irda | Institut de recherche et de développement en agroenvironnement

CRSAD
Centre de recherche en sciences animales de Deschambault

RECYCLED MANURE SOLIDS BEDDING IN DAIRY PRODUCTION

STATE OF KNOWLEDGE AND GUIDELINES

Université Laval · Institut universitaire de cardiologie et de pneumologie de Québec · Université de Montréal · Canada · UQAR · GEA

Québec · CRIBIQ · CRSNG NSERC · Novalait · Op+lait

EDITORIAL FRAMEWORK

This document was prepared as part of the research project "*Development of Optimal Strategies for the Use of Manure-based Bedding in Dairy Production*" funded by Agriculture and Agri-Food Canada (**Canadian Agricultural Adaptation Program, 2014-2019**). It was amended following the availability of results from a second study conducted by the Faculty of Veterinary Medicine (FMV) at the University of Montreal from 2017 to 2020.

Conducted in partnership with several academic institutes and research centres, this project aimed to determine what the best practices are to produce recycled manure bedding and its use in dairy production, while considering the health of workers and animals. The literature was reviewed to identify promising practices and a protocol was developed to test them. This project was conducted with cows in tie-stalls at the Centre de recherche en science animale de Deschambault (CRSAD [Deschambault Animal Science Research Centre], Quebec, Canada) from 2016 to 2019. Various aspects linked to the production and management of recycled manure bedding were studied, such as: comparison of separation equipment, solid phase conditioning techniques, bedding application under the cows, control indicators (mechanical, physicochemical, microbiological and behavioral properties), assessments of agronomic properties of the liquid fraction and socio-technico-economic aspects for the adoption of novel bedding material practices.

During the second study conducted by the FMV (in collaboration with Laval University), 27 farms using recycled manure bedding (RMSB) were compared to 61 farms using straw bedding. Traditional bacteriological analyses and metagenomic analyses were performed on bedding samples as well as on the milk tank. Parasitic load in herds was also compared, along with hygiene and comfort levels. The safety and food quality of the milk from these herds were subject to analysis. Finally, the mammary gland health of the animals housed on this bedding was monitored over a period of one year.

Based on the research findings, this document includes three parts of different scopes:

1. **General:** Background, definitions and general principle of recycled manure bedding.
2. **Current State of Knowledge:** Up-to-date knowledge from literature as well as from this research project.
3. **Guidelines:** Conclusions, recommendations, and practice framework.

[1] Institut universitaire de cardiologie et de pneumologie de Québec (IUCPQ), Université Laval, Université de Montréal, Université du Québec à Rimouski
[2] Institut de recherche et de développement en agroenvironnement (IRDA), Centre de recherche en sciences animales de Deschambault (CRSAD)

IN MEMORY OF ALAIN FOURNIER, AGR.

Mr. Fournier, the initiator of the project, had brought together the experts who were involved at various levels in this research. A visionary, Alain had an unwavering dedication to Quebec agriculture. This document is dedicated to him; hoping that the Quebec agricultural community will remember him for a long time. Thank you, Alain.

The use of bedding to ensure the well-being and health of cows is a recognized and encouraged practice in the dairy industry. However, the materials typically used as bedding (such as straw, organic residues, wood shavings, and sand) can be expensive and hard to obtain. Recycling manure and soiled bedding produced by the herd can therefore offer advantages. The feasibility of using recycled manure bedding in dairy production was studied in partnership with several academic institutes and research centers in two separate projects. The first project was funded under the Canadian Agricultural Adaptation Program of Agriculture and Agri-Food Canada. The second project was funded by a grant from Novalait-CRIBIQ-FRQNT-CRSNG and aimed to investigate the effects of this bedding on the health of animals and farm workers in a commercial farm context.

The technical challenges associated with making this bedding were discussed. Initially, a literature search was conducted to select promising equipment and processes to carry out the project. During this study, tests were conducted on manure separation equipment and on processes for conditioning manure solids. Control indicators were identified to compare recycled manure bedding with straw or wood chip beddings. The physical properties of the different types of bedding were evaluated as well as their effect on cows' health and welfare. An agronomic evaluation of the liquid fraction produced during separation was carried out to compare it to untreated manure traditionally used to fertilize the crops needed to feed the herd. The costs and environmental impact of adopting recycled manure bedding were compared to those of traditional bedding.

During the study of commercial farms, the health of the animals was investigated on several aspects: dynamics of clinical and subclinical mastitis, hygiene, comfort, presence of parasites and infectious diseases in feces and bedding. Additionally, physico-chemical and bacteriological analyses were conducted on samples of bedding, both fresh and at the end of its use. Finally,

bulk tank milk was also subjected to analysis to validate the effects of bedding on milk safety, its microbiota, and cheese production.

This project reveals that screw or roller separators are the most interesting equipment for separating the solid fraction of manure, both in terms of performance and cost. Conditioning of the solid fraction is necessary to reduce the product's water content and partially decrease the concentration of pathogens responsible for certain diseases in cows. This aerobic biological composting process can be carried out in mechanically turned windrows, aerated static piles, or closed aerated containers. The project has determined that, under Canadian conditions with significant temperature variations throughout the year, closed-container composting (rotary composter) produces a more uniform bedding. However, studies on commercial farms have shown that the current production methods for this bedding do not effectively control pathogens, including bacteria causing mastitis, Salmonella bacteria, and parasites, which can also affect humans.

[3] Consortium de recherche et innovations en bioprocédés industriels au Québec (CRIBIQ)
[4] Fonds québécois de la recherche sur la nature et les technologies (FRQNT)
[5] Natural Sciences and Engineering Research Council of Canada (NSERC)

Optimal comfort for cows is ensured at all times by complete coverage of the stalls with bedding. The resting time for cows was equivalent on both types of bedding. During the project on commercial farms, no difference in the total number of clinical mastitis cases was noted between the two types of bedding (Recycled Manure Solids vs straw). However, the number of clinical mastitis cases caused by Klebsiella pneumoniae was seven times higher in Recycled Manure Solids farms. This type of clinical mastitis is severe and often leads to culling or the death of the animal.

The agronomic value of the liquid fraction produced during separation remains interesting for crops. Greenhouse gas emissions associated with these fertilizing residues from dairy production are lower with recycled manure solids compared to straw bedding. Furthermore, the greenhouse gas emissions from the barn were lower with recycled manure solids than with wood chip bedding.

The production and use of recycled manure solids become financially viable in cases where this system replaces straw bedding applied at a rate of at least 6.1 kg of straw per day per cow, and the purchase price of straw is $0.22 per kg or higher. However, negative impacts on animal health (e.g., clinical mastitis) have not been considered in these calculations.

Also, the adoption of this type of bedding must be accompanied by changes on the part of the dairy farmer. The dairy farmer must develop expertise based on measurements and observations during the bedding conditioning process. The management and maintenance of recycled manure solids under cows are also more demanding. High moisture content can lead to compaction issues and may affect cow hygiene. Additionally, the use of recycled manure solids can result in a modification of the milk microbiota, which can impact its quality.

In conclusion, the adoption of recycled manure solids can be interesting and advantageous for dairy producers. However, those who choose this option must be prepared to address the technical and animal health challenges associated with it.

TABLE OF CONTENTS

Part 3. PRATICE'S GUIDELINES

LIST OF ILLUSTRATIONS

LIST OF TABLES

PART 1

General

BACKGROUND

BEDDINGS

PRODUCTION PROCESS

RMSB APPLICATION

LITTER
Definition: Litter consists of a soft, insulating, and absorbent bed of straw or other similar plants which is spread in livestock buildings.

In agriculture, it is commonly used for different types of breeding such as in dairy cow, dairy goat, and poultry production and in organic pig farms.

BACKGROUND

CANADA-WIDE DAIRY FARMERS PROGRAM

In Canada, the dairy sector adopted a Code of Practice for the care and handling of farm animals – Dairy Cattle (NFACC, 2009) and an animal welfare assessment program that both advocate strongly for the use of bedding. In the Code of Practice, it is agreed that most barns provide stalls containing dry, insulating and soft surface bedding that promote rest, comfort and natural postures. **ProAction® is the Canada-Wide Compulsory Certification Program initiated by Dairy Farmers of Canada.** Animal welfare is one of its six main components which includes the following in its general principles:

> *"[…] appropriate housing and husbandry are essential for the health and well-being of dairy cattle. Cleanliness scoring of dairy cattle is a tool for measuring environmental cleanliness and, the relative risks for high somatic cell counts and diseases like mastitis".*

ANIMAL WELLFARE

Beyond the Canada-wide Certification Program, the use of bedding is compatible with at least three of the Five Freedoms defined by the *Farm Animal Welfare Council*. **Good bedding provides comfort, reduces the risk of injury, and may allow for the expression of natural behaviors specific to the species.** Numerous North American studies have also shown the importance of using sufficient dry bedding in cow housing, regardless of the floor covering, to promote rest time and reduce risks of injury and lameness.

BENEFITS OF BEDDING

The benefits of the bedding used in dairy cow housing are multiple:

- Ensure animals' **comfort** and **cleanliness**.
- Absorb and **retain** animal **urine**.
- **Reduce humidity**.
- **Reduce friction** without preventing traction.
- Improve stall surface **softness**.

BEDDINGS

TYPES OF MATERIAL

There are several types of material that can be used as bedding by dairy farmers such as: grain straw, wood chips, switchgrass, peat moss, crop residues (flax/corn/soybean/canola), sand or recycled manure. Some types of bedding are better than others, but none are perfect.

SELECTION CRITERIA

Some of the expected characteristics of good quality bedding include: availability, affordability, low dust, free from contaminants, good stall cover and compatibility with manure handling equipment.

When **choosing the bedding to be used,** a farmer must consider not only the **specific characteristics of each material,** but also the **constraints** associated to his farm's specific practices and management. For example, the amount of bedding required varies depending on the material used, the application frequency and the surface to cover.

The harder the surface, the more bedding is required. When comfort is concerned, there is never too much bedding.

According to recent studies, straw and wood chips are the most common bedding material used in Canada. Their availability and cost in recent years have however led some farmers to explore the use of **alternative bedding** material, such as recycled manure bedding.

RECYCLED MANURE SOLID BEDDING (RMSB)

Among alternative beddings, the **RMSB has generated interest in many farmers due to its theoretically unlimited availability and the possibility of producing it directly on the farm,** and this for both free or stall housing.

RECYCLED MANURE BEDDING

Definition : ***The terms "recycled manure bedding" may include products extracted from manure by a variety of processes, usually beginning with the physical separation of a solid fraction (in the case of methane production, the separation follows the digestion process).***

The RMSB properties is affected by the production method. In this report, the term "recycled manure bedding" is generally used to refer to a product that has been physically separated and then conditioned to reduce the microbial load, limit the presence of pathogens, and increase the dry matter content. Unfortunately, a clear definition is not always provided in the literature discussing RMSB, which leads to some ambiguities.

RMSB is **compatible with manure management systems** since it is produced from the manure coming from the same farm it is used. The solid fraction of the manure used to produce RMSB consists mainly of fiber undigested by the cows, unconsumed feed and, bedding from calving and heifers' pens. When properly processed and used in the barn, the RMSB possesses several physical attributes expected of bedding, like improving the cows' comfort and cleanliness, being non-abrasive and, easily available. In addition, the effluent of the separation process (liquid fraction) can be stored and used as organic fertilizer on crops.

PRODUCTION PROCESS

In general, but not exclusively, the production process consists of **two main steps**: **solid-liquid separation** then **conditioning** (Figure 1). The former allows for the solid residues to be concentrated, while the latter ensures a partial sanitization and a reduction of the moisture content to further stabilize the product.

