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RENEWABLE, ALTERNATIVE BEDDING RESOURCES FOR BROILER PRODUCTION: AN EVALUATION OF PERFORMANCE, WELFARE, AND ENVIRONMENTAL IMPACTS

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ABSTRACT

Increases in price and variability of the softwood shavings market have prompted exploration of alternative, renewable bedding resources on which to rear broiler-type chickens in the northeastern United States. Although there are many available alternatives used to bed birds across the United States, these are limited by region. An option for sustainable, locally produced bedding comes from the use of biomass grasses. However, processing techniques of the biomass are numerous and have the potential to result in variability of physical properties between processed materials, which may influence their success as bedding.

It is paramount that the materials offered as alternatives perform well compared to the current industry standard of kiln-dried softwood shavings. Because the profit margin per bird is small and bedding is an important contributing factor to the environment of a chicken house, there is no room for reduced performance due to the bedding. This bedding environment is defined by moisture index, litter scores, temperature, ambient ammonia, and ammonia flux. Furthermore, the welfare of the birds must be maintained to allow for proper growth. Maintaining welfare standards allows growers to continue to be good stewards to their birds. Footpad and breast cleanliness scores can be reflective of the house environment and can directly impact the welfare of birds reared in said house. Another consideration with bedding material is the litter’s end use. It can be used as either fertilizer or fuel with thorough consideration of the nutrient profile and energy density before application of these materials.

The availability and success of an alternative bedding material will only happen in a market willing to accept it. It is therefore pertinent that the current bedding use for broilers in Pennsylvania be evaluated to determine the materials typically used, constraints set in place by integrators and growers, preferred properties, and willingness of the industry to try alternatives.
Research Objectives

1.) Evaluate the current bedding environment in Pennsylvania and see if alternative renewable bedding materials are a valid option for growers.

2.) Determine if miscanthus grass performs similarly to a softwood shaving/sawdust bedding mixture in terms of litter parameters and bird performance and welfare.

3.) Define the role switchgrass particle size plays on litter performance, bird performance, and bird welfare and compare the differences between these materials and a baled softwood shaving.

4.) Determine what the ideal particle size for switchgrass is in a commercial broiler house by evaluating litter performance, bird performance, and bird welfare using two differing bedding treatments suggested by the results from objective 3.

5.) Quantify the nutrient and energy parameters of alternative bedding materials to approximate their value as a fertilizer or fuel source.
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Chapter 1

Literature Review

Bedding in Commercial Broiler Production

Historically, there has been a wide variety of bedding materials used for broiler chicken production. Much of what is available varies by region of the country, though the industry standard for bedding material is still softwood shavings, preferably kiln-dried. Bedding characteristics are an important factor to a poultry house, since much of the climate is dictated by the state and quality of the litter and how these factors change over the course of grow-out.

Litter Performance and Shortcomings

A bedding’s performance as a litter is a primary concern in broiler houses, since much of the internal environment of a poultry barn is dictated by the quality and performance of the litter. Parameters of concern when evaluating bedding performance include ammonia emissions, litter temperature, house moisture, and level of cake, which is defined as the crusting of manure on the litter surface.

Levels of ammonia within the house have the potential to impart damaging effects on the birds. These can include increased susceptibility to diseases, including Newcastle Disease Virus [1]. Even continuous exposure (> 6 weeks) at 20 ppm has the potential to induce pulmonary congestion, edema, and hemorrhage [1]. Ocular lesions can develop at ammonia levels of 25 ppm, and levels of 50-75 ppm have caused lesions within 7 days of constant exposure [2]. These damaging effects, in combination with other factors, lead to side effects including reduced
bodyweight, which becomes more obvious as the concentration of ammonia increases [2, 3]. Levels exceeding 25 ppm have been noted in broiler management guides to have an effect on rate of gain [3], while it is recommended that 10 ppm not be exceeded [4].

Temperature has a larger effect on ammonia volatilization than litter moisture or pH [5], though ammonia levels have been noted to be more impacted by litter characteristics rather than the ventilation rate [6]. Litter pH and levels of ammonia generation have not been found to be closely linked in bedding untreated with a litter additive or amendment, so while litter moisture increases are associated with higher pH, pH cannot otherwise be controlled, making it but a small contributing factor for ammonia volatilization [11]. These factors indicate that proper litter management including the selection of an appropriate bedding material is paramount when controlling ammonia levels within a house [6].

