important to manage, excellent cow preparation, cow hygiene, bedding/stall and alley management  
263 appeared to be more important in maintaining a low somatic cell count (Husfeldt & Endres, 2012;  
264 Timms, 2008).

265

#### 266 **Bovine Tuberculosis:**

267 With Bovine Tuberculosis being a current notifiable disease causing major economic impacts  
268 through culling and movement restrictions preventing sales, the potential for recycled manure solids  
269 to spread the disease is a concern for dairy farmers. There is limited literature investigating the  
270 excretion of *Mycobacterium bovis* through faeces, urine and milk however these routes of spread  
271 are considered to be rare in the UK (Menzies & Neill, 2000). Literature studying the shedding  
272 patterns of Bovine Tuberculosis describes that a heavy load of bacteria in faeces and urine is unlikely  
273 to occur until the disease is at an advanced stage, even then the shedding can be sporadic (Neill, et  
274 al., 1988). As regular testing is mandatory in most of the UK and in all areas not declared Officially TB  
275 free, the chance of reaching this late stage is reduced. However, information on shedding patterns  
276 as the disease progresses are limited and more research is needed before conclusions can be  
277 achieved.

278

279 If the causal microorganism were to contaminate slurry from infected animals, then it is unlikely to  
280 be reduced by physical separation meaning it may be present in recycled manure. Hence, why using  
281 recycled manure from herds under tuberculosis movement restrictions due to the finding of test  
282 reactors is currently prohibited (Red Tractor). Phillips, *et al.*, (2003) discovered in their study that  
283 survival of *Mycobacterium bovis* in slurry can range from ten weeks to six months depending on  
284 temperature. The study revealed aerobic digestion or heat treatment is needed to kill the bacteria.  
285 With a paucity of literature available in this field also, more studies are needed to decipher exact  
286 conditions needed to ensure complete removal of the pathogen to make recycled manure solids a  
287 safe bedding option for herds testing positive for Bovine Tuberculosis.

288

#### 289 **Digital Dermatitis:**

290 Digital dermatitis is a painful skin condition seen in dairy cattle and is considered a major cause of  
291 infectious lameness (Stokes, 2011). Wet and unhygienic conditions underfoot along with dirty feet  
292 and legs have been highlighted as risk factors for the disease (Stokes, 2011). Considering the dry  
293 matter of recycled manure solids can increase to between 60-80% after being placed in cubicles and  
294 spread out allowing for more drying (Bradley, et al., 2014), the risk of digital dermatitis whilst using  
295 this bedding can be assumed to be reduced. Cows bedded on recycled manure solids are reportedly  
296 cleaner (Timms, 2008) and alley ways are often markedly drier (Bradley, et al., 2014) further  
297 suggesting that the risk of digital dermatitis could potentially be reduced. *Treponemes* are the major  
298 pathogens concerned causing digital dermatitis and are notably abundant in the dairy cow's housing  
299 environment (Evans, et al., 2010). The specific phylotype linked with digital dermatitis has not yet  
300 been detected in slurry samples however has been recovered from the recto-anal junction of cattle

301 (Evans, et al., 2010). Therefore, the inability to detect the causal *Treponeme* in slurry could be due to  
302 detection techniques and methods or due to intermittent shedding. The growth of *Treponemes* is  
303 promoted by damp environmental conditions (Bradley, et al., 2014) thus there is no evidence to  
304 suggest recycled manure solids would enhance pathogen numbers. Although the specific dry matter  
305 content to prevent *Treponeme* growth is currently unknown, the dry and clean environmental  
306 conditions promoted by using recycled manure solids as a bedding could mean *Treponeme* numbers  
307 to be at a minimum; however, specific research is needed before this can be assumed.