FIGURE 1. Steps in the production of RMSB

SEPARATION

Solid-liquid separation for the production of recycled manure can be done mechanically using different types of equipment:

- **Sieve** separators (stationary, vibrating or rotary).
- **Press** separators, screw or roller.
- **Centrifugal** separators.

The sieve separators are widespread, but rarely used in Canadian dairy production due to their susceptibility to clogging in northern climates with high dry content manure. Screw, roller and centrifugal separators (Figure 2) provide satisfactory separation efficiencies with dairy manure. However, the low capacity of centrifugal separators (centrifuges), combined with their purchase cost and energy consumption, make them less attractive. The choice between screw and roller press separators depends on the **types of input material,** the **desired characteristics for the separated recycled manure** and, the farmer's objectives in terms of **processing capacity.**

FIGURE 2. Examples of screw (A), roller (B) and centrifugal (C) separators

The dry matter content and the particle size distribution of the solid fraction are the most important elements to monitor to produce RMSB that will be acceptable from a compactibility perspective.

Recycled manure composed of many fine particles compacts easily under the cow and retains more moisture. It is therefore recommended to prefer a solid fraction with a limited number of particles with a diameter smaller than 1 mm (Fournel et al., 2019a).

CONDITIONING

After the separation, the conditioning of the solid fraction is the second step in the production process of the RMSB.

CONDITIONING

Definition In this document, the term "conditioning" refers to all operations associated to the aerobic treatment of the manure solid fraction" This conditioning includes a **thermophilic phase at temperatures greater than 55°C** that results from intense microbial activity and ensure the production of a partially dried sanitized material.

A conditioning with an elevated temperature is achieved by the aerobic biological processes that are similar to composting. These can be grouped into two broad categories:

- **Piles** and **windrows** that are aerated by mechanical turning or by forced aeration when not turned (static).
- Aerated **closed vessels** (bioreactor), either in continuous flow or in batches, including:
    - Rotative cylinders (drum composting);
    - Closed containers (in-vessel);
    - Horizontal silos with mechanized turning.

The production of a RMSB with constant year-round characteristics requires a strict monitoring of the conditioning process and the operating parameters. This is facilitated by the implementation of automated mechanical processes. Mechanically returned piles and windrows require more handling and time as well as a rigorous discipline. Thus, the **conditioning techniques in enclosed ventilated and insulated vessels appear particularly interesting because they allow for a rigorous control of the conditioning parameters.**

*The use of a mechanized and automated process for conditioning the solid fraction of the manure is part of a **good risk management** approach, allowing for a uniform thermophilic treatment and year-round production of consistent quality material.*

RMSB APPLICATION

Once conditioned, RMSB is applied under the cows either manually or mechanically, depending on the herd size. The quantities applied per day and per cow can vary significantly based on the management practices of the producer. Given the substantial differences in bulk density among different beddings, the daily mass to be added per cow or the thickness to be maintained must be adjusted according to the management practices.

The RMSB density is approximately 340 kg/m^3. Consequently, the amounts to be added can vary from 10 to 40 kg per day for corresponding volumes applied of 29 to 118 liters per cow per day. Therefore, the RMSB thickness under the cows can range from few centimeters to tens of centimeters.

The quantities to be added depend accordingly on the management strategy and comfort sought for the cows as well as the production performances targeted. In general, RMSB is not used in calving pens nor under heifers.

MANAGEMENT OF THE BEDDING

In **managing the risk on cows' health and the occurrence of mastitis cases,** the bedding management in the barn and under the animals is known to be as important as the initial quality of the material used as bedding. The reason being that after 24 hours, and for all bedding types, all fresh bedding is already soiled by animals' excrement. Consequently, **we will look for a material and an environment that does not promote microbial growth in the bedding under the animals. Twice-daily maintenance will ensure the removal of fresh droppings and wet litter and, the application of new RMSB. The bedding in the stall should also be levelled to ensure a uniform surface and cows' comfort.**

PART 2

Current state of knowledge

BEDDING'S MICROBIOLOGICAL PROPERTIES

DANGER TO MY HEALTH?

COWS' COMFORT AND HEALTH

UDDER'S HEALTH

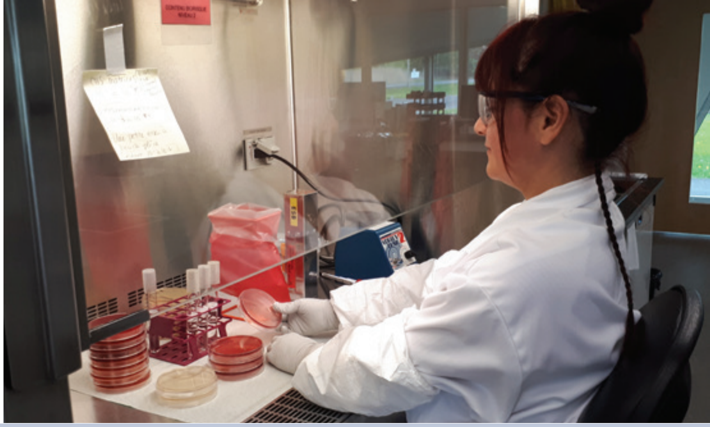
ECONOMIC ANALYSIS OF STRAW BEDDING SUBSTITUTION BY RECYCLED MANURE BEDDING

AGRONOMIC VALUE: THE LIQUID FRACTION

WHAT ABOUT THE ENVIRONMENT IN ALL THIS?

FARMERS' PERCEPTION AND EXPERIENCE

BEDDING'S MICROBIOLOGICAL PROPERTIES



The materials used as bedding, whether it be recycled manure or other substances, may contain potentially pathogenic microorganisms for humans and animals. The presence of these microorganisms in the cows' environment can increase the incidence of diseases such as clinical mastitis. To minimize risks, it is important to understand the dynamics of microbial populations during various stages of RMSB management. It is also crucial to know the potential of different bedding types to support the growth of microorganisms following contamination by animal excreta. In the study conducted at CRSAD, samples of slurry before separation, solid and liquid fractions after separation, and beddings were collected at all project phases to enumerate populations of five types of microorganisms indicative of bovine intestinal flora and the potential presence of pathogens. In the study conducted by FMV, bacteriological analyses of beddings were performed at two points in the usage cycle, namely when the bedding was ready for use and at the end of its use. For parasitological analyses, bedding samples were collected at each production stage, and feces were also harvested.

MICROORGANISMS

Since there are several types of microorganisms that are pathogenic, it would be very tedious and expensive to check for the presence of each of them in cows' manure or bedding. During the study conducted at Deschambault Experimental Farm in 2017 and 2018, the populations of the following **microorganism indicators** were monitored in raw manure and in bedding: *Escherichia coli (E. coli), Klebsiella* spp., *Enterococcus* spp., *Streptococcus* spp. *and Staphylococcus* spp. These are part of cattles' normal intestinal flora, but some types can cause animal or human health problems if they are present in sufficient amounts to cause an infection.

During the study conducted by FMV, a total bacterial count was performed, along with specific analyses on populations of Staphylococcus spp, Streptococcus spp, E. coli, Klebsiella spp, Salmonella spp, and Listeria monocytogenes. Additionally, parasitological analyses were carried out on bedding and manure samples to determine the presence of cryptosporidia and coccidia.

IMPACT OF SEPARATION

Liquid and solid separation of slurry is the first step in the RMSB production. In general, the microorganisms attach to solid particles, but several parameters influence their likelihood to remain in one fraction or the other. The study's first step was consequently to compare **three raw slurry separating methods:** screw and roller press separators and, centrifuge. The population of microorganisms' indicators were counted in the liquid and solid fractions obtained by each separation method.

In the conditions of the study, the solids from the same slurry presented a similar content of indicator microorganisms (Fournel et al., 2019a). Regardless of the equipment used, separation had no effect on the distribution of microorganisms in the solid and liquid fractions. In the parasitological analyses conducted in the second study, separation also did not reduce the content of parasites in the slurry.

EFFECTS OF CONDITIONING

In the second stage of the project, the impact of **four solid fraction conditioning methods** was evaluated under experimental conditions, namely: 1) static pile (not turned) for 10 days; 2) pile turned daily over a 10-day period; 3) 24 hours of rotary composter treatment followed by storage in static pile for 10 days; 4) 72 hours of rotary composting followed by storage in pile for 10 days. The 24-hour rotary composter treatment resulted in a reduction in *E. coli* and *Klebsiella* populations of 74% and 43%, respectively. Those populations remained stable during the 10-day storage that followed.

Under the study conditions, a 24-hour rotational composter treatment resulted in populations of the microorganisms' indicators comparable to those of 10-day storage in both turned and unturned piles.

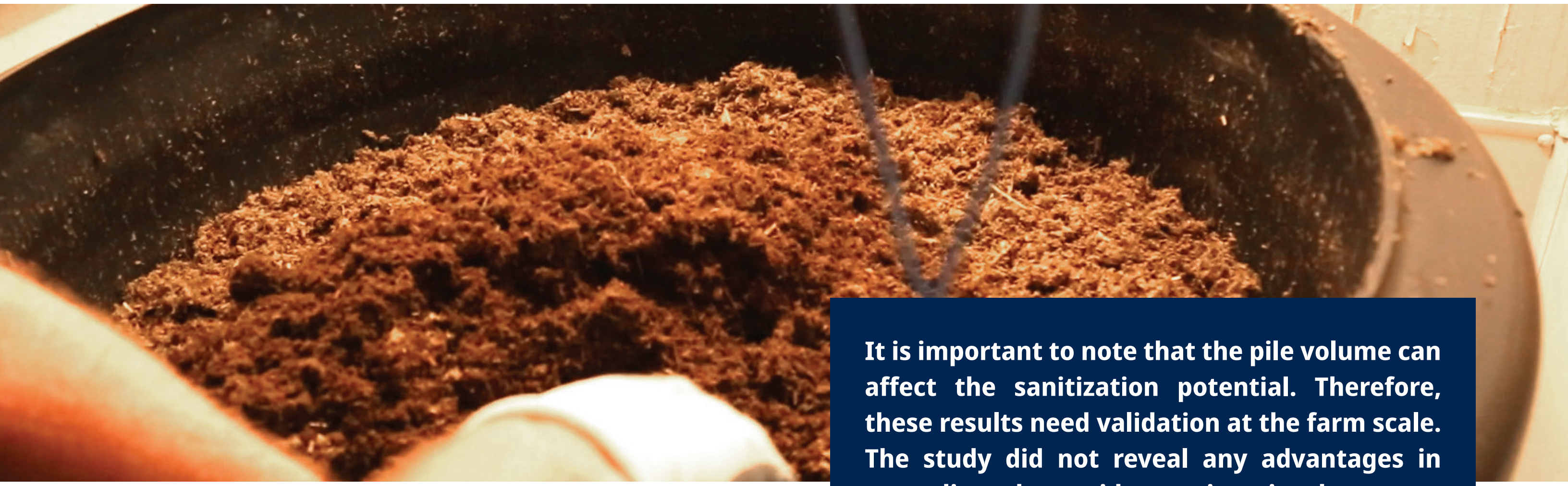
In the study conditions, a 24-hour treatment in a rotary composter led to E. coli populations comparable to those resulting from a 10-day storage in a turned or unturned pile. In the study conditions, a 24-hour treatment in a rotary composter also led to populations of indicator microorganisms comparable to those resulting from a 10-day storage in a turned or unturned pile.

In fact, while E. coli and Klebsiella populations remained stable during storage following a 24-hour composting, they increased after 72 hours of composting.

Although staphylococci populations increased after passing through the rotary composter, they reached the same level after 5 days of storage in all treatments and remained stable until the end of the trial. Finally, while there were 10 times fewer enterococci at the end of the trial than at the beginning, streptococci populations remained consistent and were similar in all treatments.