Conversely, it has been noted that pH plays a larger role in ammonia volatilization with the inclusion of litter additives or amendments. The inclusion of litter additives such as sodium bisulfate [7] alum, ferrous sulfate, and phosphoric acid [8] can lower the pH of litter over the course of grow-out, thereby reducing ammonia volatilization [7]. If the need arises, these additives can be used, but it is more cost effective for a grower if the innate properties of bedding materials can keep ammonia volatilization low.

Caking in broiler houses is typically the result of long bedding material particles rising to the bedding surface and creating a mat of material on which feces can accumulate. Other factors that influence caking include enteritis [9] and drinker design and management [10] which can increase litter moisture to the point of where the material will cake. Although high levels of cake are not recommended in broiler houses due to welfare concerns, ammonia flux is diminished on caked surfaces [5]. Another disadvantage of caking is that a high moisture environment of the cake itself will more readily dissolve ammonia, creating an alkaline solution that can burn
footpads [12]. It is for this reason that wet litter can predict the incidence of footpad lesions, whether it be too high in moisture or have too high a capacity to cake [12].

Areas of very wet litter have the potential to suppress ammonia volatilization due to the nature of such areas being relatively anaerobic. In this situation, the aerobic uric acid decomposing bacteria will not function as well as they would in a drier environment, leading to a decrease in uric acid breakdown and less ammonia overall [5]. However, litter moisture to this level is not recommended as a method to suppress ammonia volatilization.

**Preferred Bedding Characteristics**

The ability of bedding to wick moisture away from birds is one of the most important factors when determining which bedding material to use. Beddings with a higher moisture holding capacity will tend to draw moisture away from the animal. An Illinois study that evaluated different bedding materials’ abilities to hold and retain water and found that pine shavings and switchgrass tended to hold a similar amount of moisture when compared to each other, but miscanthus grass held only about half the mass of the shavings [13]. Although this study used a cattle manure slurry to determine water holding capacity, the fact remains that miscanthus fell short when compared to the other bedding materials. This study also determined that the higher levels of solids in manure result in a decreased water holding capacity by bedding materials over a water-based fluid retention evaluation [13]. This means that once in the house, bedding will not hold as much water as they would in a water based moisture retention analysis.

A study by Pearson et al. indicated that smaller particles tend to hold more moisture and be more dense than larger ones [14], impacting the performance of different bedding materials made from the same product. That being said, the ability to hold moisture at the litter surface rather than throughout the material allows for ease of removal of that moisture from the house via
the ventilation system [15]. For this reason moisture release is suggested as a complementary characteristic to moisture holding capacity. Bedding with particles that exhibit these characteristics are then optimal for use in a broiler house.

Because particle size can influence the incidence of footpad dermatitis, particle size of a bedding material can predict litter quality over the course of grow-out [12]. Younger birds are most susceptible to developing this condition when exposed to moist litter with continuous exposure leading to the development and worsening footpad lesions [16]. These lesions are a welfare concern, as pain can arise from footpad injury [16]. However, there is little evidence that incidence of footpad dermatitis can impact live performance [12]. For these reasons, footpads can indicate bird welfare and the house environment, but do not necessarily indicate a decrease in performance.

Caking in the house has been indicated to be a contributing factor in the development of footpad dermatitis. Materials that wick moisture from the birds have been shown to lower incidences of footpad dermatitis, as wetter bedding materials will lead to a higher incidence over dry [17]. Caking over of the litter surface can inhibit the removal of moisture from the birds’ environment, as a thick layer of manure effectively seals off the bedding underneath from absorbing or releasing moisture. Additionally, caked litter can increase the incidence of footpad dermatitis by subjecting birds’ feet directly to manure, which has high ammonia concentrations [12]. It has been suggested that beddings that hold moisture without caking are superior to those which cake [15].

Besides having characteristics that make a bedding material ideal for performance in a broiler house, the material should contain the smallest amount of inhalable dust possible. Bedding materials that have few particles below the threshold of inhalable dust (100 ng/m³) are safer for farm employees, as lower exposure to dust can reduce the risks of diseases including chronic bronchitis, mild airway obstruction, and asthma-like symptoms [18]. However, dust production
from litter is highly dependent on the lighting program and subsequent animal activity, ventilation system and rate within the house, and bird age [19]. Dust has been noted to be a problem in particular for chicks at 3 weeks of age, where particles become trapped deeply in the lungs and air sacs, making the birds more susceptible to disease and reduced gain [20].

