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Communication

A Composting Bedding System for Animals as a Contribution to the Circular Economy

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Abstract: By-products from forestry, agriculture and nature areas are used in compost bedded-pack housing (CBP) systems for animals. In this communication, we discuss the application of a CBP system to animal farms and aspects related to the recycling and reuse of the materials in the context of a circular economy. This study is based on data from ongoing projects and literature. The following systems are discussed: (i) composting material applied to a specialized animal housing system; (ii) adding a horticultural component to the animal farm by reusing the compost, and (iii) a cooperative mixed cattle and crop farming system. The success of integrating a compost bedding component in the system depends largely on the skills of managing the composting process, the application of the material in the field, and the cost of acquiring the material. When materials are amply available, then a real contribution to the circular economy can be made. Cooperation between farmers in the utilization of by-products is another route to a more circular economy. Moreover, the analyzed systems can be seen as a Greenhouse Gases (GHG) mitigation practice because they store carbon in the soil and improve soil quality.

Keywords: by-products; composting material; animal housing; field application; circular economy; carbon storage

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1. Introduction

There are many definitions of circular economy [1]. One definition is "an economic system of closed loops in which raw materials, components and products lose their value as little as possible, renewable energy sources are used, and system thinking is at the core". The three key Rs of sustainability are Reduce, Reuse and Recycle. Thus, the recycling and reuse of materials in agriculture contribute to a sustainable circular economy. An example is the recycling of wood remnants from sawmills, straw from grain farming, grass cuttings from nature areas and roadsides, and discarded thatch from roofs. Such materials are used in animal housing as bedding. In this communication, we focus mainly on the bedding materials used in cattle barns, especially the innovative compost bedded-pack (CBP) barns where the materials are gradually mixed with animal excreta and regularly aerated. After some time, when the bedded-pack is (semi) composted, the compost is applied to the land and reused as a soil improver.

The majority of cows in the Western world are housed in cubicle barns (free stalls; Figure 1) [2,3]. One cubicle per cow is ideal and a limited amount of bedding material is used (see Figure 1). The CBP barn (Figure 2) has a lying and movement area which, on average, is more than twice that in a cubicle barn [4]. The bedding material layer increases over time as fresh material is regularly added. The amount of bedding material used is known to be significantly higher than the quantity used in cubicle housing [4] and it gradually undergoes a composting process [5]. The CBP system for cattle was initially developed in Israel and the USA and spread, with some modification, to Europe in the last decade. Presently, it is increasing as a system in Brazil [6]. It allows cows more freedom of movement than conventional tie-stalls and cubicle barns [2–4]. The CBP is composed of a large bedded-pack, located in part of the barn and most times separated from the feed alley by a 0.5–1 m high concrete wall. A successful composting process requires the input of oxygen, so the bedded-pack is mechanically cultivated once or twice daily (see Figure 3). Additional assistance to the composting process is provided, especially in the Netherlands, by supplementary aeration of the bedded area. For this, pipes are laid on the floor under the bedded-pack (Figure 3), which facilitates either the sucking or pushing of air through the pack [3].

Figure 1. Cubicle barn for dairy cows.

Figure 2. Compost bedded-pack (CBP) barn for dairy cows.

Figure 3. Illustration of the stimulation of the composting process by mechanically aerating with oxygen into the pack (**left**) and the use of pipes in the concrete floor for suckling or pushing air in the bedded-pack (**right**). Source: Authors.

Most studies describe the CPB barn as animal welfare friendly (less lameness, fewer hock and leg lesions, and more natural behavior than in common housing systems) [7,8], but opinions differ on the effects on animal health. A review study [4] did not indicate real differences with respect to somatic cell count in milk from CBP compared to cubicle housing, but a study in progress using data from the FreeWalk project reported higher cell counts in the CPB system [9]. In general, a tendency towards increased longevity of the cow herd is observed while estimates of the costs of housing differ. A multi-criteria analysis in Europe estimated higher costs for the CBP system mainly because of its larger surface area per animal [10]. In contrast, US researchers reported lower costs for the CBP system [2]. Although housing construction requirements and costs differ among countries there is a general agreement that the CBP system has higher bedding costs than cubicle housing [2,10,11].

