Evaluation of Available Design Criteria for Modern Deep-bed Pack Beef Production Facilities

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ABSTRACT

Deep bed pack beef finishing facilities, in which bedding is utilized to absorb excess moisture from feces and urine, represent a resurgent technology that until recently had been almost abandoned by the U.S. beef industry. However, environmental regulations and increasingly stringent requirements for beef producers to manage runoff from open-lot systems have promoted producers to revisit the use of in-barn solid manure handling systems. Design data to estimate total manure storage required for these systems is limited. The purpose of this paper was to evaluate the current methods available to estimate the storage needs for bed pack systems and determine whether new design criteria are appropriate. A comparison of the three methods used to estimate total storage volume for these solid manure bedded systems showed tremendously different volume recommendations, ranging from 2.0 to 6.6 kg (4.1 to 14.5 lb) total bedding required per animal per day. Total daily manure (plus bedding) volume production ranged from 0.016 to 0.064 m\textsuperscript{3} (0.55 to 2.25 ft\textsuperscript{3}) per animal.

Keywords: Bedding, Hoop Structure, Monoslope, Solid manure, United States

1. INTRODUCTION

United States livestock producers are experiencing increased regulations which require the management of runoff from open lot facilities that use traditional containment or alternative treatment technologies (U.S. EPA., 2008). Consequently, producers are showing increased interest in rearing systems that eliminate the need for runoff control and/or treatment. The most common types of such beef production systems in the midwestern U.S. are bedded hoop structures and monoslope buildings. These systems move the animals from unroofed lots to roofed structures year around and eliminate the risk of non-point source pollution from runoff produced by rain events occurring on open-lot systems (Bond et al., 2011).

Monoslope and hoop structures are both solid manure systems where bedding is added daily or weekly according to the individual management style of the producer to control excess moisture and allow for manure stackability (Shouse et al., 2004). Typically, the manure bedding mixture is allowed to build up within the barn for six months to a year depending on the number of animals and specific applicable state and federal regulations. For example, in the state of Illinois current regulations require that solid manure systems be able to store at least one hundred and eighty days worth of manure and bedding (LMFA, 1997). Therefore, a means of accurately estimating the amount of volume needed for the manure-bedding mixture over time is important.

There are three primary estimation methods used for the volume of a manure-bedding mixture produced in these bedded pack systems. The first two methods were published in MWPS-18 (2000) but based on earlier work. MWPS-18 recommends that the total storage volume needed is
equal to the manure volume produced plus one half of the total bedding volume added over the storage period. However, the determination for added bedding volume is different for these two MWPS-18 methods. The third method is a mass balance approach that uses previously reported literature values for daily bedding requirements, bed pack moisture and density (South Dakota NRCS, 2011). The primary differences in these methods are the moisture-related assumptions. The first two methods from MWPS-18 assume a closed system in which there are no losses of moisture occurring from evaporation or other means, but assumes 50% of added bedding volume is lost, presumably from compaction. The third method assumes losses are occurring due to evaporation by using the total solids added to the system (manure and bedding) along with final pack moisture and density to determine total storage volume.

There are several techniques for determining total bedding volume needed for these closed systems. Depending on the assumptions made during the design process, bedding volume is typically calculated to achieve a final pack moisture content or to absorb a certain amount of free water in the system. Alternatively, some states use reported bedding amounts from data collected from full-scale operations (Honeyman et al., 2008). These values are typically lower than the calculated amounts based on moisture content, but similar to the amount calculated using free water absorption. Bedding amounts for bedded systems can range from 1.4 to 6.8 kg (3 to 15 lb) per day per animal depending on the criteria and method used (MWPS-18, 2000; Honeyman et al, 2008; Russelle et al., 2009; Spiels et al., 2011).

Therefore, the purpose of this paper was to evaluate the current design criteria for total storage volume and daily bedding amount for bedded back systems with the aim of assessing whether new design criteria are needed.

2. METHODS

Three methods were compared, the first two of which are presented in MWPS-18 (2000). These methods use the same fundamental total storage volume equation, but differ in the way bedding volumes are determined. The third method was a mass balance approach developed by South Dakota Natural Resources Conservation Service (South Dakota NRCS, 2011). This method uses reported literature values for daily bedding amounts, final pack moisture content, and final pack density to determine required design values for total storage volumes.

In order to compare these three estimation methods for bedded pack facilities two assumptions were made. Daily manure production volumes and mass from the ASABE standard (ASABE D384.2, 2005) for beef cattle were used. For beef cattle these values were 29.4 kg (64 lb) of manure per day and 0.029 m$^3$ (1.04 ft$^3$) per day per animal. Additionally, all bedding was assumed to have a bulk density of 96.1 kg m$^{-3}$ (6 lb ft$^{-3}$).