In the second study, the Recycled Manure Solids (LFR) analyzed before introduction under the cows generally had more bacteria than straw, except for Klebsiella, which had a higher concentration in straw.

LFR farms also had significantly more Salmonella, Listeria monocytogenes, cryptosporidia, and coccidia than straw-based farms.



It is important to note that the pile volume can affect the sanitization potential. Therefore, these results need validation at the farm scale. The study did not reveal any advantages in extending the residence time in the rotary composter from 24 to 72 hours.

IMPACT OF BEDDING THICKNESS

In the third stage of the project, conditions from two thicknesses of Recycled Manure Solids (LFR) (2 and 6 inches) were compared to those of a barn using straw bedding for 21 days. Before its introduction into the barn, the LFR was previously treated for 24 hours in the rotary composter. Samples of clean and soiled beddings were collected six times during the trial to enumerate populations of indicator microorganisms.

The soiled beddings collected under the cows had a similar bacterial content and reflected the stall contamination regardless of the type of bedding used.

The materials used as bedding can have a high content of certain indicator or potentially pathogenic microorganisms even before their application under the animals. To these initial quantities, contamination from animal excrements is added. Environmental conditions (i.e., temperature and humidity) and the physico-chemical properties of the bedding (i.e., available nutrients) within the bedding itself contribute to the proliferation of certain types of harmful microorganisms. For example, Cryptosporidia, which cause severe diarrhea in young animals, are particularly resistant to heat and are not controlled by the processes currently used in RMSB production. Similarly, beddings, including RMSB, can support the growth of bacteria such as Klebsiella.

Due to the presence of multiple pathogens in the ready-to-use bedding, RMSB should not be used under young animals (less than 6 months of age) or in calving areas.

DANGER TO MY HEALTH?

Dairy farmers are exposed to significant amounts of organic particles in the air, called bioaerosols, that they can inhale. Feeding and bedding application released bioaerosols (Kullman et al., 1998) composed of living or dead microorganisms as well as plant and animal cells fragments (Donham, 1986). In our dairy production conditions, the cows are kept in enclosed buildings; bioaerosols concentrate in the farmer's work environment and may present a risk to their respiratory health (Donham 1986, Schenker et al. 1998).

In our study, the air quality in the barn varied with the conditioning method used (Table 1). In fact, a 72-hour rotary composting treatment increased the amount of dust in the air during the handling of the bedding, as well as the quantities of bacteria and molds that can be inhaled. On the other hand, static or daily turned piles or windrows seem to lower the risks to farmers' respiratory health. It should be noted that dust concentration in the air never exceed the exposure limit values (ELV) recommended when handling RMSB. However, bacteria and mold concentrations exceeded the ELV for the 72-hour rotary composting treatment (Fournel et al., 2019b).

The air quality was assessed through dust, bacteria and mold counts. A DustTrak™ DRX Aerosol Monitor (TSI) measured dust in real time. Bacteria and molds were aspirated and impacted in a solution using a Coriolis® Biological Air Sampler (Bertin Corp.) The solution was then spread on culture media to grow bacteria and mold. The concentrations obtained were compared to the ELV imposed by the Quebec Government's Occupational Health and Safety Act (10 mg/m^3 dust) and suggested in scientific literature (104 CFU/m3 bacteria, 5×10^4 CFU/m^3 mold).

Furthermore, the air quality varied depending on the distribution method used. The use of equipment such as a straw chopper or conveyor generates a higher level of bioaerosols compared to manual methods. The quantity of bioaerosols in the air was even higher during the cold season when ventilation in the barn was reduced.

In the study conducted on commercial farms, pathogens such as Listeria monocytogenes, Salmonella, and cryptosporidia were found in RMSB before its use. All these pathogens are zoonotic, meaning they can be transmitted to humans. Symptoms can range from mild to severe and may lead to hospitalizations. Some of these pathogens are also highly damaging to dairy cattle, causing significant production losses and severe diseases, especially in young animals.

Dairy farmers are advised to wear an effective protective mask against both coarse and fine particles during the distribution of bedding, regardless of the season or method used. Farm workers should also wear gloves when handling bedding and thoroughly wash their hands after coming into contact with it.

TABLE 1. Relative exposure risk to bioaerosols related to handling and storage per composting method

	RISK WHEN HANDLING		RISK DURING STORING	
BIOAEROSOLS MESURED	LOWEST	HIGHEST	LOWEST	HIGHEST
Dusts	TW[1]	DC72[2]	DC72	SW[3]
Bacteria	SW	DC72*	SW	DC72
Mold	TW	DC72*	TW	DC72

[1] TW = Static composting returned daily

[2] DC72 = 72-hour composting in rotary composter

[3] SW = Static composting

* Exceeding recommended exposure limits

COWS' COMFORT AND HEALTH

The effect of RMSB on the comfort of cows kept in tie-stall housing was studied in a cross-over experiment with three treatments: 5 cm of chopped straw, 5 cm of RMSB, and 15 cm of RMSB. In total, 18 cows spent three weeks on each bedding treatment during the winter of 2018. The characteristics of stall bedding (cleanliness, thickness, moisture), as well as the cleanliness of the cows, time spent "lying down," injuries, and lameness, were monitored to compare the three bedding treatments. In the study on commercial farms, 30 cows per herd were evaluated for hygiene quality and the condition of their hocks, a factor reflecting the comfort of the animals.

The type, quality, quantity, and management of the bedding used for cows are factors that can affect their comfort and health on a daily basis. Indeed, they can influence the resting time and cleanliness of the animals, as well as the risks of injuries, lameness, and diseases. When evaluating bedding, the condition of its surface in the stall, the resting time of the cows, as well as their physical condition and udder health, should be taken into consideration.

TYPE OF STALL SURFACE

The type of stall surface (deep bedding vs bedding cover on a mat or mattress) may influence the types of pathogen present and in contact with the teats, but no association has been shown with the prevalence of mastitis (Rowbotham and Ruegg, 2016a, 2016b). The amount and frequency of bedding application affects the cover rate, the compressibility and the moisture content of the stall. These elements also impact the animals' comfort.

- Aim for full bedding cover of the stall at all times to avoid knee and forearm friction with an abrasive surface.
- Maintaining a minimum of 5 cm (2 inch) bedding in tie-stalls will ensure full cover and some surface softness.
- The frequency of bedding addition should be adjusted according to the stall type and the amount and quality (% dry matter) of the bedding applied. Frequent addition of fresh RMSB at low dry matter content can increase the stall's moisture, especially in deep bedding condition.
- In tie-stalls, a minimum addition of 20 kg of bedding per day is necessary to maintain a thickness of 10 cm. This seems a good compromise between animal comfort and ease of daily management.
- The presence of excrement in the stall is a discomfort to cows. Consequently, excrements and wet litter should be removed at least twice a day.
- A high maintenance frequency where soiled bedding is removed and the surface is leveled can help increase cows' cleanliness and comfort.

REST TIME, INJURIES, LAMENESS AND CLEANLINESS

A stall that offers adequate comfort, including bedding that is dry, absorbent and, soft, promotes rest time and lowers the risks of injuries and lameness. According to recent literature, the adequate daily rest period for dairy cows ranges between 11 and 14 hours depending on the lactation stage and the stall type (Solano et al., 2016, Charlton et al., 2016). When the resting time of dairy cows is insufficient, their milk performance is affected.

The rest time of the cows kept on RMSB is equivalent to the one of those kept on other bedding types.

The cows' cleanliness is an indicator of animal welfare and is linked, among other things, to the hygiene of the herd. The Code of Practice requires the use of bedding material suitable for maintaining sanitary conditions in cows' barns and a frequent removal of manure to maximize animal cleanliness (NFACC, 2009). The quantity and quality of the bedding used can influence the animals' cleanliness and the ease of daily barn management.

During the tie-stall study over a period of three weeks, no differences in resting time or the prevalence of injuries and lameness were observed when the stalls contained 5 or 15 cm of RMSB or 5 cm of chopped straw. However, cows kept on RMSB had softer hooves than those kept on straw. The cleanliness of cows kept on RMSB was lower than when kept on straw, especially at the teats (Figure 3). Cows kept on 15 cm of RMSB were generally dirtier than those kept on 5 cm, possibly due to difficulties in maintaining a dry bedding surface with deep RMSB.

In the study on commercial farms, no difference in the cleanliness level of cows housed on LFR, compared to those housed on straw, could be identified.

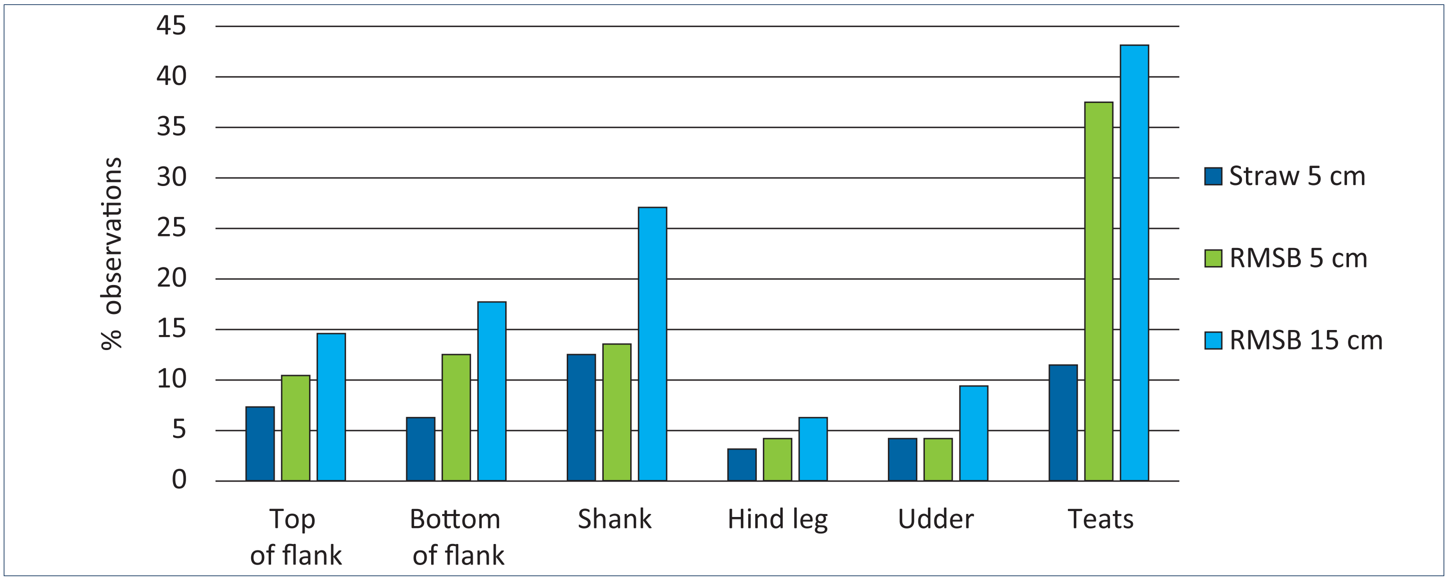


FIGURE 3. Proportion of observations for which cows were considered dirty (% of observations made)