Compost bedding systems are also used in poultry husbandry [12]. Manure from poultry is drier than manure from cattle, which results in different management of the pack. Scratching of the pack by the birds serves as a natural means of aeration, in contrast with the mechanical cultivation used in CBP for cattle.

Compost production experiments in catering companies dealing with food waste [13], as well as agronomic characteristics of [14] and gaseous emissions from the CBP materials [15] were studied in view of circular processes. To our knowledge, no study has been reported linking CBP as a holistic system to the circular economy. This communication study attempts to fill that gap. Aspects of three possible CBP systems (animal based, animal plus horticulture, and mixed farming) are illustrated in the context of a circular economy. Furthermore, farmer and consumer perceptions towards the compost bedding systems are summarized, and the key practices and difficulties to the successful application of the system are synthesized and discussed on the basis of existing projects and literature sources.

2. Materials Used

This communication synthesizes the results from previous and ongoing studies. It is based on results from: (1) the FreeWalk project [16], with some additional analysis and observations. The FreeWalk project collected animal, climate, and nitrogen and phosphorus data from a group of study farms across six European countries. A sample of 22 CBP case farms and 22 reference cubicle farms with cattle were monitored during six visits in a two-year period (2018–2019). The case and reference farms were paired based on similar characteristics and region. Farmer and consumer perceptions of the two housing systems in the participating countries were assessed using surveys during 2018. In total, 78 farmers from six European countries, all known to are working or acquainted with the two housing systems, and 3693 consumers from eight European countries, participated in the respective surveys. (2) First outcomes of the Climate Care Cattle farming project [17], which monitors 60 innovative farms in Europe in relation to carbon management and methane and ammonia emissions from the barns and fields. (3) Information about the management of bedding materials in poultry housing. (4) Literature sources (39), which supported describing the merit of compost bedding material systems for a circular economy.

3. Practices and Synthesis of Results

3.1. Circular Systems of Applying Bedding Material

Three such systems are described:

3.1.1. Application on a Dairy Farm

Wood chips and sawdust, among other materials, are used to develop the bedded-pack of, on average, 15 m^2 per cow with a rather wide variation between countries [2–4]. The pack is mechanically aerated by use of a tractor with tillers. Additional aeration is provided by pipes installed to stimulate the composting process [3]. In spring, the exhausted pack material is transported and superficially spread on the land (Figure 4).

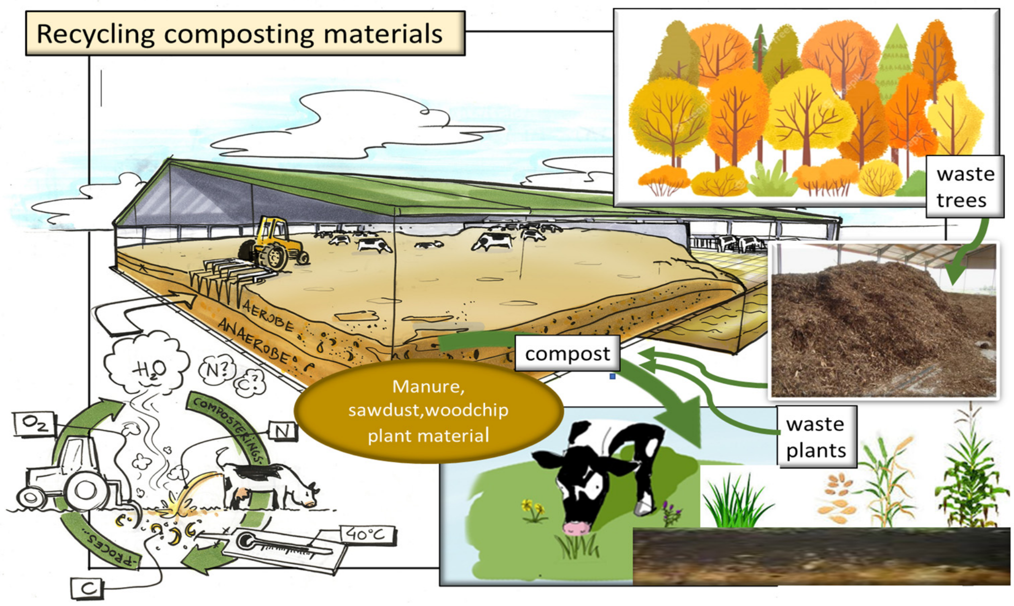

Figure 4. Dairy farm with compost bedded-pack and its application in the field. Source: Authors.