2.1 MWPS-18 Method 1

Method 1, from MWPS-18 (2000), uses the governing equation which is the most commonly used means of estimating storage volume for solid manure with bedding systems (Equation 1). Total bedding mass was determined from Figure 1, which estimates the total amount of bedding needed per animal per day to reach a specific bed pack dry matter content. This figure was developed from a figure shown in MWPS-18 (1985), but updated for current manure production standards. The total bedding volume was then found by dividing the total amount of bedding
required from Figure 1 by the assumed bedding bulk density of 96.1 kg m\(^{-3}\) (6 lb ft\(^{-3}\)). For the purpose of this paper a desired final dry matter content of 25% was used.

\[
V_t = V_m + \frac{1}{2} V_b
\]  
(1)

Where,

\(V_t\) = Total storage volume needed, m\(^3\) (ft\(^3\))

\(V_m\) = Total manure volume, m\(^3\) (ft\(^3\))

\(V_b\) = Total bedding volume, m\(^3\) (ft\(^3\))

2.2 MWPS-1 Method 2

The second method also used equation 1, however the bedding volume requirements were calculated based on the amount of free water absorption available for the specific bedding type. Common bedding materials (corn stover, soybean stover, and ground corn cobs) were used for comparison. Bedding absorption values from Spiehs et al. (2013) were used for all three bedding types. The total mass of bedding required was calculated using Equation 2, then divided by the bulk density of 96.1 kg m\(^{-3}\) (6 lb ft\(^{-3}\)) for all three bedding types to determine total bedding volume (Equation 3).

\[
M_b = \frac{(M_m \ast W_e) \ast W_b}{\alpha}
\]  
(2)

Where,
\( M_b \) = Total mass of dry bedding required, kg hd\(^{-1}\) day\(^{-1}\) (lb hd\(^{-1}\) day\(^{-1}\))  \\
\( M_m \) = Total mass of manure produced, kg hd\(^{-1}\) day\(^{-1}\) (lb hd\(^{-1}\) day\(^{-1}\))  \\
\( W_c \) = Moisture content of manure, %  \\
\( W_b \) = Desired moisture absorbed by bedding, %  \\
a = Absorption (water holding) capacity of bedding, kg-H\(_2\)O kg-bedding\(^{-1}\)(lb-H\(_2\)O lb-bedding\(^{-1}\))

\[
V_b = \frac{M_b}{\rho_b}
\]  
(3)

Where,  
\( \rho_b \) = Bedding bulk density, kg m\(^{-3}\) (lb ft\(^{-3}\))

For the purpose of this paper, it was assumed that the added bedding absorbed 25% of the moisture from the manure. The absorption (water holding) capacity values used for the bedding types were 3.6, 2.8 and 2.2 for corn stover, soybean stover, and ground corn cobs, respectively (Spiehs et al., 2013).

### 2.3 South Dakota NRCS Method 3

The last method evaluated was a mass balance approach developed by South Dakota NRCS (2011) (Equation 4). This approach uses published literature values for daily dry bedding amounts and bed pack moisture content to determine total bed pack mass. Unlike the first two methods discussed, this method assumes losses occur within the system via evaporation of moisture from the bed pack. This assumption results in a reduction of final volume, and thus a reduction in the total amount of storage ultimately needed. The final pack volume is determined by dividing the total bed pack mass by the final bed pack density (Equation 5).

\[
M_p = \frac{(M_s + M_b)}{1 - W_p}
\]  
(4)

Where,  
\( M_s \) = Total manure dry matter, kg hd\(^{-1}\) day\(^{-1}\) (lb hd\(^{-1}\) day\(^{-1}\))  \\
\( M_p \) = Total mass of bed pack, kg hd\(^{-1}\) day\(^{-1}\) (lb hd\(^{-1}\) day\(^{-1}\))  \\
\( W_p \) = Final moisture content of bed pack, decimal

The daily bedding amounts used for this method vary based on building type: 2.4 kg (5.2 lb) per day per animal is recommended for use with hoop structures and 2.8 kg (6.1 lb) per day per animal for monoslope buildings (South Dakota NRCS, 2011; Honeyman et al., 2009). A final bed pack moisture of 68.1% (Spiehs et al., 2011) and a final pack density of 932.2 kg m\(^{-3}\) (58.2 lb ft\(^{-3}\)) (Russelle et al., 2009) were used.

\[
V_p = \frac{M_p}{\rho_p}
\]  
(5)

Where,  
\( \rho_p \) = Bed pack bulk density, kg m\(^{-3}\)
3. DISCUSSION

A comparison of the three design methods demonstrated substantial differences between volume estimation amounts for total storage volume for solid manure bed pack systems (Table 1). Method 1 yielded the largest volume requirement, with a daily bedding recommendation of 6.6 kg (14.5 lb) per animal per day and a volume production of 0.064 m$^3$ (2.25 ft$^3$) per animal per day. For the other two methods, the average daily bedding requirements were 2.5 kg (5.5 lb) per animal per day, nearly 3-fold less bedding than obtained using Method 1. For Method 1, more bedding is needed in order to achieve an increase of 17% dry matter (assuming initial dry matter content is 8% as excreted and a final dry matter content of 25%) in the bed pack. Currently in Illinois all solid manure bed pack systems are required to meet this 25% final dry matter content threshold.