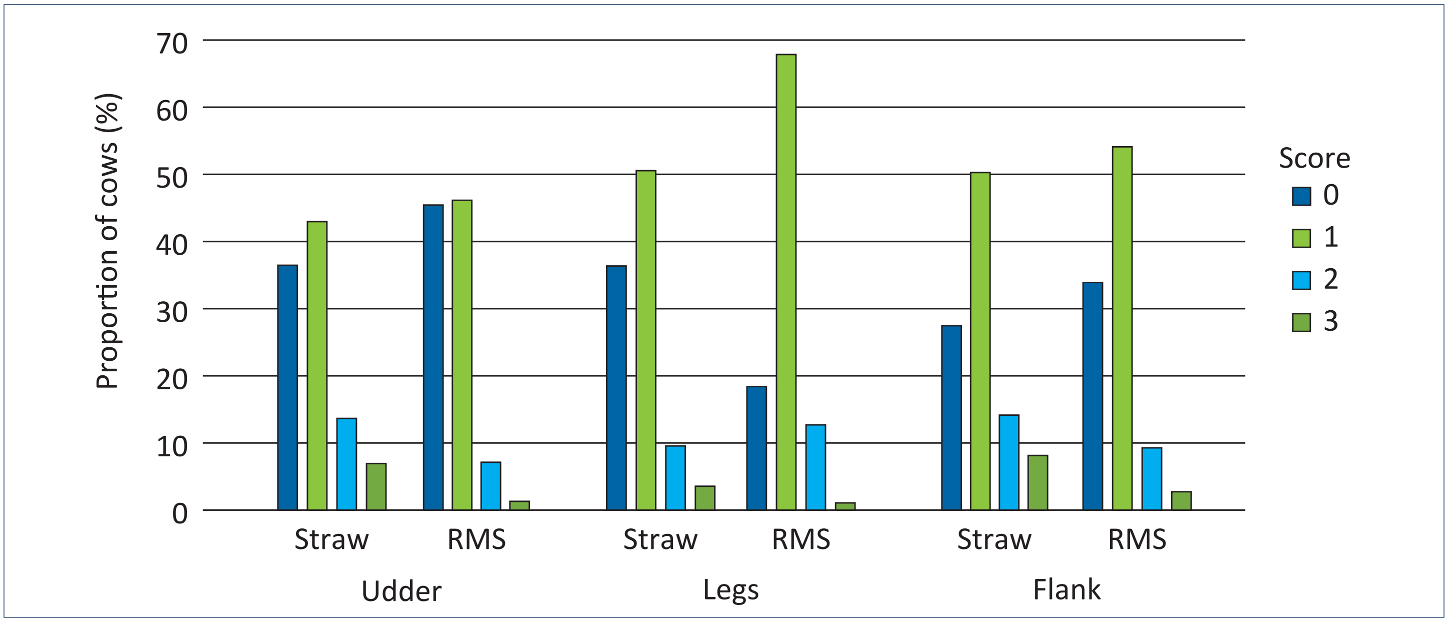


FIGURE 4. Proportion of cows with a given cleanliness score, by body area

- In a preference test, the cows chose the stalls covered with RMSB compared to sand, straw or wood chips bedding. This preference was remarkable when the barn's ambient temperature was colder (Adamski et al., 2011).
- In free housing conditions where RMSB was used, longer rest time and lower lameness and injury prevalence were observed when deep bedding was available compared to shallow bedding covering mattresses (Leach et al., 2015. Husfeldt and Endres, 2012).
- In tie-stalls and on a three-week period, we did not observe differences in rest time or lameness and injury prevalence when the stalls contained 5 or 15 cm of RMSB or 5 cm of chopped straw. However, cows had softer hooves when kept on RMSB compared to straw.
- In tie-stalls, the animals' cleanliness on RMSB was lower compared to straw, especially for the teats (Figure 3). Cows kept on 15 cm of RMSB were generally dirtier than those kept on 5 cm, probably due to the difficulty of keeping a dry stall surface with the deep bedding.

Regarding comfort, RMSB provides an alternative option to conventional bedding. The quantity of bedding used should allow for complete coverage of the stall surface to provide a certain level of softness. Daily bedding management aims to remove excreta and overly wet bedding while keeping the bed surface level.

In the study conducted on commercial farms, cows housed on RMSB had hock lesion scores similar to those housed on straw, indicating a comparable level of comfort.

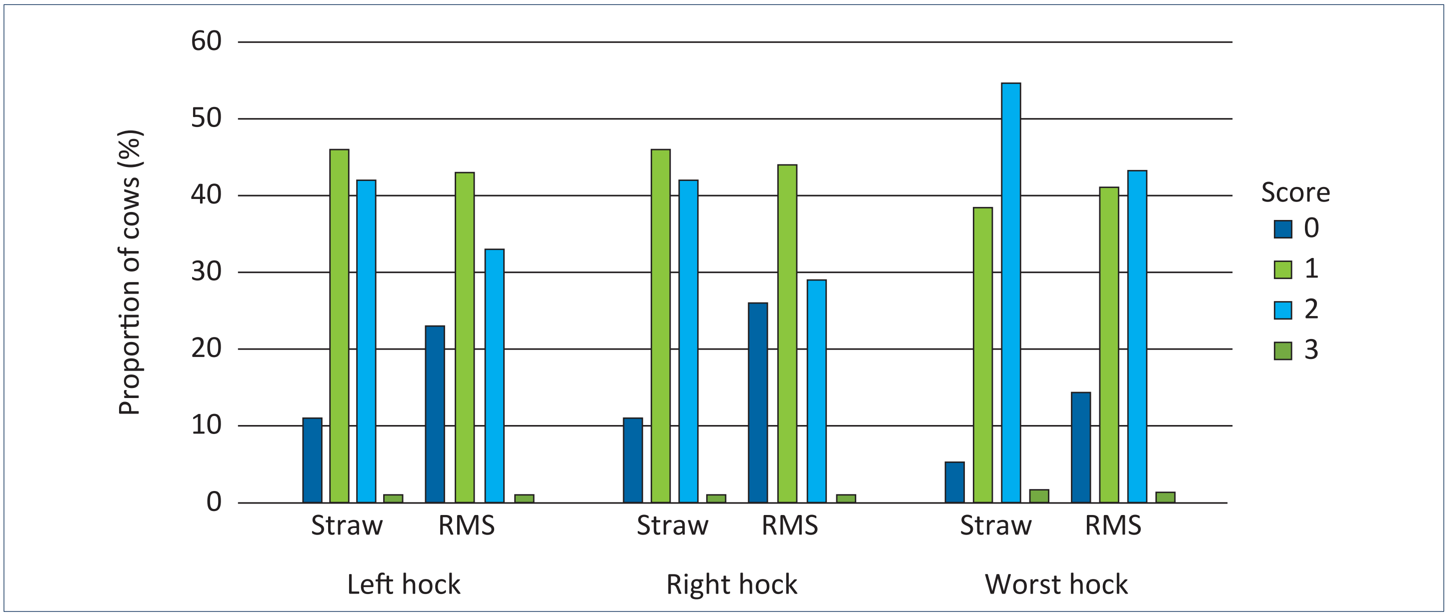


FIGURE 5. Hock injury scores of the cows enrolled on commercial dairy farms

UDDER'S HEALTH

In the study conducted on commercial farms, 11,000 cows were monitored over a one-year period to assess somatic cell count (SCC) dynamics, an indicator used to determine the presence of subclinical mastitis. There was no difference in the lactational SCC average whether cows were housed on Recycled Manure Solids (LFR) or straw.

Furthermore, there was no difference in the total number of clinical mastitis cases experienced by the animals based on the type of bedding. However, the pathogens causing clinical mastitis were different. Cows housed on LFR were seven times more likely to experience a clinical mastitis episode caused by Klebsiella pneumoniae than those housed on straw.

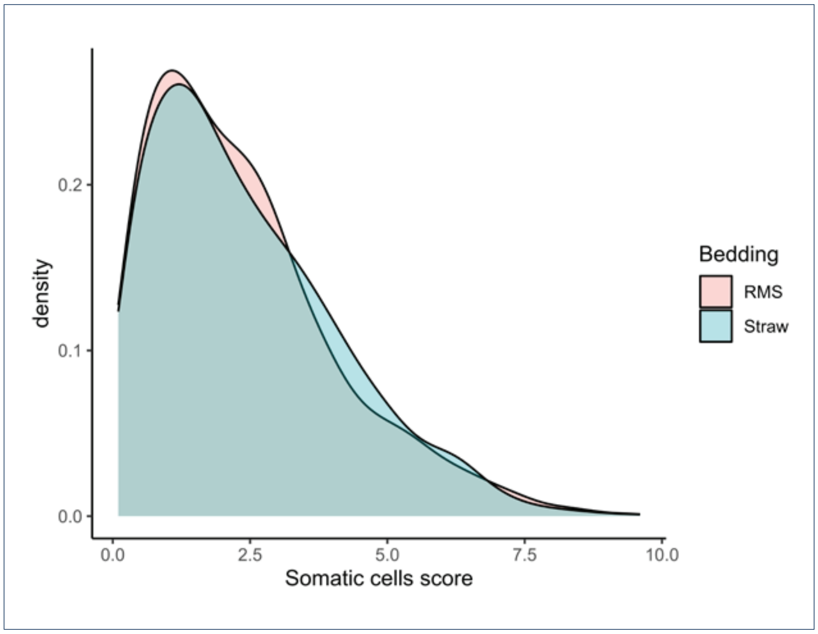


FIGURE 6. Average somatic cells score for different beddings.

Clinical mastitis caused by Klebsiella pneumoniae is severe and can compromise the life of the affected animal. If cows survive, their milk production will be greatly affected, placing them at a high risk of culling.

the scientific community recognizes that the farm environment to some extent influences the microorganisms found in milk. Considering that the udder of the cow is in direct contact with the bedding, microorganisms from the bedding are likely to end up in bulk tank milk. As mentioned earlier, the microbiological quality of the bedding is important, but additionally, the moisture content influences its ability to contaminate the udder (Robles et al., 2020). Indeed, the wetter the bedding, the more likely it is to contaminate the udder and, consequently, the milk. Therefore, special attention during milking should be given to udder cleaning to limit contamination of milk by recycled manure solids during milking.

Results available in the literature regarding the impacts of using RMSB on the microbiological quality of milk vary among different studies. This variability is partly attributable to different farm management practices and RMSB production methods. In the study on commercial farms, Gagnon et al. (2020) demonstrated that the quantity of heat-resistant bacteria was similar between bulk tank milks from farms using RMSB and those using straw. However, in terms of proportions, seven times more Streptococcus spp. and twice as much Enterococcus faecalis were found in the milks from farms using LFR. These heat-resistant bacteria are likely to be present in cheese production, resisting the heat treatment applied to milk, such as pasteurization. During the simulated production of fresh cheddar, the authors did not observe a negative impact of bacteria associated with recycled manure solids. However, it is plausible that Enterococcus faecalis, through milk proteolysis (Figure 7), could affect the taste of the cheese during aging.

Optimizing the production of Recycled Manure Solids (LFR) to limit the quantity of Enterococcus and Streptococcus spp. is an interesting avenue. Zigo et al. (2020) compared the use of straw to an alternative bedding composed of limestone powder, straw, and recycled manure. Microbiological analysis of the beddings showed that the alternative bedding contained fewer coliforms and fecal streptococci than straw.

Figure 7. Growth of non-proteolytic (left) and proteolytic (right) Enterococcus faecalis on milk agar. Credit Mérilie Gagnon

ECONOMIC ANALYSIS OF STRAW BEDDING SUBSTITUTION BY RECYCLED MANURE BEDDING

The economic analysis carried out in this study assessed the break-even point of replacing straw bedding with RMSB for a medium-sized farm. The calculation is based on the use of a screw or roller separator to obtain the solid fraction. This break-even point is measured by the amount of straw applied from which its replacement by RMSB is of equal or lesser cost.

To determine the break-even point of this substitution, annual costs per cow for the use of RMSB and straw bedding were evaluated. The economic analysis was based on a medium-sized farm of 65 dairy cows in Quebec. Replacement subjects are not considered in this analysis. Also, the negative impacts of RMSB on animal health have not been considered (e.g., culling due to clinical mastitis caused by Klebsiella; one cow per year in a herd of this size).