3.1.2. Application on a Poultry Farm

In Central Europe, corn spindle granules as left over from the maize harvest, among other materials, are used as bedding. In a fattening period of 28–40 days, 1 kg bedding/m^2 will end up as 0.8 kg bedding/kg live weight at a stocking density of 18–20 birds/m^2 [12]. Scratching of the pack by the birds serves as a natural means of aeration, while moisture is supplied via the ventilation system to assist the composting process, which can start as early as 10 days after installation. Problems arise if slab formation occurs due to coccidial disease or another reason, which means the animals cannot scratc anymoreh. Animal welfare guidelines require the litter to be degradable. Mulching is a possibility to prevent or solve the formation of slabs (Figure 5). Although some farms greatly appreciate hard, flexible litter, others find that too much of it is eaten as ballast by the laying hens [12]. The resulting compost from these farms can be easily marketed.

Figure 5. Mulching of slabs in a broiler housing facility. Source: Hiller, P., 2018 [12].

3.1.3. Added Horticultural Activity Utilizing Composted Bedded Materials

During the grazing season when the cows are at pasture, the CBP barn can be used to grow horticultural products, such as tomatoes and lettuce (Figure 6). The building has a horticultural green-house type roof that allows sunlight to enter. A layer of about 10 cm of sandy soil is spread over the bedded-pack, on which seedlings can be planted and the underlying compost supports plant growth [11]. This approach can lead to the sale of a mixture of agricultural products such as milk and vegetables from the one farm and the production system is readily visible to visiting buyers of the produce. However, the system also carries risks. Firstly, the addition of sand to the bedding and its later removal is a tedious chore that must be repeated each year; secondly, the horticultural component of the system requires additional temporary labor and skills [11].

Figure 6. Utilizing a compost bedded-pack barn for growing horticultural products. Source: Farm Veld & Beek, Doorwerth, the Netherlands.

3.1.4. Cooperative Crop–Cattle Farm Exchange of Composting Materials and Manure

European agriculture has seen a continuous trend of intensification and specialization with the result that mixed farming systems now cover only 14% of the total agricultural area [18]. Intensification has advantages in economies of scale (efficiency of labor and equipment) but can also have drastic environmental consequences (on water and soil quality, on the atmosphere and biodiversity). Market volatility has increased over the years, and alongside climate change this threatens the resilience of specialized farms. For these reasons, "new" farming systems that adopt circular approaches are advocated with a view to further improve efficiency, while reducing their climate and environmental impacts [18].

One such a system involves closing the mineral loop by the exchange of materials and manure, and by the better use of manure (Figure 7). The mixed farming system fits this concept [19]. For instance, crop farming allows the composted materials to be incorporated into the soil. Collaboration on a local level will also play a crucial role in integrating different farming resources together with crop and livestock farmers, as illustrated in Figure 7.