308

#### 309 **Antibiotic resistance:**

310 There is a relative paucity of research investigating antibiotic resistant bacteria specifically in  
311 recycled manure solids but there is more readily available literature looking at antimicrobial  
312 resistant organisms and their genes in livestock manures in general. A study was conducted  
313 comparing antibiotic resistant microbes in manure from livestock treated with antibiotics and those  
314 with control medication. As expected higher levels of antibiotic resistant microbes were identified in  
315 manure from livestock which had been treated with antibiotics (Sharma, et al., 2009). This trial also  
316 investigated treating the manure and the effect this had on the organisms. The study which lasted  
317 for 18 weeks explored the survival total *Escherichia coli*, *Escherichia coli* resistant to ampicillin and  
318 tetracycline and select tetracycline and erythromycin resistance methylase genes. The results  
319 showed that even though the compost temperatures did not reach the recommended temperature  
320 of 55°C for 15 days, the effect of composting was still apparent and reduced high initial levels of total  
321 *Escherichia coli* resistant to ampicillin and tetracycline after two weeks. However even after  
322 composting, tetracycline and erythromycin resistant methylase genes were still detected. Despite  
323 composting being an economical and environmentally friendly approach to stabilising livestock  
324 organic matter, optimum conditions are needed for the process to remain efficient, any deviation  
325 from these conditions can lead to reduced efficiency and the potential for microbial growth (Selvam  
326 & Wong, 2017). Considering this and the lack of literature regarding antimicrobial resistant  
327 organisms, a cautious approach to discard excreta from animals under antimicrobial treatment  
328 instead of using them to provide bedding materials should be recommended.

329

#### 330 **Ammonia emissions:**

331 Dairy cattle barns are a major source of gaseous ammonia emissions. The negative impacts of  
332 elevated ammonia levels on human and animal health are well documented and highlight the  
333 irritation caused to lungs and eyes (Bradley, et al., 2014). Studies have been conducted which  
334 investigate whether the type of bedding can influence the emissions of ammonia within the

335 livestock buildings. Emissions demonstrated a linear increase with the absorbance capacity of  
336 bedding material and were inversely related to bulk density of the bedding material (Misselbrook &  
337 Powell, 2005). The properties of recycled manure solids therefore advocate that ammonia emissions  
338 may be slightly higher compared to other bedding materials. Thus, recycled manure solids should  
339 only be considered in well ventilated cattle buildings to prevent the build-up of emissions which  
340 could potentially impinge on animal and human health.

341

342 **Attempts to reduce bacterial load within the recycled manure solids:**

343 There is an evident element of risk when using recycled manure solids as a bedding material. Smith  
344 and Hogan (2006) stated that when using recycled manure solids there was a “significant risk factor  
345 for exposure to environmental pathogens that cause mastitis in dairy herds” but also commented  
346 that this was the case when using most other commercial organic bedding materials too. Harrison *et al*  
347 (2008) went on to discover that the management of the bedding is more crucial to controlling  
348 microbial populations compared to what bedding material is used in the first place. Management of  
349 bedding particularly the use of conditioners and changing bedding frequency has been investigated  
350 in a number of studies.

351 The use of “conditioners” in recycled manure solids has been explored as this can lead to the  
352 alteration of the pH of the bedding which can subsequently help to control microbial populations. A  
353 study was conducted which compared levels of common environmental mastitis pathogens in  
354 recycled manure treated with a commercial bedding conditioner containing 93% sodium  
355 hydrosulphate, to bedding which received no treatment and remained as a control. The results  
356 showed that the effects of adding chemical conditioners to the organic bedding material were  
357 relatively short lived (Hogan, *et al.*, 2007). This study also revealed that alkaline conditioners were  
358 more effective in recycled manure solids and had a more profound effect on the microbial  
359 population. Gram negative bacterial and streptococcal counts were reduced in recycled manure  
360 solids immediately after application of the conditioner on day one. Bacterial counts however did not  
361 differ between treated and untreated recycled manure bedding on day two and six after application.  
362 The antibacterial activity of the conditioner was found to be related to the pH of the bedding and  
363 was diminished by day two after application. The short period of action is thought to be linked to  
364 the bedding being contaminated with manure as the cows enter the stall and removal of the  
365 bedding along with the conditioner as the cows leave the stalls. The practice of adding a conditioner  
366 to the bedding can therefore be described as ineffective.