RMSB COST

The annual cost of producing the RMSB is based on ownership of equipment and operating costs (see Table 2). The application cost of the RMSB in the barn has not been accounted for. The total annual cost of producing RMSB per cow, TAC_{RMSB}, is calculated as following: $\mathbf{TAC_{RMSB} = (ACOE + ALC_{RMSB} + AEC)/65}$.

TABLE 2. Details of the RMSB production cost according to the press separator used

	SCREW	ROLLER
Equipment acquisition ($)	**318,000**	**336,778**
Equipment lifespan (years)	**15**	**15**
Building value ($)	**100,000**	**100,000**
Building lifespan (years)	**25**	**25**
CAPE : Coût annuel de possession des équipements ($) [1]	**33,324.84**	**34,838.01**
Standardized hourly wage ($/h)	**18**	**18**
Daily check (minutes/day)	**10**	**5**
Weekly check (minutes/week)	**15**	**15**
Monthly cleaning (minutes/month)	**60**	**15**
Monthly maintenance (hours/month)	**1**	**1**
Annual maintenance (hours/year)	**0**	**2**
$CAMO_M$: Annual labor cost	**1,761.00**	**1,087.50**
Separator consumption (kWh/m^3 litter produced)	**0.38**	**0.13**
Composteur consumption (kWh/day)	**18**	**18**
Amount of RMSB for 65 cows (m^3 or kg)	**3.8 or 16.9**	**4 ou 17.7**
CAE: Annual electricity cost [2] ($)	**641.67**	**610.62**
CTA_{RMB}: Total annual cost ($)	**35,727.51**	**36,536.12**
CTA_{RMB} per cow: Total annual cost per cow ($)	**549.65**	**562.09**

[1] Based on the DIRTA method

[2] The cost of electricity, at rate D, effective since April 1st 2018, is 0.059$ for the first 36 kWh and 0.0912$ for the excess.

STRAW BEDDING COST

The total annual straw bedding cost is based on the annual purchasing cost (APC) and the labor cost for the application (ALC) of the straw. The total annual cost of straw per cow, TACstraw, was calculated as follows: **$TAC_{straw} = (APC + ALC_{straw})/65$.**

APC: Annual Purchasing Cost of Straw

- The amount of straw to be applied per cow per day is typically 3 kg (Adam, 2018). For herds kept in pens with composted or accumulated bedding, the amount of straw needed ranges between 6 and 15 kg per day (Adam, 2018). For this analysis' calculations, the amounts considered were 3, 6, 8,33 and 15 kg of straw per cow per day knowing that 8.33 kg were applied in this study.
- The straw purchase price used was $0.22/kg (a smoothed average price for straw delivered at the farm per quantities declared on Haybec.com between 2016 and 2018). The median and average values of the asking prices were $0.15/kg and, the maximum value was $0.26/kg.

ALC_{straw}: Annual labor cost

- For an average herd of 65 cows, it takes 30 minutes per day to apply the straw. The application time does not vary with the quantity of straw applied per cow but rather with the herd size.

BREAKEVEN

For a farmer to replace straw with RMSB, the straw cost would have to be at least equal to the RMSB cost. Knowing the RMSB cost, the purchase price of straw and the labor cost for its application, the threshold quantity of straw for a profitable substitution (PS) for each of the two manure separators is: **$PS = (TAC_{RMSB} - ALC_{straw})$ / Purchase $price_{straw}$.**

To obtain a daily breakeven, the PS value is divided by 365 days.

RESULTS OF THE ECONOMIC ANALYSIS

The total annual cost per cow of the RMSB production is $550 and $562 respectively for the screw separator and the roller separator (Table 2). The total annual cost per cow for straw bedding varies between $296 and $1278 depending on the amount of straw applied at an average purchase price of $0.22/kg (Table 3).

If a farmer of an average size herd applies 3 kg of straw per cow per day and switches to RMSB, there will be an additional cost of $254 or $266 per cow respectively for the screw separator and the roller separator (Table 3). In this project where 8.33 kg of straw per cow per day was applied, savings of $183 per cow per year can be achieved if the straw is replaced by RMSB produced with a screw separator (Table 3).

Using an average purchase price of $0.22/kg, the breakeven of replacing straw bedding by RMSB is 6.1 kg of straw per cow per day if the farmer chooses the screw separator and 6.2 kg if he opts for the roller separator (Table 4).

TABLE 3. Assessment of gain or loss if straw bedding is replaced by RMSB depending of the type of separator

		ANNUAL LOSS OR PROFIT PER COW WITH RMSB	
Quantity of straw (kg/day/cow)	**Total annual cost of straw per cow**	**Screw separator**	**Roller separator**
3	**$296.05**	**- $253.60**	**- $266.04**
6	**$541.56**	**- $8.09**	**- $20.53**
8.33	**$732.51**	**$182.86**	**$170.42**
15	**$1,278.09**	**$728.44**	**$716.00**

Since the straw purchasing cost is subjected to relatively large fluctuations depending on bale type and size, producing areas, and transportation costs, a sensitivity analysis was also conducted on the purchase price. This analysis shows that with a median asking price of about $0.15/kg of straw, the substitution of straw for RMSB would be profitable only for farms that apply at least 9.2 kg of straw per cow per day, regardless of the separator (Table 4).

TABLE 4. Quantity of straw (minimum daily application rates) to justify substitution of straw by RMSB for the two types of separators used

	STRAW PURCHASE PRICE ($/kg)		
	$0.15	**$0.22**	**$0.26**
Screw separator (kg of straw/cow per day)	**9.18**	**6.10**	**5.20**
Roller separator (kg of straw/cow per day)	**9.41**	**6.25**	**5.33**

IN SUMMARY

The total annual cost per cow for RMSB is lower when a screw separator is used, this cost being $550. Currently, considering an average purchase price of straw of $0.22 per kilogram and a medium-sized herd dairy farmer in Quebec, straw must be applied at a rate of at least 6.25 kg per cow per day in order for a change to RMSB to be profitable.

It is important to mention that other factors can influence the breakeven point and make the substitution of RMSB for straw bedding interesting for smaller amounts of straw use. These factors include, among others, the evolution of RMSB production technology that would reduce costs, an increase in herd size to reach the full capacity of RMSB production equipment, or the production of a drier bedding material that offers better absorption, reducing the amount of bedding needed. Obviously, negative impacts on cow health are more challenging to quantify but should also be considered. For example, the costs of a typical clinical mastitis case have been estimated at $744/case (Aghamohammadi et al., 2018). However, it is well known that clinical mastitis caused by Streptococcus spp. is much more costly than a typical clinical mastitis case, as it often leads to the death of the animal or a cessation of production.

AGRONOMIC VALUE: THE LIQUID FRACTION

PHYSIO-CHEMICAL PROPERTIES

Depending on the separator type, the change in the liquid fraction properties may be major or negligible. In this project, the liquid fraction from the roller separator had the highest C/N ratios (average of 6.18) compared to the other two separators and it was followed by the screw separator (average of 5.08) and than the centrifuge (average of 4.38). In addition, the roller separator produced the effluent with the lowest ($N\text{-}NH_4$ + $N\text{-}NO_3$)/NTK ratio (average of 0.39; P<0.001; Table 5).

Table 5. Ratios C/N, (N-NH4+ + N-NO3)/NTK, N/P and K/(Ca + Mg) of liquid fraction produced by centrifuge (C), roller separator (RS) and screw separator (SS)

PARAMÈTRE	WEEK 1			WEEK 2		
	C	RS	SS	C	RS	SS
C/N	**4.47** [c]	**5.87** [a]	**5.23** [b]	**4.3** [b]	**6.5** [c]	**4.93** [b]
($N\text{-}NH_4$+$N\text{-}NO_3$)/NTK	**0.47** [a]	**0.39** [b]	**0.46** [a]	**0.48** [a]	**0.39** [a]	**0.48** [a]
N/P	**11.02** [a]	**5.82** [c]	**6.08** [b]	**11.65** [b]	**5.65** [a]	**6.33** [b]
K/(Ca + Mg)	**1.39** [a]	**1.02** [b]	**0.96** [c]	**1.38** [c]	**0.96** [a]	**1.04** [b]

[a-c] A different letter indicates a significant difference between the two values within the same week and for the same parameter (P < 0.05).

The nitrogen utilization coefficient is inversely proportional to the C/N ratio and proportional to the ratio ($N\text{-}NH_4$ + $N\text{-}NO_3$)/NTK. In our study, it was 10% higher for the screw separator and the centrifuge (average of 0.65) compared to the roller separator (Table 6). This difference, although small, can become substantial when combined with the effect of the separators on the phosphorus content. Since the centrifuge produced a smaller amount of phosphorus in the liquid fraction than the other types of separators, the N/P ratio was accordingly higher (P <0.001, Table 5).

Table 6. Efficiency coefficient of N, contents of N, P2O5 and K2O, application rate of effective N and K2O for 40 kg of P2O5 of the liquid fractions produced by the centrifuge (C), the roller separator (RS) and that at screw (SS)

PARAMÈTRE	WEEK 1			WEEK 2		
	C	RS	SS	C	RS	SS
Efficiency coefficient of [1]	**0.66**	**0.59**	**0.64**	**0.66**	**0.59**	**0.65**
N efficient [kg/t]	**2.17**	**2.05**	**2.28**	**2.38**	**2.26**	**2.49**
P_2O_5 [kg/t] [2]	**0.62**	**1.23**	**1.2**	**0.64**	**1.4**	**1.24**
K_2O [kg/t] [3]	**2.81**	**2.83**	**2.77**	**3.11**	**3.07**	**3.11**
N efficient for 40 kg of P_2O_5 [kg/ha] [4]	**140.41**	**66.81**	**75.9**	**149.57**	**64.81**	**79.96**
K_2O [3] **for 40 kg of P_2O_5 [kg/ha]** [4]	**181.63**	**92.03**	**92.52**	**195.26**	**88.01**	**100.1**

[1] Efficiency coefficient of N for spring and summer, soil G2-G3, annual crop (CRAAQ, 2010)

[2] Efficiency estimated at 90% (CRAAQ, 2010)

[3] Efficiency estimated at 100% (CRAAQ, 2010)

[4] Recommended doses for intermediate P/Al Mehlich-3 saturation soil (5.1 to 10%) for corn silage cultivation (CRAAQ, 2010)

Mechanical separation alters the agronomic value of the liquid fraction by modifying:

- **The N, P and K contents and, the C/N and ($N\text{-}NH_4$ + $N\text{-}NO_3$)/NTK ratios (Table 5), which determine the total nitrogen fertilization efficiency.**
- **The amount of organic matter and the cation balance (Table 5), which impact soil quality in the long-term.**

FERTILIZING VALUE

In this context, the liquid effluent from the centrifuge may provide a greater share of the crop nitrogen requirement if manure application is limited by soil phosphorus content. For example, for silage corn that has been grown on a soil with an average phosphorus content and considering a guideline of 40 kg P_2O_5/ha (CRAAQ, 2010), the centrifuge's effluent can supply about 145 kg of available nitrogen while both types of press separators provide a maximum of 80 kg (Table 6).

On the other hand, the K_2O applied from the liquid fraction of the centrifuge is twice the recommended application rate (90 kg/ha), whereas this limit would generally be respected by the use of both types of press separators. This excess in K_2O in the centrifuge effluent is even more problematic since the existing imbalance of the K/(Ca + Mg) ratio (differs from 1.00, Table 5) could cause a reduction in Ca and Mg uptake by the culture. Consequently, the application of the centrifuge's effluent to fertilize the crops dedicated to cow feed would be problematic due to poor Ca and Mg contents which could respectively lead to milk fever and grass tetany (Thomas and Miner 1996, Leduc and Robert 1997).