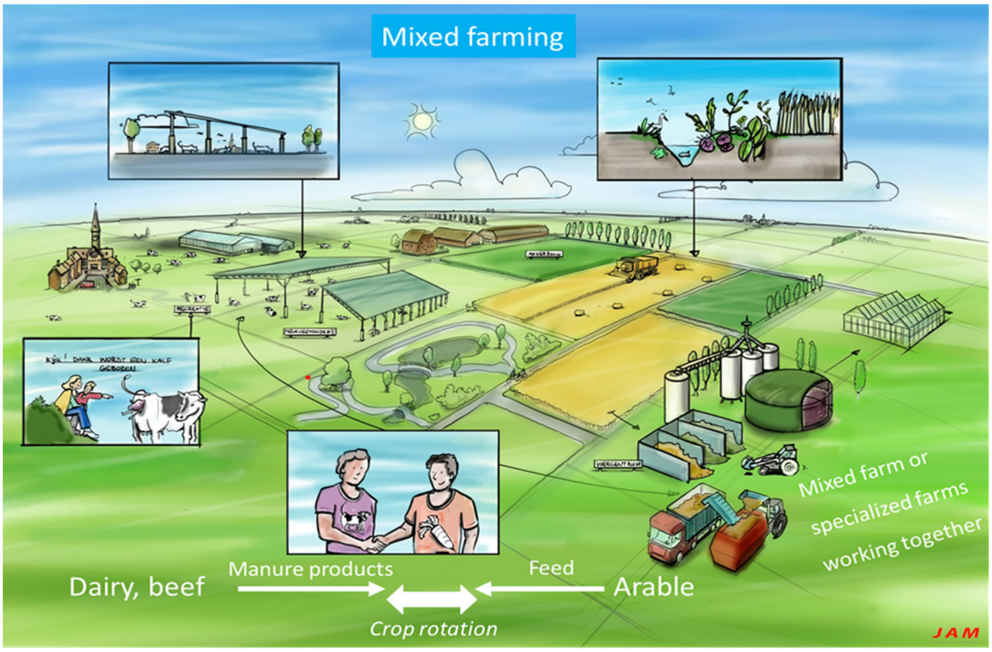

Figure 7. Mixed farming as a system realizing a circular economy. Source: Authors.

3.2. Perceptions towards Bedded-Pack Barns and Compost

3.2.1. Farmers' Perceptions

Eighty-seven farmers from the six European countries involved in the FreeWalk project were selected on the basis of their experience with both CBP and cubicle housing systems and asked their opinions on these systems [11]. This was done via questionnaire during group meetings, guided by the local researchers who explained the questions. A Likert scale of 1 to 7 was used to compare the systems (1 = very negative to 7 = very positive).

The farmers from the various countries expressed quite similar opinions about a set of characteristics of the two housing systems (Table 1). Those from all six countries considered the CBP system more sustainable and it offered more market opportunities than the common cubicle housing system. In addition, the composted bedding material was judged a better soil improver. However, the cost of the bedding material was considered a highly significant negative aspect of the CBP system by all farmers [11]. In Europe, prices for fresh bedding materials range from around 100 euro to over 300 euro per ton [3].

Table 1. Appreciation of composting bedding material in CBP versus regular manure in cubicle housings (C) by farmers from these two farm housing systems in six European countries (scores from 1 = very negative to 7 = very positive) [1,2].

All Six Countries Total				
	CBP	**C**	**CBP-C**	**Mann-Whitney Test**
Cost aspect				
Cost of bedding material	3.58	5.53	−1.95	0.000 ***
Sustainability aspects				
Bedding material and slurry as soil improver	6.15	3.61	2.54	0.000 ***
Bedding material and slurry as fertilizer	5.82	4.06	1.76	0.000 ***
Bacteria in bed and milk	5.15	4.91	0.23	
Smell	5.98	4.53	1.45	0.000 ***
Marketing aspects				
Better animal life certificate	6.05	3.52	2.54	0.000 ***
High quality dairy products	5.69	4.06	1.63	0.000 ***
High quality manure products	5.67	3.32	2.34	0.000 ***

[1] Mann–Whitney two-tailed exact significance test was applied; *** $p < 0.001$. [2] Number of farmers participating: from the Netherlands CBP 24 and C 20, Germany CBP 7 and C 7, and other 4 countries (Austria, Italy, Slovenia, and Sweden) CBP 10 and C 10. Source: Adapted from Klopčič et al., 2021 [11].