367

368 Frequent removal and replacement of any bedding material is recommended to maintain good cow  
369 hygiene and to reduce the transmission of a variety of diseases. Studies have shown management  
370 factors can help reduce the impact of recycled manure solids on mastitis and other disease risks,  
371 these include maintaining adequate bedding in stalls, frequent stall grooming, excellent ventilation  
372 and parlour hygiene (Godden, et al., 2008). Harrison *et al.*, (2008) also conducted a comprehensive  
373 study of pathogens in bedding materials and concluded that individual farm factors and  
374 management had a strong influence alongside that of the underlying bedding type. Sorter, *et al.*,  
375 (2014) compared deep beds with shallow layers which were replaced daily. Conclusions were that  
376 coliform and *Klebsiella* spp. bacterial counts were lower in daily replaced bedding compared with  
377 deep packed bedding across the experiment on day zero, one, two and six but there was no  
378 measurable effect on *Streptococcus* spp. counts. Bradley *et al.*, (2014) argued that applying less  
379 bedding and keeping a thin layer of recycled manure solids offered the advantage that the bedding  
380 material could dry out further and maintain a lower dry matter content. The study investigated this  
381 potential advantage and saw an increase from an initial 29% dry matter to a range between 45-62%  
382 dry matter. Although the bedding material was less likely to stick to the cows and contaminate milk  
383 there was no significant reduction in bacterial numbers. Furthermore, Rowbotham and Ruegg (2015)  
384 supported this conclusion and commented that bulk milk somatic cell score for farms using organic  
385 bedding was reduced when bedding in the back of stalls was replaced regularly.

386

387 One study has also been performed which investigated the effect of alley- floor scraping frequency  
388 on environmental bacterial counts which were regularly involved in mastitis cases. Lowe, *et al.*,  
389 (2015) conducted a small study lasting six weeks from which results indicated that increasing alley-  
390 floor scraping to a frequency of two times a day decreased all bedding pathogen counts, teat end  
391 coliform, *Escherichia coli*, *Streptococcus* species and milk coliform counts. Increased scraping did not  
392 however correlate to a profound effect on milk *Escherichia coli*, *Streptococcus*, *Klebsiella* or somatic  
393 cell count. More studies are therefore needed to accredit these results and to highlight other  
394 potential mechanisms which may reduce the bacterial burden within dairy cow housing.

395

#### 396 **Consumer perception and risks:**

397 Consumer perception is often the largest battle for dairy farmers when using recycled manure solids  
398 as the customer often assumes recycled bedding is dirty with a higher bacterial burden which may  
399 have an impact on milk and food quality (Bradley, et al., 2014). Perception that recycled manure  
400 solids have high bacterial counts means some dairy producers are sceptical about using manure  
401 solids as bedding for cows (Husfeldt, *et al.*, 2012). The main risk identified when considering the

402 impact of recycled manure solids on food quality is of coliforms, bacterial spores, yeast and fungi in  
403 the milk all which could potentially increase the risk of food spoilage, particularly in cheeses  
404 (Bradley, et al., 2014).

405

406 As food safety is of uppermost importance, numerous studies have been conducted considering the  
407 effect of recycled manure solids on potential risk pathogens. One study conducted compared  
408 recycled manure solids with sawdust and demonstrated that all bedding materials are potential  
409 sources of contamination for raw milk (Driehuis, et al., 2012). The study commented that bacteria  
410 can be killed by pasteurisation of milk however some spores of certain bacteria can survive  
411 pasteurisation and high temperatures and high concentrations of these pathogens can lead to  
412 production losses of cheese and reduced shelf life of milk. Driehuis, *et al.*, (2012) demonstrated that  
413 spore levels of *B.cereus*, butyric acid bacteria and mesophilic aerobic spore formers in milk were no  
414 higher on farms using recycled manure solids than those farms using straw or sawdust.

415

416 Leach, *et al.*, (2015) discussed that other important pathogens to consider in regards to human  
417 health are *Escherichia coli* and *Salmonella*. The risk of increased levels of these pathogens in recycled  
418 manure solids is not well defined or investigated, but mitigation is straight forward and affordable  
419 through pasteurisation. Leach, *et al.*, (2015) also went on to discuss mesophilic, thermophilic, heat  
420 resistant and aerobic spores and concluded freshly separated manure solids did not show elevated  
421 levels to raise concern. More recent work (Bradley et al. 2018) compares bacterial load in sand,  
422 sawdust and RMS bedded cubicles, finding substantial differences in bacterial counts both within  
423 and between bedding materials; there were no significant differences between bedding types in the  
424 counts in milk for any of the organisms studied, and no significant correlations between bacterial  
425 load in the bedding used and the milk. Higher levels of bacterial load in RMS were found but did not  
426 necessarily correlate with an increase of bacteria in milk. However, it is very important to note that  
427 teat preparation did have an effect upon reduction of milk bacterial load and that the parlour  
428 routine offers control points for the minimisation of bacteria in milk. The choice of a bedding  
429 material is not a substitute for correct procedures in the parlour, nor does the choice of bedding  
430 negate the need for good management practices within the housing.