Environmental factors within the house are critical, as they have the potential to ultimately lead to impacts on mortality and performance. Switchgrass has been already identified as an alternative bedding material that holds promise. The research to date has shown that mortality incidence is not impacted when using this bedding over softwood shavings [21, 22]. In general, rates of mortality should not exceed the national average of 4-5 %, regardless of litter type [23]. Performance of birds reared on switch versus those reared on softwood shavings has mixed conclusions. It had been shown to either not been affected [22, 24] or influenced [21]. In a study by Davis et al., bodyweights, bodyweight gain, and feed conversion were shown to be lower for birds reared on switchgrass at day 12, though these differences diminished over the course of the grow-out and were eventually nonexistent by 48 days [21]. Even with the mixed performance results, biomass grasses such as switchgrass are promising alternatives to softwood shavings, as performance and mortality are generally not affected and are closely tied to profit margins.

**Renewable, Alternative Bedding Material Options**

**Biomass Grass Field Crops**

Both switch and miscanthus grasses have been found to grow well in Pennsylvania. Miscanthus grass will experience 15-20 years of persistence before the need to replant [25]. Switchgrass is similar, where a properly managed stand will produce for up to 20 years [26].
Switchgrass tends to grow to a height of 0.9-1.5 m [27], while miscanthus can grow to heights of 4 m by the end of the growing season [28].

It is not uncommon to see yields of 9.0-13.5 dry megagrams of material per hectare for switchgrass or 17.9-26.9 dry megagrams per hectare of miscanthus grass [25]. The amount of biomass needed to bed a barn will depend on when the product is removed from the field and how it is harvested as density, moisture content, and particle size all affect the volume per tonne. Switchgrass has the advantage over typical field crops in that it can be grown with great success in soils with low fertility, poor drainage, tendency to flood, and high water tables [26]. Miscanthus grass also does well on marginal land with little nutrient input [25].

Biomass grass species are used in vegetative filter strips or grassed areas, which reduce erosion and capture nutrients, preventing their entry into waterways [29]. When considering funding opportunities to instate these practices including state government cost share programs to help landowners implement these ideas, proposals using native species have a higher probability of being funded than those utilizing nonnative species. In this case, switchgrass has an advantage over miscanthus is that it is a native species to much of the United States, whereas miscanthus is not.

Multiple research efforts regarding biomass grasses have shown that they have the potential to be harvested from the field with moisture values typically below 20%. Both switchgrass and miscanthus dry along a curve such that their biomass will have 50% moisture by October and will further dry down to less than 10% by February, given the appropriate weather conditions [30]. Low levels of moisture make this bedding an attractive alternative to softwood shavings, as many producers prefer a kiln-dried or otherwise very dry product.

Another advantage of growing these plants for biomass material is that the plants will stand in the field from late fall to early spring, presenting the grower with an opportunity to “store” the bedding in the field, potentially reducing the need for on-farm bedding storage. A late
fall harvest will yield the greatest mass and volume of product in part due to the higher moisture level in the stem and also in part due to the leaves having not shattered off due to heavy snow, rain, or over drying [31]. That being said, for broiler growers, the preferred product would be harvested towards the end of winter when the moisture in the biomass in the Northeastern U. S. is closest to that of kiln-dried softwood shavings at 10% moisture [30].

When harvesting these dry biomass crops, it is paramount to keep in mind the risk of combustible particles. According to the most recently updated U.S. Department of Labor’s OSHA Protocol, combustible dust is a “finely divided solid material 420 microns or smaller in diameter (material passing through a U.S. No 40 Standard Sieve)” [32]. Harvesting the product earlier in the winter where it has a higher moisture content or in the morning of later winter when the plant will have dew on it are both efforts that can be taken to reduce dust production. This makes for a safer harvesting environment.

**Biomass Crops as Vegetative Buffers**

If field planting is not an option, another possibility for biomass crops is that they are grown as part of a vegetative buffer. Vegetative buffers are defined by plants that shield areas and provide other benefits such as capturing emissions, screening, and providing biomass [33]. They have been successful in the poultry industry where they shield houses from the scrutiny of the public eye as well as capture some of the high volumes of dust and other emissions leaving the houses through the fans.