3.2.2. Consumers' Perceptions

An extensive consumer survey [20] was carried out in eight European countries to compare the three most widely used cattle housing systems. The survey of random participants, which was carried out by a marketing bureau, used photographs of the various housing systems to illustrate them to the respondees. A Likert scale of 1 to 10 was used (1 = not worried at all/fully safe to 10 = very worried/not safe at all). Overall, the consumers were concerned over the safety of their food but felt that products grown using the compost from the CBP barns was safer (Table 2). Only small differences existed between countries [20]; otherwise, all of the differences mentioned here were statistically significant ($p < 0.05$). Males were less concerned than females over food safety but still felt that food from the CBP system was safer. Younger consumers were more concerned about food safety than older consumers, and across all age groups, the youngest age group felt that food grown in the barn compost was less safe. Those in urban areas were more concerned over food safety than those in suburban areas and, compared with those in rural areas, felt that the food from the compost system was less safe [20]. Some responses in focus groups indicated concerns over antibiotic seepage, bacteria in the pack, and the hygiene of the pack [11].

3.3. Choices and Dilemmas

3.3.1. Management of the Bedded-Pack

Two key variables in managing the pack and creating a proper composting process are pack temperature and moisture content [2]. A high temperature (45–65 °C) is considered necessary to create effective composting and material sanification [5,13,21]. The pack temperature (10 to 50 °C) and moisture content (55 to 70%) at 20 cm deep of the 22 CBP included in project FreeWalk are illustrated in Figure 8 over 12 months [22]. A higher temperature was associated with lower moisture content. Clearly, the optimal composting temperatures are not reached in practice. This is partly because the system is still in development, but also because the need is not felt, such as in the summertime when the packs are mostly good looking and dry enough. In fact, under these conditions a semi-composting process takes place.

An over-wet pack is detrimental to the composting process, and it also increases the dirtiness of the cows. Thus, managing the pack requires a particular skill set [4,5,22]. In Europe, bedded-packs tend to be drier and warmer during the summer period. However, higher temperatures most likely result in increased ammonia and methane emissions from the pack [15] and increased thermophilic bacteria activity in the pack [23].

Table 2. Mean scores and standard deviations for worry about (a) the safety of food consumed in general (1 = "not worried at all" to 10 = "very worried") and (b) safety of consuming food products using the compost from the compost bedded-pack housing system (1 = "fully safe" to 10 = "not safe at all") by country and in total [1,2].

	(a) Food Safety Worry in General		(b) Compost Food Products Safety	
Variable	**Mean**	**Std. Dev**	**Mean**	**Std. Dev.**
Country				
Austria	6.01 [cd]	2.20	3.02 [bc]	1.85
Germany	6.15 [c]	2.18	3.13 [c]	1.86
Italy	7.62 [a]	1.79	3.15 [c]	1.90
Netherlands	5.65 [d]	2.15	3.21 [c]	1.66
Norway	5.65 [d]	2.67	2.60 [a]	1.97
Slovakia	6.94 [b]	2.22	3.07 [bc]	2.00
Slovenia	7.88 [a]	2.10	2.37 [a]	2.24
Sweden	5.77 [cd]	2.43	2.77 [ab]	2.09
Total	**6.49**	**2.36**	**2.94**	**1.96**

[1] The different letter within each mean column section indicate the significant differences between variable options as evaluated by Tukey's HSD ($p < 0.05$). [2] The number of consumers who participated in the survey from Austria was 415; Germany 633; Italy 592; the Netherlands 423; Norway 401; Slovakia 410; Slovenia 397; and Sweden 422. Source: Adapted from Waldrop et al., 2021 [20].