431 Importantly, some zoonotic bacteria were found, not specifically relating to the use of RMS, but  
432 their presence demonstrates the importance of pasteurisation in the production of milk for human  
433 consumption.

#### 434 **Conclusion**

435 It is evident that recycled manure solids have the potential to offer a safe and sustainable alternative  
436 to more traditional bedding materials, but that appropriately high standards of hygiene and  
437 husbandry in the cattle environments must be maintained. There is a lack of evidence to suggest  
438 whether composting is an appropriate means of processing the product and the procedure remains  
439 prohibited in the UK at the time of writing.

440 Using recycled manure solids provides cows with a welfare friendly resting surface and reduces  
441 lameness and hock lesions potentially reducing the burden of lame dairy cattle that dairy producers  
442 currently face. Considering other diseases, recycled manure solids have shown there is no positive  
443 correlation between the high bacterial count sometimes seen in recycled solids and the incidence of  
444 mastitis within herds. As reiterated in many studies, the management of cows in the milking parlour  
445 and the bedding itself is more important in managing disease prevalence. Daily removal of recycled  
446 manure solids and keeping the bedding dry and clean is imperative to keeping bacterial levels to a  
447 minimum. Being as the teats often look cleaner as the recycled solids do not stick to the animal,  
448 farm workers can become complacent when it comes to teat preparation. The failure of teats to be  
449 cleaned correctly before milking can predispose dairy cows to mastitis and an increased somatic cell  
450 count, independent of the bedding material used. Thus, pre-milking teat disinfection should be  
451 compulsory on any farm but particularly those using recycled manure solids to ensure an increase in  
452 either somatic cell count or mastitis cases cannot be attributed to using recycled manure.

453

454 There are still significant uncertainties regarding any detrimental effects on human health due to  
455 using recycled manure solids and customer perception is a massive problem faced by dairy  
456 producers. Consumers can be reassured that bacterial counts in milk however are not affected by  
457 using recycled manure and pasteurisation is an effective way of making milk products safe for  
458 consumption. The strict controlled conditions that must be followed by all participating farmers  
459 reduces the possible detrimental effects of using recycled solids on milk products; but only if farmers  
460 follow the correct procedures for composting and RMS management, as well as maintaining high  
461 standards of hygiene in the housing and milking parlour, thus minimising all risk factors for microbial  
462 growth and infection.

463

464 Despite the uncertainties there are also apparent benefits of using solids as bedding both financial  
465 and in terms of animal welfare. Further research is warranted into the relative economic advantages  
466 of using recycled manure solids once initial costs for the set up and acceptable storage buildings are  
467 considered. Concerning animal welfare, provided excellent milking preparation is adopted along  
468 with adequate bedding management, recycled manure solids have no increased associated risks for  
469 common diseases.

470

471 There are still substantial gaps within the research regarding recycled manure solids which should  
472 prompt future investigations. The paucity of research into the effect of manure solids on antibiotic  
473 resistance highlights the need for additional research. Potential investigations may include  
474 determining whether different antibiotic resistant pathogens can survive composting and whether  
475 an increased level of antimicrobial resistant pathogens within the bedding material itself pose any  
476 substantial threat to the cattle and potentially consumers. As mastitis is an economically important  
477 disease in the dairy industry and has been identified as a multifactorial disease, this too poses an  
478 opportunity for further investigations. Different risk factors, for example genetic predisposition and  
479 anatomical positioning of teats and their effect on mastitis prevalence should be investigated as it  
480 can be assumed it is more than just different bedding materials that influence a herd's mastitis  
481 prevalence.

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501 **Bibliography**

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