Although there are many successful species used in these barriers, some can withstand the high dust and ammonia accumulation better than others [34]. Deciduous species are preferred over coniferous one because when deciduous species drop their leaves in the fall, the accumulated particles and excess nutrients are removed from the plants’ canopies. The new foliage in the
spring allows for the plants to better capture sunlight than those coniferous plants which still have their leaves covered in dust, leading to better success of these species [34]. Biomass grass crops also fall into this category, as they abandon their above ground biomass in winter and put on new growth in the spring.

When considering harvesting biomass from a buffer, the vegetation must be maintained such as to keep the integrity of the buffer. As the plants regrow after harvest, they will become more effective at capturing ammonia and dust [34]. This promotes the idea of alternative harvesting, where upon removal of a plant from the buffer, there will be another to stand in its place until that plant either grows back or is replanted. This is most crucial in winter when deciduous species lose their leaves, effectively lacking the potential to capture significant levels of dust, ammonia, and odor.

**Litter as a Fertilizer**

Spent poultry litter has a high nutrient value and is commonly used as a fertilizer to supply the N, P, and K needs of agronomic fields. Spent poultry litter is typically high in nitrogen, but considerations must be made before application. According to the Penn State Agronomy Guide, a product with a C:N ratio above 30:1 has the potential to not properly supply nutrients, most notably N, as readily as a material with a lower C:N ratio [30]. This is because high volumes of C immobilize soil N via increased microbial decomposition of the C, making a litter that is normally high in N effectively lower.

Because P and K are inert compounds, differences in concentrations in spent litter are in part influenced by the levels initially present in the bedding. However, these differences are typically diminished by the overwhelming volume of poultry feces added to the bedding over
grow-out, yielding few differences in these two nutrients between switchgrass and pine shavings, for example [21].

Nitrogen is a more volatile compound, especially ammonium N, which can volatilize depending on the house environment, storage, and presence of litter treatments. If a poultry house experiences high litter moisture for a period of 1-2 weeks, the transfer of ammonia to the air will be greater than with a drier material [36], decreasing its value as a fertilizer if it is applied for its nitrogen. If this litter was to be applied to meet field nitrogen requirements even with the lower N level, the levels of P and K required by the field will be exceeded. Special considerations should be made for phosphorus when applying poultry litter at high rates. Because phosphorus is an environmentally damaging nutrient once it enters a body of water, care must be taken to not over apply it, especially if dictated by tested soil P levels.

**Litter as a Fuel**

A relatively modern concept is one that utilizes poultry litter as a fuel source. Burning litter has the potential to reduce or eliminate the need to burn propane to heat a house. A consideration of this unique fuel is that it produces a dry heat, rather than the moist heat of propane. Using the balanced equation for the combustion of propane, \( C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \), an optimum burn of one liter of propane has the potential to yield a liter of water vapor that is effectively released inside of the poultry house if a grower is using an older style propane burner, which completes its combustion within the house. By using a litter burner equipped with a hot water exchange system in place of this older system, the house can be kept drier, especially in times of high heat demand and lowered ventilation requirements, as are such during brooding and in the winter months.
With the combustion of fossil fuels also comes the product of CO$_2$. Heaters within the house place combustion byproducts of propane inside of the house, with the CO$_2$ adding to the house environment. While levels of CO$_2$ up to 6,000 ppm have been shown not to harm broiler performance [37], keeping the levels below 3,000 ppm is suggested [4]. Supplementing or replacing a farm’s propane burners with the combustion or gasification of spent litter via equipment outside of the house and sending the heat through a hot water heat exchange system is an alternative to keep the levels of CO$_2$ in the house lower. This is especially helpful early in grow-out, as propane use is at its highest and ventilation is at its lowest.

It should be noted that there are more modern propane heater designs now available, which conduct their combustion outside of the house, sending the heat inside. With these systems, there is no buildup of moisture of ammonia or CO$_2$ in the house, as mentioned above. In these cases, burning spent litter on the farm can hold the advantages of cost savings or nutrient reduction.