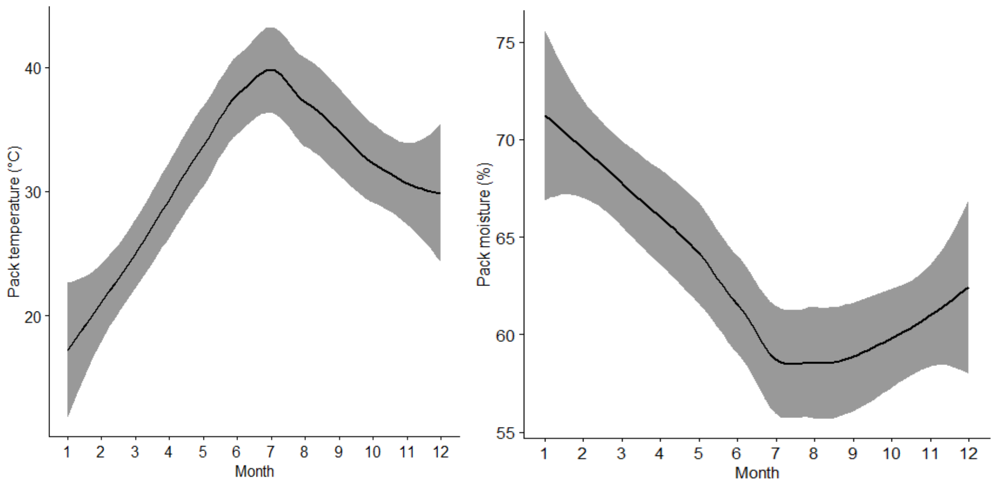

Figure 8. Development of the average and range in temperature (**left**) and the moisture content (**right**) at 20 cm deep in 22 composting bedded-pack's over the year. Source: Taken from Leso, L., 2021 [22].

3.3.2. Bacterial Flora

Household litter composted in bedded-pack barns at higher temperatures was found to have high levels of thermophilic aerobic sporeformers (TAS) [24]. This may threaten the quality of sterilized milk products and, consequently, its use was prohibited in barns in the Netherlands. Certain strains of mastitis bacteria also like high temperatures [25], while other strains do not [7].

The moisture content of the bedding material, the relative humidity at 0.10 m and 1.30 m above the surface, and the season of sampling, all significantly affected the level of TAS [23]. The relationship between moisture content and TAS is illustrated in Figure 9. A higher moisture content of the pack seems to be associated with less thermophilic activity, probably because of the lower temperatures and composting activity inside such a pack.

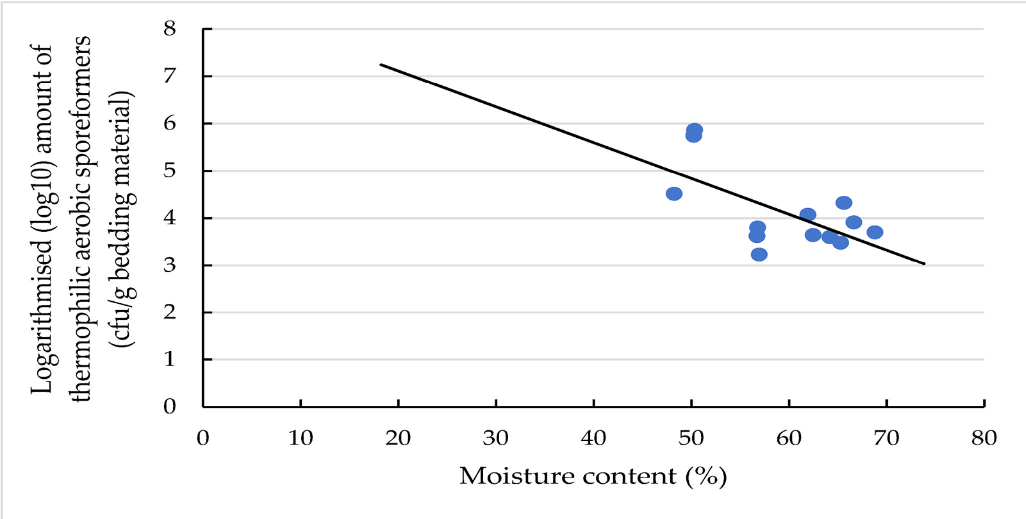

Figure 9. Relationship between thermophilic bacteria and moisture content in composting bedding material; $y = -0.08x + 8.62$ ($R^2 = 0.34$). Source: Taken from Giambra et al., 2021 [23].

3.3.3. Application in the Field

An important benefit of composted bedding material is as a source of organic matter and nitrogen fertilizer for the soil [14,26] as illustrated in Figure 10. Although compost is known to improve the soil structure and bioactivity, the composting process is more complicated than generally appreciated. When the composting of bedding materials was experimentally simulated in trials of three months duration, the stability of the organic matter did not indicate real evidence of composting [14]. Further, some farmers have claimed an increased ash content (nonorganic matter) of grass samples harvested from compost treated swards [27], but this was not observed in the survey of the farmers described above (Table 1).