SOIL HEALTH

Since the preservation of soils' health and fertility is linked to the carbon balance, the roller separator has a slight advantage over the screw separator and the centrifuge because it produces a liquid fraction richer in carbon. When reported on its liquid fraction, the roller separator's effluent contains 22.6 kg C/t, while the ones from the centrifuge and the screw separator contain up to 15.1 and 18.7 kg C/t respectively.

When considering fertilization and soil's health, it appears that the screw and roller separators produce a more valuable liquid fraction compared to the centrifuge.

WHAT ABOUT THE ENVIRONMENT IN ALL THIS?

AGRICULTURE, A MAJOR SOURCE OF GHG AND POLLUTANT EMISSIONS

Agriculture is a major source of greenhouse gas (GHG) emissions, which amounted to 7.6 Mt CO^2e in 2016. This represents 9.6% of Québec's total GHG emissions (MELCC, 2018). These emissions come mainly from ruminants' enteric fermentation (38.6%), soil management (29.5%) and manure management (26.7%). Agricultural activities also emit other pollutants into the environment, such as fine particles and ammonia (NH_3). NH_3 is an irritant gas that is toxic when inhaled in very high quantities. It also contributes to acidification, degradation and eutrophication of streams. Some practices have therefore to be improved to reduce the environmental footprint of agriculture.

ENVIRONMENTAL IMPACT LINKED TO BEDDING.

The environmental impacts of the RMSB used in dairy cattle farming were theoretically compared to the ones from a dairy herd in which wheat straw bedding is used. The approach recommended by the Life Cycle Assessment (LCA) methodology targets all activities on and off the farm. Consequently, the emissions considered come from straw harvesting (operations and soils), manure management, RMSB production (separation and composting) and fertilizer application (operations and soils).

The emissions linked to both scenarios are grouped into three impact categories (Table 7): climate change (carbon dioxide equivalent: kg CO_2e*/cow-year), eutrophication potential (phosphate equivalent: kg PO_4^{3}e*/cow-year) and acidification potential (sulfur dioxide equivalent: kg SO_2e*/cow-year). Overall, the GHG emissions of the RMSB scenario are slightly lower (120.2 kg CO_2e/cow-year less) than the one where wheat straw is use. When put in perspective, the RMSB is advantaged as the difference between the two scenarios for a herd of 65 cows is 7814 kg CO_2e/year. This is equivalent to planting 43 trees according to Compensation CO_2 Québec (2018).

The main difference lies with the manure management, as the emissions of the RMSB scenario are lower by 213 kg CO_2e/cow-year. This difference is explained by the fact that the manure solid-liquid separation allows for volatile solids removal from the liquid fraction that is stored. Consequently, the CH_4 emissions from storage are lower in the RMSB scenario.

The difference between both scenarios relative to acidification and eutrophication is negligible. In fact, only the fertilizers application is accounted for these impact categories, whereas the fertilizer application rate is similar for both scenarios.

TABLE 7. Emissions from the wheat straw bedding and the RMSB scenarios

	STRAW LITTER	RMSB
Climatic changes	kg CO_2e / cow per year	
Straw harvest (operations)	17.0	0.0
Straw harvest (soil)	54.2	91.5
Manure management	1,232.5	1,019.6
Manufacturing of RMB		52.7
Spreading fertilizers	1,344.7	1,364.5
Total	2,648.48	2,528.27
Acidification potential	kg SO_2e / cow per year	
Spreading fertilizers	231.1	243.6
Eutrophication potential	kg PO_4e / cow per year	
Spreading fertilizers	28.5	28.8

In this analysis, the impact of the type of bedding on the dairy cows' productivity was not considered. If the use of RMSB is shown to increase productivity, this could help reduce the environmental impact of the RMSB scenario.

GHG AND AMMONIA EMISSIONS FROM THE BARN

As part of the CRSAD research project, GHG and ammonia (NH_3) emissions from the barn using RMSB were compared to the ones from the same building using wood chip bedding. The GHG (CH_4, N_2O and CO_2) and NH_3 emissions were measured in the CRSAD experimental building by multiplying the gas concentration (outlet-inlet) by the theoretical fans' flow. The results showed that GHG emissions from the RMSB building (6.65 g CO_2e/min-cow) were slightly lower than when wood chip bedding was used (8.26 g CO_2e/min-cow). This difference comes mainly from the CH_4 emissions. However, the measured NH_3 emissions were slightly higher with RMSB (3.6 mg/min-cow) compared to wood chip bedding (2.7 mg/min-cow).

The impact of RMSB on barn emissions was not included in the environmental analysis. However, if additional studies can demonstrate that emissions from RMSB barns are lower than with traditional bedding, the emission factors used to calculate CH_4 emissions associated with manure management could be modified to account for the type of bedding used.

FARMERS' PERCEPTION AND EXPERIENCE

The adoption of RMSB in dairy farms brings about changes for the farmers who choose it. In this regard, a study was conducted from a social sciences perspective to understand its implications

A MAJOR CHANGE

It seems that dairy farmers are taking advantage of a renovation or a new construction opportunity to test new systems such as the RMSB.

Farmers find it more practical and easier to introduce the RMSB at the same time as overall improvements to their barn are made. These are required as the building is aging or are favored by a personal financial context conducive to investment.

The adoption of RMSB in their barn first comes with breaking with preconceived ideas as to the nature of manure.

Recycling soiled bedding, previously perceived as "dirty", requires to consider that soiled bedding can become hygienic and reusable. Further, the rational associated with manure being used as a fertilizer for the crops has now to be debunked. In fact, this traditional organic fertilizer is not completely replaced with an equivalent amendment once the solid fraction is removed.

CONTROLLING THE PRODUCTION PROCESS

One element standing out from the research is that the farmers that adopt RMSB have to embark on a steep learning curve to understand and uptake this new system.

The separator is a technical equipment that the farmer must understand and operate on their own. The supplier will generally adjust the machine and guide the producer. However, small adjustments will be necessary over time to optimize the process according to the specific conditions of the farm, such as during the first winter or a change in the cows' diet. Trial and error are crucial as they develop different ways of doing things. Adding water to the manure before separation to facilitate processing by the machine may be necessary. The producer will rely on both a device to measure moisture content and their senses to smell, touch, and observe the RMSB during production.

Producers express uncertainties regarding the organic matter content of the liquid fraction (derived from the separation).

Their reasoning is more in terms of fertilization of the plant, than in terms of soil amendment, and the farmers sometimes question the long-term effects of a potential change in the manure fertilizing content.

[3] Qualitative research: 14 semi-directed interviews with farmers from 5 regions of Quebec (Montérégie, Estrie, Centre du-Québec, Chaudière-Appalaches, Mauricie), visit to their dairy farms having adopted the RMB, and 11 additional interviews in the technical network, particularly with researchers and equipment suppliers.

CONDITIONING

The conditioning operation is perceived as essential to the acceptance of the RMSB, as producers believe it helps sanitize the solid fraction. Conditioning leads to the understanding that there are "good bacteria" in this fraction that facilitate composting, representing a significant mindset shift for the producer.

Temperature management in the composter is seen by producers as a crucial aspect of the system.

Producers state that they need to assess the achievement of a satisfactory heat release to destroy pathogens during the conditioning of the RMSB. They rely on their senses and sometimes temperature measurements. However, the presence of numerous pathogens in the RMSB evaluated in this study seems to question this assessment by producers. The veterinarian may sometimes intervene, especially when certain producers have the solid fraction and then the RMSB analyzed after composting.

A COZY BED

The ways of applying the RMSB under the cows that were observed during the project varied greatly. They depend on several factors such as the farmer's working habits (work schedule, disturbing the animals as little as possible), the building type (free housing, tie-stalls, hollow/basic stalls), the material used previously (wood chip/sawdust) or external factors to the farm (like seasonal changes). A benchmark on how to do it does not seem to exist.

However, the application is taken seriously by the farmers interviewed. According to them it is when the cow comes into contact with the RMSB that a cow's disease can develop itself and challenge the acquired practice.

ANIMAL WELFARE CONSIDERATIONS

One of the main strengths of the RMSB is the animal's welfare improvement, which dairy farmers describe by the resting behaviors and the general state of their animals.

They observe that the cows spend more time lying down, have fewer injuries and are noticeably cleaner. Note that the economic aspect linked to the fact that bedding material is no longer bought but produced on the farm seems to results in larger amount of bedding being applied under the animals, which plays a role in the comfort offered to the cows.

Farmers also see the introduction of RMSB on dairy farms as part of a wider movement (in the industry and the society) demanding better animal welfare on farms, especially at the consumers' and markets' requests. Moreover, farmers who adopted RMSB have usually modified the barn from tie-stalls to free housing to promote animal welfare. The farmer's work habits encompass, in fact, several major changes related to these technical transformations.

However, they consider that the farm's performance can be increased by the adoption of RMSB due to lower bedding costs but also higher cows' productivity.

BALANCE BETWEEN COWS' COMFORT AND HEALTH

The farmers interviewed are acutely aware of the difficult balance they have to maintain since the adoption of the RMSB. They state that they daily pay more attention to the health of their cows. When the RMSB is used in the barn, several abnormal situations may be observed: high leucocyte count, recurrence and/or virulence of udder's infection. To solve these issues, additional care is given to the cows. This remedial approach can be burdensome in terms of costs, animal welfare and time allocated to treatments, but especially with everything linked to a reduction of the cows' productivity.

The veterinarian is therefore the main support to the farmer, with his guidance on the care of the cows but also with his help in the analysis of the RMSB to root out anomalies and potentially harmful elements that can affect cows' udder and health. Changes can then be made to the RMSB production and application.

For some, the animals' health problem will be solved, but for others the search for solutions does not succeed and can lead to the abandon of RMSB use.