Another advantage to heating with spent litter is that it can reduce propane costs by up to 90% [38]. This reduces one’s reliability on fossil fuels, which in turn decreases costs to both the environment and grower. Single-cycle litter ash represents a 90% reduction in mass from the spent litter [38]. One of the benefits of the reduced mass is the reduction in transportation costs if shipping the nutrients from the farm. If applying the ash for agronomic purposes, consideration should be taken to apply it to soils that have low to moderate pH, as poultry litter ash is innately alkaline [39].
Literature Cited


Chapter 2

Evaluation of the Bedding Environment in Pennsylvania

Summary

Bedding is an important consideration of broiler production as it significantly contributes to the house environment and ultimate success of the birds within it. Although Pennsylvania produces a significant number of birds annually, there is little homogeneity in terms of bedding types used across the state and between management styles. This survey was sent to determine the bedding environment in Pennsylvania and see if alternative, renewable bedding resources would fit well into the industry. Additionally, this survey aimed to determine the price point at which these bedding materials should be sold in order to be competitive in the marketplace. It was found that both broiler breeder operations and grow-out operations prefer similar qualities in their bedding materials, with broiler breeder producers having more stringent requirements than commercial growers. Broiler breeder producers were also less open to trying alternative bedding materials. Typically, commercial broiler integrators have bedding restrictions as well, but are more willing to try new bedding materials. The one integrator which did not have bedding restrictions had the greatest variety of products used among growers. It was concluded that if alternative materials can be made readily available, priced competitively, and shown to have the same or better performance than the product currently used or preferred, growers are open to trying those materials.
Description of the Problem

Pennsylvania is ranked as the 15th state in the U.S. for broiler production, with 185.7 million head reared annually [1]. Several management styles exist and all include some type of material with which the birds are bedded. These bedding types can range from kiln-dried softwood shavings to byproducts from other manufacturing processes.

Although a great deal of research has been conducted to determine the best properties for a multitude of beddings, these properties need to be reflective of what a commercial grower is looking for. With the system of integrators and growers in the United States, bedding not only has to meet the expectations of individual growers, but also the integrators. To date, there is not a publically available evaluation of the bedding market in Pennsylvania. This project aims to make such an evaluation to help determine if alternative, renewable bedding resources have a chance of becoming a player in this marketplace.

Materials and Methods

In March of 2016, a committee of Pennsylvania broiler integrators from differing parts of the state was brought together for the purpose of sharing information and identifying cooperators for another project, “Poultry Manure Nutrient and Volume Production in the Chesapeake Bay Watershed”. A list of integrators and growers that agreed to work with Penn State on this project was established. After a year of communication for this project, the preliminary list was further reduced to those integrators and growers who were known to be responsive and willing to work with representatives from the university.

A list of broiler industry cooperators meeting the above criteria was used for this bedding survey in order to assure a high response rate. The goal was to contact as many integrators and
growers as possible to get a more complete overview of the bedding environment within the state. Two distinct surveys were created: one for integrators and one for growers. Both the integrator and grower surveys were sent to the integrators first to accomplish two goals. The first was to allow the integrator to complete the integrator survey, and the second was to request permission from the integrator to contact selected growers. Sending out the integrator survey in addition to the grower survey helped to cross reference concepts including who is financially responsible for the bedding, restrictions set forth by the integrator versus restrictions set by the grower from his or her experiences, and whether or not the consideration of alternative bedding materials was something that could be done by the grower or if it was up to the integrator.

All integrator surveys were sent out March 10, 2017. A reminder to those who had not responded after two weeks was sent out on March 27, 2017. Selected growers were all contacted by the integrators, who sent back the responses for them. In this scenario, there was no direct contact between the university and the growers. One integrator provided the names and phone numbers of growers that he believed communicated well, and those four growers were contacted directly and asked the survey questions over the phone.

**Integrator Survey**

The integrator survey asked the following questions:

1. Are farmers responsible for paying for their bedding material out of pocket or does each use an allowance from the company? If yes, what is that allowance?
2. Are there restrictions on the type of bedding a grower can use?
3. Are there seasonal restrictions on the use of new bedding material? (ex: cannot bed with new material in the winter months)
4. Would you be open to your growers using a new bedding material source? If not, what would make you more open to use of a new bedding material?

**Grower Survey**

The grower survey asked the following questions:

2. How many flocks do you rear per year?
3. How much bedding do you use to fully bed a house and what are the house dimensions?
4. How long do you keep bedding under the birds/ how many flocks do you rear on one bedding cycle?
5. Do you top dress your litter in-between flocks and if so, how much material do you use?
6. What type of bedding do you currently use? (material, percent moisture)
7. Do you have a preferred bedding type? Are there any preferred characteristics you are looking for?
8. What do you currently pay for bedding? Does that price include delivery? Do you think that this price is too high, too low, or fair?
9. What have you paid historically for bedding?
Results and Discussion

Survey Response

Out of the nine integrators contacted, only six responded, representing six different companies within Pennsylvania’s broiler industry. Of these, two were broiler breeder operations and four were commercial grow-out operations. About half of the respondents replied within two weeks of the initial survey, while the other half responded after the reminder email.