Figure 10. Bedding material spread on grassland and arable land. Source: Authors.

The slow release of nitrogen from the bedding materials has been reported by several authors [28,29] so grassland management and fertilizer appplication may need to be adapted for the effects of compost bedding material as a fertilizer and soil structure improver.

3.3.4. Opportunities

The product from the successful composting of bedding materials mixed with excreta of animals is commercially valuable. Selling the compost in bags or loose as pellets provides the opportunity for additional income [29,30]. An example is the providing of organic bedding material by a CBP farmer in Slovenia to farmers engaged in the production of vegetable and flower seedlings.

Some farmers use the heat of the composting bedded-pack to warm up their farm office or visitors' room, or to prevent the animal drinking bowls from freezing. In another case, a German farmer with both a CPB and cubicle barn reused about 75% of the CBP compost as bedding material in the cubicle stalls with the remainder used as fertilizer. It was estimated that this reduced the total bedding material costs by 80%. Afterwards, the bedding material from the cubicles was used in the farm biogas plant to produce energy. These are examples of circularity within or between farm businesses.

The relatively high cost of the bedding materials is a negative factor but new materials such as Posidonia oceanica and miscanthus [31], and grass harvested in nature areas and on roadsides [32] should be less expensive.

Within the European Green Deal Package [33] there are opportunities to increase carbon storage in soil to combat climate change. In the CBP system, carbon enters the farm via industry or agricultural by-products and is mixed with animal manure. This is then applied to the soil thereby sequestering carbon, which might otherwise be lost to the atmosphere. Carbon certificates are being considered as a tool for advancing the Green Deal objectives. An innovative farmer in the Netherlands has already deployed a novel climate mitigation practice on his farm. The air from manure storage, rich in ammonia and methane, is pushed through tubes to a special drainage system 60 cm underground from where it diffuses into the soil. The ammonia and methane are thought to be fixed by soil bacteria, although this is not yet proven.

4. Discussion

The EU New Deal [33], and the Horizon Europe Research Program 2021–2027 [34], together with similar worldwide programs have, as top priorities, the achievement of carbon neutrality. The recycling and reuse of organic materials, including the use of organic bedding materials in CBP systems, can help to increase carbon storage in the soil. This contributes to mitigating global warming, improves soil structure and bioactivity, and enhances biodiversity. It is enhancing a circular economy.

While in Israel and Brazil there is widespread use of CBP systems, the number of such systems in all other countries remains limited [2,3]. Much more common are the conventional 'deep straw' barns (yards) [2]. In these barns, the lying area consists of straw, which is stapled over time, but composting is not a systematic part of the system and the surface per cow is less than in CBP. Deep straw barns are most widely used for fattening cattle and suckler cows. The relatively dry manure of these animals helps to maintain a rather dry pack. The pack tends to grow in volume during the season, while in CBP, composting degrades the material to smaller particles, which makes the pack more compact [21].

Although the CBP housing system is still in development [2,3], both farmer and consumer surveys revealed positive impressions of its sustainability compared to cubicle or tie-stall barns [11,20]. The CBP system was also preferred on food safety criteria [20]. Alongside these positive impressions, however, are some concerns on the possible risk of bacteria and antibiotic transfer from the compost bedding material to the growing vegetables and horticultural products from compost treated soil [11].

The high material costs of the wood by-products and straw due to competition from bio-gas and other industries adversely affects the economic viability of the system. Accordingly, exploration of cheaper by-products and waste products will be of increasing interest [11,14,31].

The operation of a successful bedded-pack system requires particular management skills. The composting process is affected by the temperature and moisture content of the bedding, as well as the ambient temperature and humidity [4]. In temperate climates, maintaining adequate conditions and a proper composting process in the bedded-pack to achieve a stable humus-like end-product, especially during the winter, can be a severe challenge [5,14,22].