The volume requirements for the three methods ranged from 0.064 to 0.016 m$^3$ (2.25 to 0.55 ft$^3$) per animal per day. Compared to Method 1, on average Methods 2 and 3 estimated 35% and 75% less volume required per animal per day, respectively. These results have significant implications for livestock producers wishing to construct a solid manure bed pack system in Illinois compared to surrounding states in terms of both capital and operation cost. Essentially, these results indicate a bedded pack barn constructed in South Dakota can be a third of the size of one built in Illinois for the same number of animals.

The discrepancies between these methods are primarily driven by water related assumptions. Method 1 requires that the bed pack have a final dry matter content of 25% and assumes no losses occur within the system (i.e. evaporation etc…). This recommendation comes from MWPS-18 (2000), that states if a solid manure system is less than 25% dry matter then the potential for seepage may occur and stackability of the manure may be reduced. However, there is no reference or explanation for this statement. Method 3 however, assumes that a large amount of evaporation is occurring naturally within the barn which aids in keeping the bed pack dryer without the need for additional bedding. This third method is limited currently by the small amount of published data on bed pack moisture content and density. More data needs to be collected in order to substantiate the two previous studies (Russelle et al., 2009; Spiels et al., 2011) that report these values and to determine if bed pack characteristics vary by region and climate.

Method 2, like Method 1, neglects evaporation within the system, but rather accounts for a fixed percentage of free water in the bed pack to be absorbed by the addition of bedding. For the results presented in Table 1, it was assumed that 25% of the liquid fraction of manure was absorbed into the added bedding, regardless of bedding material type. This doesn’t mean the final dry matter content of the bed pack was 25%, rather the estimated final dry matter contents were 13.6%, 15.1%, and 16.8% for corn stover, soybean stover, and ground corn cobs respectively. If evaporation is naturally occurring in these system then the dry matter percentage would be greater and would likely meet the arbitrary 25% dry matter threshold, currently required for Illinois. Unfortunately, there are no data available from Illinois or surrounding states to indicate what level of evaporation occurs. Also, the water holding capacity values reported in literature are for bedding only, and data to describe how the water holding capacities of bedding material is impacted by mixing the bedding with manure is lacking.
Table 1. Comparison of the three methodologies currently being used to determine storage volume requirements for solid manure bed pack systems in the Midwestern U.S.

<table>
<thead>
<tr>
<th>Method Used</th>
<th>Bedding Type</th>
<th>Bedding Required (kg hd(^{-1}) d(^{-1}))</th>
<th>Total Volume (m(^3) hd(^{-1}) d(^{-1}))</th>
<th>% of Method 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>All types</td>
<td>6.6</td>
<td>0.064(^1)</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>Corn stover</td>
<td>1.9</td>
<td>0.039(^1)</td>
<td>61</td>
</tr>
<tr>
<td>2</td>
<td>Soybean stover</td>
<td>2.4</td>
<td>0.042(^1)</td>
<td>65</td>
</tr>
<tr>
<td>2</td>
<td>Corn cobs</td>
<td>3.0</td>
<td>0.045(^1)</td>
<td>71</td>
</tr>
<tr>
<td>3 – Hoop Structure</td>
<td>All types</td>
<td>2.4</td>
<td>0.016(^2)</td>
<td>24</td>
</tr>
<tr>
<td>3 – Monoslope building</td>
<td>All types</td>
<td>2.8</td>
<td>0.017(^2)</td>
<td>26</td>
</tr>
</tbody>
</table>

\(^1\)Bedding bulk density of 96.1 kg/m\(^3\) was assumed.

\(^2\)Bed pack density of 932.2 kg/m\(^3\) was assumed.

4. CONCLUSIONS

Comparison of the three primary methods used to estimate total storage volume for solid manure bedded systems showed significantly different volume recommendations. Total bedding required per animal per day ranged from 1.9 to 6.6 kg (4.1 to 14.5 lb). Daily volume production estimates ranged from 0.016 to 0.064 m\(^3\) (0.55 to 2.25 ft\(^3\)) per animal. These substantial variations in required volume storage have significant implications for livestock producers wishing to construct a solid manure bed pack system in Illinois compared to surrounding states in terms of both capital and operation cost. Essentially, these results indicate a bedded pack barn constructed in South Dakota can be a third of the size of one built in Illinois for the same number of animals.

Based on the current methodologies and design criteria available to estimate total storage volume requirements for deep bed pack systems, new design criteria or validation of a current method are needed. In order to accurately design these systems, temporal characterization of the environmental conditions within the bed pack needs to occur. This includes determining the effects on bedding water-holding capacity by the addition of manure and naturally occurring evaporation losses within the system on bed pack dry matter content.

5. REFERENCES