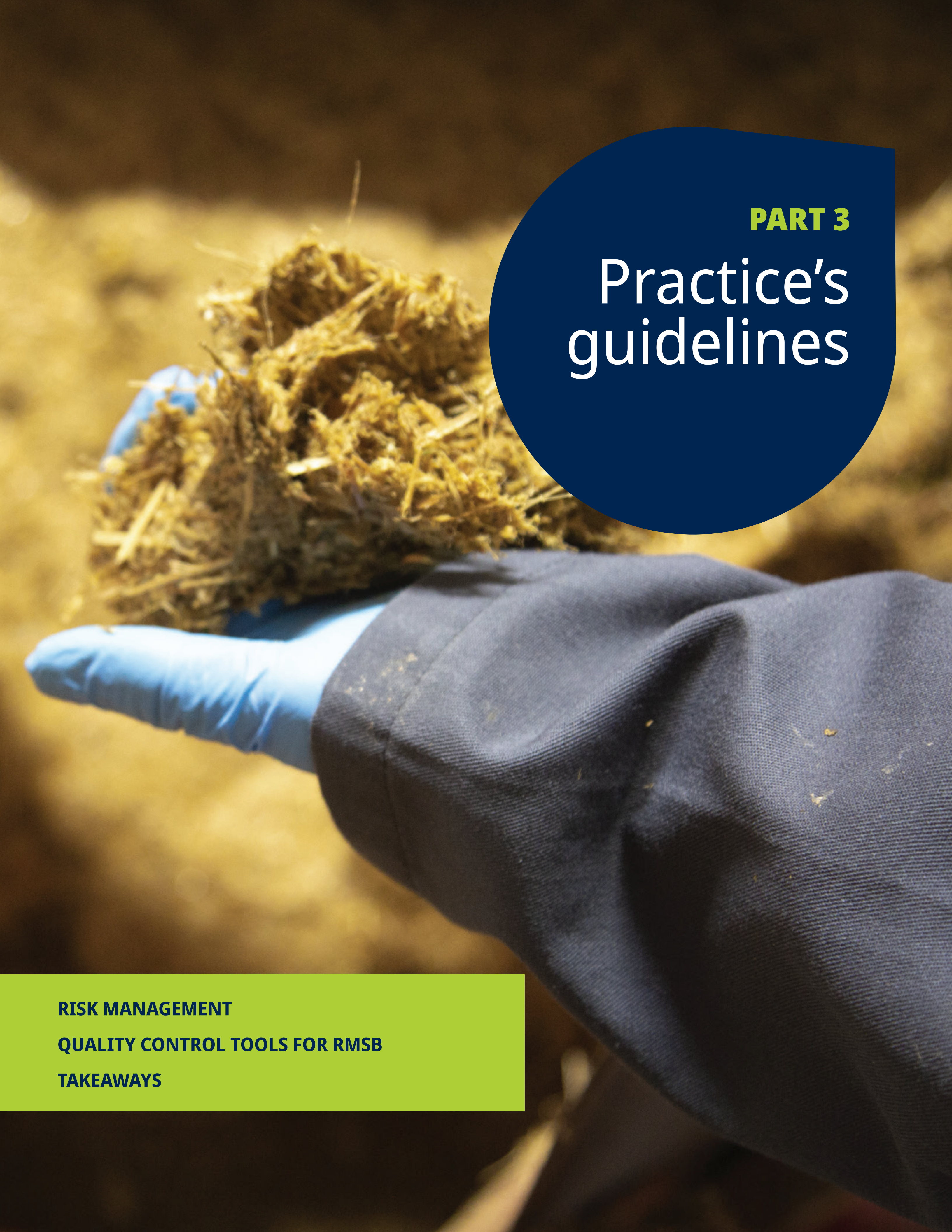
SEVERAL QUESTIONS REMAIN

The use of the RMSB presents advantages for the farmers interviewed: financial savings, improved comfort of the cows, circular reuse of manure. However, they believe that the implementation occasionally results in animal health issues, which may even hinder its adoption into on-farm practices. Moving toward RMSB also means mastering new equipment and the conditioning microbiological process. The RMSB also goes hand in hand with animal welfare considerations on the farm; but these are sometimes challenged by herd's health.

The overall interviews done highlight the learning curve and development of on-farm expertise. Since few clear guidelines exist in this field, a singular mode of knowledge transmission emerges with a network created from the base up to the machinery designers and the scientists. On-farm experimentation generates a know-how then shared within dairy farming networks.

It is clear that the RMSB challenges several preconceived ideas, including those related to the very nature of manure. Consequently, this comes with important social, cultural and conceptual adjustments in dairy farming.

So far, the use of RMSB has had a limited impact on the microbiological quality of milk, but its use is relatively recent. Due to its production, long-term use (over several years) may promote heat-resistant bacteria in milk, which could be problematic for dairy processing.



PART 3

Practice's guidelines

RISK MANAGEMENT

QUALITY CONTROL TOOLS FOR RMSB

TAKEAWAYS

RISK MANAGEMENT

Once applied under the cows, the bedding quickly becomes soiled by fresh animal waste. The RMSB that accumulates under the animals should not become an environment conducive to microorganisms' development and proliferation, particularly pathogens. The three main conditions promoting the microorganisms' development and proliferation are: **moisture, heat** and **nutrients**. On those points, conditioning the solid fraction:

- **reduces the moisture content** of the solid fraction obtained by mechanical separation;
- **reduces the microbial load**, especially pathogens and,
- **stabilizes the product** (reduce the fermentable nature of the organic material).

MOISTURE CONTENT REDUCTION

All microorganisms need water to grow therefore moisture removal in the RMSB is desirable to limit their proliferation. **The RMSB applied under the cows should not be too moist so udder diseases are not triggered, or too dry to avoid excessive dust being generated during handling**. The conditioning reduces moisture content according to the composting time and the ventilation rate through the material.

Drying with aerobic conditioning is a good risk management practice. A dryer RMSB sticks less to the teats and limits the environmental conditions conducive to microbial growth.

MICROBIAL LOAD REDUCTION

Materials (plant-based or manure) used as bedding should be free of pathogens in order to minimize the risk of disease in a herd. Sanitation by the temperature increase resulting from intense microbial activity during composting has long been recognized. Several countries, such as the United States, have adopted sanitation criteria (combination of temperature and composting residence time) to reduce for microbial load and regulate the safe use of residual materials and compost.

SANITATION BY THERMOPHILIC COMPOSTING PROCESSES (USA)
The US Environmental Protection Agency (EPA, 2018) sanitation requirements for reducing the microbial load and pathogen content of municipal sludge composts stipulate that the temperature in the compost must be maintained at:

- **55°C or more for at least 3 consecutive days for composting processes in aerated static piles or in enclosures;**
- **55°C or more for at least 15 consecutive days for windrows turned 5 times.**

By analogy, it is reasonable to believe that conditioning operations that do not meet the parameters listed in the "Process to Further Reduce Pathogens (PFRP)" (Environment Protection Agency, 2018) guideline could produce a material who's microbial and pathogens loads present a higher level of health risks.

During conditioning and under optimal operating conditions, the temperature within a heap of solid fraction (chamber, bioreactor, silos, piles) can quickly reach the necessary temperatures for sanitating (>55° C). Conserving the heat produced by bacteria is an important key to maintaining high temperatures and for the conditioning success. Consequently, **very cold winter conditions may require insulation of the conditioning enclosure**.

STABILIZING THE ORGANIC MATTER

The conditioning of the solid fraction, as currently done on commercial farms, is much too short and does not allow the microbial population to consume energy and nutrients before the distribution of RMSB under the cows. Indeed, since this process is incomplete, bacterial proliferation occurs when the bedding is under the animals. However, a complete process would require more than three weeks, which seems hardly achievable under current production conditions.

QUALITY CONTROL TOOLS FOR RMSB

Conditioning requires monitoring and maintaining the favorable conditions to the development of aerobic microorganisms. **The characteristics of the solid fraction and the operating conditions must be rigorously monitored (moisture, structure, temperatures)**.

Key parameters to control for the production of a RMSB suitable for its use under the cows include dry matter content and composting residence time at high temperature. These parameters can be easily measured on the farm. Although they do not reveal the presence of pathogens, they are indicators of the performance of the conditioning process and consequently of the quality of the RMSB produced.

FIGURE 8. Koster® device for dry matter content measurements

The measure of the dry matter contents is done using an oven and a scale under controlled temperature conditions until a constant dry weight is obtained. Some producers use a device that assess the animals' feed moisture content, such as Koster® (Figure 4) Such a device can not replace a laboratory analysis but it can estimate RMSB dry matter content rather quickly.

To measure the temperature in a pile or windrow being conditioned, a long-stem thermometer is required to reach the center of the heap. A 48" (120 cm) long thermometer is usually adequate. The thermometers used can be the types "dial" with expansion coil or "electronic" with thermocouples (Figure 5).

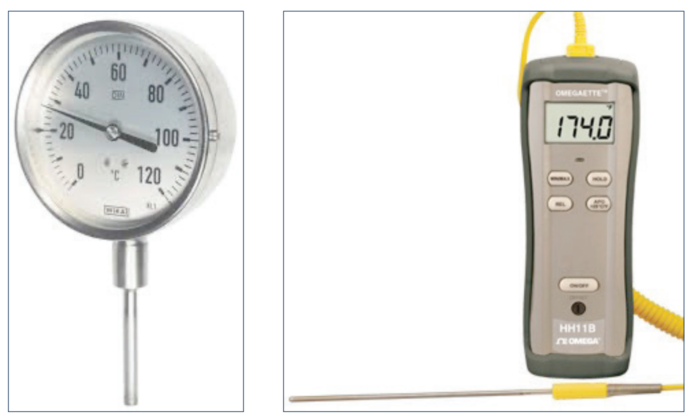


FIGURE 9. a) Dial or b) electronic thermometers for temperature measurements

FARM RISK MANAGEMENT

To minimize the potential impacts of using RMSB on animal health, several critical points can be assessed with the veterinarian and farm stakeholders. Firstly, cows should have access to a high-quality diet and management conditions that minimize animal stress. Milking procedures should be optimal to ensure proper teat cleaning and to avoid overmilking, which could damage teat ends and compromise the first line of defense against the introduction of pathogens. Finally, a clinical mastitis vaccination program should be implemented on the farm.

TAKEAWAYS (Study and literature)

Separation for RMSB production

The separation aims to extract solids from the slurry/manure, which consists of undigested fibers, unconsumed feed, bedding from calving pens, etc. The solid fraction may contain pathogens responsible for certain diseases in cows.

CRITERIA TO CONSIDER FOR THE SOLID FRACTION

- **Particle Size: Limit particles < 1 mm**
  (Excessively fine solid fraction = excessively fine RMSB)

AVAILABLE SEPARATOR TYPES

- **Sieve Separator**
  - Uncommon, tends to clog in a northern climate.
- **Screw Separator or Roller Press (recommended in this study)**
  - Choice depends on processing capacity, type of input, and product characteristics.
  - Breakeven point reached if RMSB replaces 6.1 kg to 9.2 kg of straw (at a purchase price of $0.22/kg to $0.15/kg).
- **Centrifuge**
  - Expensive (both in acquisition and energy consumption during operation).
  - Fine-structured solid fraction.
  - Less desirable liquid fraction.

SEPARATION FOR RMSB PRODUCTION

FIGURE 10. Physical processes for concentrating solid residues

Conditioning of the RMSB

Conditioning through an aerobic biological process requires rigorous monitoring of the thermophilic phase, residence time, aeration rates, and dry matter content.

3 TECHNIQUES FOR AEROBIC BIOLOGICAL PROCESS

- **Mechanically turned windrows**
  > 55°C, minimum 15 days with 5 turnings
  - Requires more handling and time.
  - Lower respiratory health risks: compliance with exposure limits (EL).
- **Static piles with forced aeration**
  > 55°C, minimum 3 days
  - Lower respiratory health risks: compliance with EL.
- **Closed aerated chambers (rotary cylinders, closed containers, horizontal silos)**
  > 55°C, minimum 3 days. Isolate to maintain high temperature during winter.
  - Allows control of operational parameters, maintaining a constant thermophilic phase, and obtaining a consistent quality product.
  - A residence time of 72 hours in a rotary cylinder increases dust quantity (compliance with the exposure limit, EL), bacteria, and molds (exceeding EL) that can be inhaled during handling.

CONDITIONING

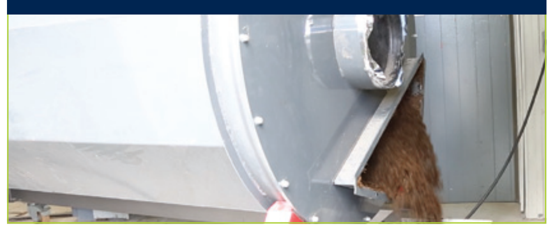


FIGURE 11. Conditioning process of the RMSB production

QUALITY CRITERIA AFTER CONDITIONING

- **Particle Size: Limit particles < 1 mm**
  (LFR plus grossière limite le compactage sous les vaches et la quantité de bioaérosols lors de sa manipulation).

Management and maintenance of the RMSB

The management and maintenance of RMSB are as important as the initial quality of the bedding.

Conditioning processes used for producing bedding do not allow control over the presence of pathogens in the ready-to-use bedding.

A respiratory protection mask is recommended for RMSB distribution, as well as wearing gloves.