Variation existed in the types of responses garnered. Some integrators answered the surveys for the growers from their records, while others allowed the growers to fill out the survey directly. Some responses had a great level of detail for each grower while others were a generalization of all grower responses. Calling the growers from the integrator who provided names and phone numbers allowed for complete responses to questions. Furthermore, the number of grower responses was varied, with numbers from 0 to “several”, as seen in Table 2-1.

Management styles including conventional, natural, antibiotic free (ABF), and organic were well represented.

Survey Results

The survey response encompassed a variety of management styles for grow-out operations, with the average number of flocks per year ranging from 5.5 to 6.5 (Table 2-1). Individual grower responses totaled 9 plus “several” from the integrator who did not provide a specific number. Typically in grow-out operations, the integrator pays for the bedding, with a few exceptions. One integrator leaves purchasing the bedding to the farmer, while another offers an
allowance, where if the cost allowance is exceeded, the remainder of the cost is the farmer’s responsibility.

Bedding restrictions are present depending on the integrator. Restrictions typically limit bedding materials to kiln-dried wood products. In one incidence, there is a specific company which supplies the certified organic bedding to the organic growers whereas conventionally and ABF reared birds have no restrictions, though the source needs to be approved by the integrator (Table 2-2).

The current product used by growers matches the restrictions put in place by the integrators. Not surprisingly, growers have bedding characteristic preferences that are reflective of the product they are restricted to. This is likely because the product that they use works consistently and gives them a good rate of return on their flocks. Interestingly, all growers are willing to try new products, though stipulations are present. These include the new product meeting the standards of the integrator and not impacting production (Table 2-2).

Integrator 3, which did not have bedding restrictions, has the greatest variety in products, illustrated in Table 2-2. The integrator allows a bedding allowance of $0.43 per square meter ($0.04 per square foot). The materials currently used by the growers range from kiln-dried hardwood shavings to green sawdust, with other combinations in-between. The preferred product is just as variable, but either a kiln-dried or fresh (if the product is “green” so that it does not introduce mold into the house) product that is highly absorbent with low dust production and is easily spreadable. This integrator allows the growers free reign over their bedding as long as it does not impact their production performance. Because of this, what is available as traditional bedding material or byproduct from local wood manufacturing is what is used as a bedding material, even if the product is not ideal.

The costs associated with beddings are highly variable (Table 2-3). The range in price from the breeders cannot be commented on, as these integrators did not share this information.
Integrator 3, which uses the bedding allowance, exhibits the highest variability in bedding costs. This may be because whatever money is not used by the grower for bedding is effectively additional income, which can be said especially of growers paying the lower end of the range. The price differences may also reflect product quality and availability, which can drive prices up for growers on the higher end of the range. For instance, the grower who purchases green sawdust under integrator 3 pays $3.85 per m³ ($5.04 per yd³) while the price of softwood shavings is no less than $9.17 per m³ ($12.00 per yd³). The other three groups of growers surveyed indicate bedding ranges from $6.50-$17.58 per cubic meter ($8.50-$23.00 per cubic yard). It does not appear that integrators who pay for bedding materials (Integrators 4 and 6) necessarily pay more than what farmers who source bedding on their own do.

An additional consideration of cost is if the bedding material provider also hauls the product to the farm and spreads it. All bedding prices in Table 2-3 included delivery, but only two included spreading. Integrator 4, which purchases a softwood shaving, pays the highest of all integrators and growers surveyed, at $17.58 per m³ ($23.00 per yd³) for a product that is hauled and spread. The other grower that had bedding delivered and spread paid $10.65 per m³ ($13.93 per yd³), which was lower the cost of bedding with delivery only for another grower under the same integrator at $12.23 per m³ ($16.00 per yd³). From this, it can be reasoned that delivery is typically included in the bedding price and if spreading is included, it does not necessarily increase the price above other materials that do not include spreading.