While the composting process is enhanced by higher temperatures, such temperatures also facilitate the growth of thermophilic bacteria [23,24]. Bacteria such as (X)TAS are disliked by dairy processing companies in some countries because of their possible effects on sterilized dairy products [24]. To date, research with CBP systems did not find any detectable (X)TAS in cows' milk even though detectable levels were found in the bedded-pack [35]. In addition, several strains of mastitis-causing bacteria thrive in similar conditions to that of composting bacteria and microbes [7,24,25]. This suggests that the microbiology of the bedded-pack aerobic and anaerobic processes and the possible transfer of bacteria to the animal and animal products may be complex and requires more fundamental research. Maintaining optimal animal hygienic procedures is likely to be important [25].

Combining all of the new insights gained concerning the management of the bedded-pack leads to the conclusion that the moisture and dry matter content may be the best indicator for the quality of the pack [22]. A dry pack (above 40% dry-matter) has, indeed, several advantages such as a better composting process and cleaner cows [25], affecting the quality of the end-products. However, the risk of TAS [23,24] and particular mastitis bacteria presence [25] increase with the combination of higher dry matter content and higher temperatures of the pack. The composting process and risk of TAS presence is expected to slow down when the pack reaches above approximately 65% dry matter, but more knowledge is needed to typify the ongoing processes in this dry matter range.

In addition, new insights into ammonia and carbon dioxide emissions from composting bedded-packs would be particularly beneficial in evaluating these systems. One study indicated that the critical pack Carbon:Nitrogen (C:N) ratio at which volatile N loss from the barn was zero, was 35 in line with critical ratios found in other studies [36]. The authors concluded that controlled thermophilic composting of a woodchip bedded-pack, at a relatively high C:N ratio, has the potential to minimize volatile N loss from the CBP barns. Another study [37] showed ammonia emission to be reduced by 32% but methane emission was increased by 34% compared to a reference cubicle housing system with slurry.

Organic bedding materials enriched with nitrogen and phosphorus from manure and urine is a good soil improver [26] comparable with old fashioned manure from tie-stall and deep straw barns. The CBP system aims to degrade the materials in the compost to a product ideal for spreading on grassland swards or soil. However, when the composting process is incomplete, its application to grassland may result in some large particles which take longer to degrade. This is not a problem in soil application where the compost is incorporated into the soil at some depth, as in arable farming.

A mixed animal-crop farming system can make a positive contribution to the circular economy [18,26]. Such a system can be operated either within a single farm business or by cooperation between specialised animal and arable or open field vegetable farms [19]. Its use in individual farms, or via cooperation between farms, may also reduce the import of animal protein feed from outside of the farm, thereby conserving resources and reducing fossil fuel use while contributing to replenished soil carbon reserves [19,34].

Most studies cited in this communication are on-farm based studies. Aditionally, models scaling-up from farm to regional or international level [38], including Life Cycle Analysis (LCA) studies [13,39], are recommanded to picture the whole cycle of by-products and materials. Such studies should preferably also compare composting to other processes, such as using the materials for energy production and include the complete (international) transport and marketing chain [39].

5. Conclusions

The recycling and reuse of by-products in agriculture can contribute to a sustainable circular economy. In this communication, we focused on the recycling of bedding materials from animal barns, especially the innovative CBP barns, and on cooperative crop-animal farm exchange of composting materials and manure. A holistic and synthesizing approach was used to evaluate the contribution of these systems to the circular economy.

Both farmer and consumer surveys revealed positive impressions of CBP's sustainability compared to cubicle or tie-stall barns. Reuse of the compost from the CBP system is also promising for horticultural production. However, managing the bedded-pack requires a particular skill set, and the high costs of wood by-products and straw can adversely affect the economic viability of the system. Accordingly, an exploration of cheaper and suitable by-products and waste products is of crucial interest.

Mixed animal-crop farming systems that foster the exchange and reuse of materials would make a positive contribution to the circular economy. The recycling and reuse of organic materials helps to increase carbon storage in soil. This contributes to mitigating global warming and improved soil structure and bioactivity. Greater insight into ammonia and carbon dioxide emissions would be beneficial in evaluating these systems. Additionally, the scaling-up of models from farm to regional, national, or international level is recommended to obtain an overview of the complete cycle of by-products and materials.

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