APPLICATION OF THE RMSB

FIGURE 12. Application of the RMSB

RECOMMENDATIONS AND OBSERVATIONS

- **In general**
  - Completely and evenly always cover the stall surface.
  - Maintain RMSB at least twice a day to remove fresh excrement, stir it, and add more as needed.
  - The quantity and frequency of application influence the coverage, compressibility, and humidity rate of the stall surface, as well as comfort.
  - The use of RMSB did not increase the total number of cases of subclinical or clinical mastitis.
  - The risk of clinical mastitis caused by Klebsiella pneumoniae was significantly higher in cows housed on this bedding.
  - Hygiene, comfort, and resting time (11-14 h) were similar for RMSB and straw.
  - Cows preferred RMSB when the ambient temperature was colder (Adamski et al., 2011).
  - Greenhouse gas emissions in the barn were lower with RMSB than with wood shavings.
- **In general, the ready-to-use RMSB contained more bacteria than straw, but once used, the beddings were comparable.**
  - Cows housed on RMSB had a higher frequency of gastrointestinal parasites (e.g., cryptosporidia, coccidia) than those on straw. The manure conditioning did not destroy these pathogens.
  - RMSB should not be used under animals under six months of age and in calving areas.
- **Farm workers should wear gloves when handling RMSB**
  - A plan should be developed with the veterinarian and various interveners.

Fertilizing value of the liquid fraction

The liquid fraction is still an interesting fertilizer for the crops.

EFFECT OF SEPARATION ON THE LIQUID FRACTION'S FERTILIZING VALUE

- **Roller separator**
  - Higher C/N ratio and lower ($N\text{-}NH_4$ + $N\text{-}NO_3$)/NTK ratio compared to the ones of the other two separators
  - The carbon balance promotes soil health and fertility
- **Centrifuge**
  - RN/P ratio almost double the ones of the other two separators. Can provide a greater share of nitrogen to crops if manure application is limited by soil phosphorus content
  - Risk of excessive K_2O
  - The imbalance in the K/(Ca + Mg) ratio could cause a decrease in Ca and Mg plant uptake. This could lead to milk fever and grass tetany if the crops are used to feed the cows
- **Environmental impacts**
  - Impacts on eutrophication and acidification similar between RMSB and straw bedding
  - GHG emissions due to storage of fertilizer residues resulting from the use of RMSB are lower compared to straw bedding

FERTILIZER VALUE LIQUID FRACTION

FIGURE 13. Fertilization with the liquid fraction resulting from the production of LFR.

References

Adam, S., Valacta. Personal communication, September 2018.

Adamski, M.; Glowacka, K.; Kupczynski, R.; Benski, A. (2011). *Analysis of the possibility of various bedding beddings application with special consideration of cattle manure separate*. Acta. Sci. Pol. Zootechnica. 10(4):5-12.

Charlton, G. L.; Bouffard, V.; Gibbons, J.; Vasseur, E.; Haley, D.B.; Pellerin, D.; Rushen, J.; de Passillé, A.M. (2016). *Can automated measures of lying time help assess lameness and leg lesions on tie-stall dairy farms?* Appl. Anim. Behav. Sci. 175:14-22.

Conseil national pour les soins aux animaux d'élevage (CNSAE) (2009). *Code de pratiques – Pour le soin et la manipulation des bovins laitiers*. Conseil national pour les soins aux animaux d'élevage, Agriculture et Agroalimentaire Canada, 67p.

Compensation CO2 Québec (2018). Calculer et compenser vos émissions. [Online] http://www.compensationco2.ca/calcul-emissions-co2/#compensationdirecte (Page consultée le 10 décembre 2018).

Centre de référence en agriculture et agroalimentaire du Québec (CRAAQ) (2010). *Guide de référence en fertilisation du Québec*. 2e édition. Centre de référence en agriculture et agroalimentaire du Québec (CRAAQ), Ste-Foy, QC, Canada.

Donham, K.J. (1986). *Hazardous agents in agricultural dusts and methods of evaluation*. Am. J. Ind. Med. 10 (3):205-220.

Environment protection agency (EPA) (2018). Protection of Environment – Standards for the use or disposal of sewage sludge (Code of Federal Regulation, 40 part 502), United States Environmental Protection Agency, United States Government. [Online] https://www.govinfo.gov/content/pkg/CFR-2018-title40-vol32/xml/CFR-2018-title40-vol32-part503.xml

Fávero, S.; Portilho, F.V.R.; Oliveira, A.C.R.; Langoni, H.; Pantoja, J.C.F. (2015). *Factors associated with mastitis epidemiologic indexes, animal hygiene, and bulk milk bacterial concentrations in dairy herds housed on compost bedding*. Livest. Sci. 181:220-230. [Online] https://doi.org/10.1016/j.livsci.2015.09.002.

Fournel, S.; Godbout, S.; Ruel, P.; Fortin, A.; Généreux, M.; Côté, C.; Landry, C.; Pellerin, D. (2019a). *Production of recycled manure solids for use as bedding on Canadian dairy farms: I. Solid-liquid separation*. J. Dairy Sci. 102(2):1832-1846.

Fournel, S.; Godbout, S.; Ruel, P.; Fortin, A.; Duquette-Lozeau, K.; Létourneau, V.; Généreux, M.; Lemieux, J.; Potvin, D.; Côté, C.; Duchaine, C.; Pellerin, D. (2019b). *Production of recycled manure solids for use as bedding in Canadian dairy farms: II. Composting methods*. J. Dairy Sci. 102(2):1832-1846.

Hauge, S.J.; Kielland, C.; Ringdal, G.; Skjerve, E.; Nafstad, O. (2012). *Factors associated with cattle cleanliness on Norwegian dairy farms*. J. Dairy Sci. 95:2485-2496. [Online] https://doi.org/10.3168/jds.2011-4786.

Husfeldt, A. W. et Endres, M.I. (2012). *Associations between stall surface and some animal welfare measurements in freestall dairy herds using recycle manure solids for bedding*. J. Dairy Sci. 95:5626-5634.

Kullman, G.J.; Thorne, P.S.; Waldron, P.F.; Marx, J.J.; Ault, B.; Lewis, D.M.; Siegel, P.D.; Olenchock, S.A.; Merchant, J.A. (1998). *Organic dust exposures from work in dairy barns*. Am. Ind. Hyg. Assoc. J.59 (6):403-413.

Leach, K.A.; Archer, S.C.; Breen, J.E.; Green, M.J.; Ohnstad, I.C.; Tuer, S.; Bradley, A.J. (2015). *Recycling manure as cow bedding: Potential benefits and risks for UK dairy farms*. The Vet. J. 206:123-130.

Leduc, R. et Robert, L. (1997). *Alimentation: Spécial K*. Le producteur de lait québécois. Vol. Avril, pages 38-40.

Ministère de l'environnement et de la lutte contre les changements climatiques (MELCC) (2018). *Inventaire québécois des émissions de gaz à effet de serre en 2016 et leur évolution depuis 1990*. Direction générale de la réglementation carbone et des données d'émission, 40 p. [Online] http://www.environnement.gouv.qc.ca/changements/ges/.

Rowbotham, R. F. et Ruegg, P.L. (2015). *Association of bedding types with management practices and indicators of milk quality on larger Wisconsin dairy farms*. J. Dairy Sci. 98:7865-7885.

Rowbotham, R.F. et Ruegg, P.L. (2016a). *Association of selected bedding types with incidence rates of subclinical and clinical mastitis in primiparous Holstein dairy cows*. J. Dairy Sci. 99:4707-4717.

Rowbotham, R. F. et Ruegg, P.L. (2016b). *Bacterial counts on teat skin and in new sand, recycled sand, and recycled manure solids used as bedding in freestalls*. J. Dairy Sci. 99:6594-6608.

Sant'Anna, A. C. et Paranhos da Costa, M.J.R. (2011). *The relationship between dairy cow hygiene and somatic cell count in milk*. J. Dairy Sci. 94:3835–3844.

Schenker, M.B.; Christiani, D.; Cormier, Y.; Dimich-Ward, H.; Doekes, G.; Dosman, J.; Douwes, J.; Dowling, K.; Enarson, D.; Green, F.; Heederik, D.; Husman, K.; Kennedy, S.; Kullman, G.; Lacasse, Y.; Lawson, B.; Malmberg, P.; May, J.; McCurdy, S.; Merchant, J.; Myers, J.; Nieuwenhuijsen, M.; Olenchock, S.; Saiki, C.; Schwartz, D.; Seiber, J.; Thorne, P.; Wagner, G.; White, N.; Xu, X.P.; Chan-Yeung, M. (1998). *Respiratory health hazards in agriculture*. Am. J. Respir. Crit. Care Med. 158 (5): S1-S76.

Solano, L.; Barkema, H.W.; Pajor, A.E; Mason, S.; LeBlanc, S.J.; Nash, C.G.R; Haley, D.B.; Pellerin, D.; Rushen, J.; de Passillé, A.M.; Vasseur, E.; Orsel, K. (2016). *Associations between lying behavior and lameness in Canadian Holstein-Friesian cows housed in freestall barns*. J. Dairy Sci. 99:2086-2101.

Thomas, E.D et Miner, W.H. (1996). *Fertilizing forages*. In Dairy Day at Miner Institute. The William H. Miner Agricultural Research Institute, Chazy, NY.

How refer to this document:

Godbout et al., 2019. Recycled Bedding in Dairy Production: Current State of Knowledge and Guidelines. CRSAD-IRDA, 51 pages

For more information, contact:

Stéphane Godbout
Institut de recherche et de développement en agroenvironnement (IRDA)
2700, rue Einstein, Québec (Québec) G1P 3W8
Phone: 418 643-2380, ext. 600
Email: stephane.godbout@irda.qc.ca

Project and writing team

- Steve ADAM, agr. (Valacta)
- Luc BELZILE, M. Sc. (IRDA)
- Patrick BRASSARD, ing. jr, Ph. D. (IRDA)
- Lila CHAUVEAU, B. Sc., étudiante à la maîtrise (Université du Québec à Rimouski)
- Caroline CÔTÉ, agr., Ph. D. (IRDA)
- Caroline DUCHAINE, Ph. D. (IUCPQ – Université Laval)
- Simon DUFOUR, DMV, Ph. D. (FMV – Université de Montréal)
- Karine DUQUETTE-LOZEAU, B. Sc., étudiante à la maîtrise (IUCPQ – Université Laval)
- Gilles FECTEAU, Diplomate ACVIM (FMV – Université de Montréal)
- Sébastien FOURNEL, ing., Ph. D (Université Laval)
- Mylène GÉNÉREUX, M. Sc. (IRDA)
- Stéphane GODBOUT, ing., agr., Ph. D. (IRDA)
- Denise GODONOU, ing., M. Sc. (IRDA)
- Christine LANDRY, agr., Ph. D. (IRDA)
- Valérie LÉTOURNEAU, Ph. D. (IUCPQ – Université Laval)
- Ariane LÉVESQUE, ing. jr, M. Sc. (IRDA)
- Salma OUSLATI, étudiante à la maîtrise (Université Laval)
- Denis POTVIN, agr., B. Sc. (IRDA)
- Pierre RUEL, ing. (CRSAD)
- Marianne VILLETTAZ ROBICHAUD, agr., Ph.D. (FMV – Université de Montréal)
- EDITING AND TRANSLATION: Liliane CHÉNARD, M. Sc.

The funding for this research comes from the Canadian Agricultural Adaptation Program of Agriculture and Agri-Food Canada. The authors thank all collaborators in the project, specifically GEA and the farms Hamelin et Fils, Boivert inc., Aston inc., Landrynoise inc., Barmlait inc., and Rufer inc. The authors also thank all technicians and workers from CRSAD and IRDA who actively participated in the project.