The survey results from the breeder operations were more difficult to make definitive conclusions from since there were only two replies and of those two, one did not give permission to send the grower survey. However, the responses indicate that standards of broiler breeder operations are more strict than traditional grower operations in that they currently only allow their growers to bed their birds with kiln-dried softwood shavings. This is also typically their preferred product, though one breeder noted that any dry material would suffice. The strict nature of the
breeder industry is split when considering new products. One is not willing to try new products while the other is willing to try new products that are biosecure (heat-treated) with good absorptive properties. (Table 2-2).

From talking to the growers from Integrator 3, there seems to be a trend in traditionally sourced bedding availability. As of spring 2017, there was an abundance of forestry by-products available for bedding. However, some years ago when fuel prices were high and the wood pellet industry was picking up speed, at its peak, there was a shortage of bedding for these growers. They reflected that this area of the market is currently stable, but if there was to be another surge in fuel prices or other economic change, this may create the opening needed for other bedding options to truly establish themselves in the market. This statement was expressed by only two of the phone-interviewed growers, so it may only be reflective of their immediate area. However, it should not be ignored, as it may be a valid analysis of past and future trends in this market in Pennsylvania.

An opening for alternative bedding products remains to be realized in PA, and testing to verify their performance may facilitate their adoption. The survey results would suggest that the market is looking for a product reflective of kiln-dried shavings with low dust, good moisture retention and evaporative loss, and easy handleability. These products should also be tested to ensure they are free of molds and other pathogens or that these are at a very low level.

Application of pesticides and herbicides to the fields of biomass can leave residue which can harm poultry, so these must also be considered. Once these factors can be consistently proven with alternative biomass bedding materials, they will have to be priced at a point to be competitive in the marketplace. A combination of these factors will allow success of an alternative, renewable biomass product.
Table 2-1. Broiler survey results including the number of grower responses, management style, flocks per bedding cycle, and flocks per year

<table>
<thead>
<tr>
<th>Integrator ID</th>
<th>Industry type</th>
<th># Grower responses</th>
<th>Management style (^1,2)</th>
<th>Average number of flocks per bedding cycle (^2)</th>
<th>Average number of flocks per year (^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Breeder</td>
<td>0</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2</td>
<td>Grow-out</td>
<td>“Several”</td>
<td>Organic</td>
<td>5.5-6</td>
<td>5.5-6</td>
</tr>
<tr>
<td>3</td>
<td>Grow-out</td>
<td>4</td>
<td>Conventional and Natural</td>
<td>1</td>
<td>6-6.5</td>
</tr>
<tr>
<td>4</td>
<td>Grow-out</td>
<td>4</td>
<td>ABF and Organic</td>
<td>1</td>
<td>5.75</td>
</tr>
<tr>
<td>5</td>
<td>Breeder</td>
<td>2</td>
<td>Conventional</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Grow-out</td>
<td>1</td>
<td>Conventional ABF</td>
<td>2</td>
<td>5-6</td>
</tr>
</tbody>
</table>

\(^1\) Response is from the integrator
\(^2\) Response is from the growers
\(^3\) --- indicates no response was recorded for a particular category
Table 2-2. Broiler survey results including bedding cost responsibility, restrictions, preferred product, and willingness to try new products

<table>
<thead>
<tr>
<th>Integrator ID</th>
<th>Industry type</th>
<th>Who pays for bedding?</th>
<th>Bedding restriction</th>
<th>Current product</th>
<th>Preferred product</th>
<th>Willingness to try new product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Breeder</td>
<td>Integrator</td>
<td>Yes- kiln-dried softwood only</td>
<td>---</td>
<td>---</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Grow-out</td>
<td>Farmer</td>
<td>Yes- only a pure wood product without chemicals</td>
<td>Kiln-dried wood shavings</td>
<td>- Kiln-dried shavings</td>
<td>Yes- if meets standards and cost-competitive</td>
</tr>
<tr>
<td>3</td>
<td>Grow-out</td>
<td>Integrator - farmer if quota exceeded</td>
<td>No- unless grow-out issues</td>
<td>- Kiln dried hardwood shavings</td>
<td>- Kiln-dried</td>
<td>Yes- if does not impact production</td>
</tr>
<tr>
<td>4</td>
<td>Grow-out</td>
<td>Integrator</td>
<td>Yes- Softwood bedding only</td>
<td>Softwood shavings</td>
<td>Shaved logs</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Breeder</td>
<td>Integrator - farmer if quota exceeded</td>
<td>Yes- Only kiln-dried, bagged shavings</td>
<td>Dry wood shavings</td>
<td>Dry material</td>
<td>Yes- if biosecure with good absorption properties</td>
</tr>
<tr>
<td>6</td>
<td>Grow-out</td>
<td>Integrator</td>
<td>- Yes- specific company only for organic growers - No- for conventional and ABF, but source needs to be approved</td>
<td>Kiln-dried shavings under 9% moisture</td>
<td>- A material that does not dry to keep dust down</td>
<td>No- maybe in the future</td>
</tr>
</tbody>
</table>

1 Response is from the integrator
2 Response is from the growers
3 --- indicates no response was recorded for a particular category
Table 2-3. Broiler survey results including current product cost and if the cost includes delivery and/or spreading

<table>
<thead>
<tr>
<th>Integrator ID</th>
<th>Industry type</th>
<th>Current cost per m$^3$ (yd$^3$)$^{1,2}$</th>
<th>Cost includes delivery?$^{1,2}$</th>
<th>Cost includes spreading?$^{1,2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Breeder</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>2</td>
<td>Grow-out</td>
<td>$8.28-$10.19 ($10.83-$13.33)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>Grow-out</td>
<td>$12.23 ($16.00) $3.85 ($5.04) $9.17 ($12.00) $10.65 ($13.93)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>Grow-out</td>
<td>$17.58 ($23.00)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Breeder</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>6</td>
<td>Grow-out</td>
<td>$6.50 ($8.50)</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

$^{1}$Response is from the integrator  
$^{2}$Response is from the growers  
$^{3}$--- indicates no response was recorded for a particular category
Chapter 3
Chopped Miscanthus Grass versus Softwood Shavings as a Bedding Material for Single Cycle Broiler Grow-Out in Commercial Production

Summary

Increases in price and variable availability of softwood shavings have prompted exploration of alternative, renewable bedding resources on which to rear broiler-type chickens in the northeastern United States. Miscanthus grass, which produces a large volume of biomass annually, can be grown on-farm or locally to provide a steady, local supply of biomass bedding to the grower. Using readily available farm equipment, it can be processed into bedding for poultry. A comparison of a standard softwood shaving/sawdust mixture (SS) to chopped miscanthus grass (MG) was made in a commercial single-cycle production system with commercial broilers reared to 35 days of age. Although miscanthus and softwood are innately different, particle size was a large contributing factor to moisture holding capacity and bulk density. No differences in litter parameters were found between the two treatments including ambient ammonia, ammonia flux, CO₂, surface temperature, litter moisture, litter score, and nutrient values. Differences in bird bodyweights, foot pad scores, and breast cleanliness scores were not significantly different and further validated that both materials worked just as well for broiler bedding. Differences in miscanthus grass fractions combined for this study were observed in nutrient analyses (total N, organic N, P₂O₅, K₂O), particle distribution, % moisture, and moisture holding capacity. These differences indicate that harvest location, variety, field management, and/or processing technique have the potential to greatly impact miscanthus.
Description of Problem

In recent years, the softwood shavings market in Southeast PA has become unstable. Both price and availability fluctuate by season. This is especially concerning in winter, as woody byproducts are sent for the manufacture of wood pellets for the heating season. The scarcity of shavings results in either an increased cost for the growers who bed broilers with these products or a scarcity of a preferred product, resulting in the purchase of a product that is less than ideally suited as a broiler bedding material.

Biomass grass crops are becoming recognized as an alternative to traditional bedding materials. With their ability to grow on marginal land and produce large amounts of dry biomass, they are a crop that can be grown on site or locally to be at the ready to harvest when bedding is needed. Miscanthus can produce 17.9-26.9 dry megagrams per hectare once the plants are established [1], and roughly 1.05 hectare of material would be required to bed a 15.2 m x 152.4 m house to a depth of 10.2 cm. When the plants are allowed to dry down in the field, as is typical for biomass production, moisture content will fall along a curve with 50% moisture in typically drying down to less than 10% by February [2]. The lower moisture content is attractive to poultry farmers, who prefer to bed with drier materials to control house moisture, ammonia levels, diseases, and footpad quality.

Bedding particle size is important, as the ability of a bedding material to hold and quickly release its moisture is a large part of what defines the quality of a bedding material. The better it performs both of these actions, the better the material is. A study by Pearson et al. in 1999 indicated that smaller particles tend to hold more moisture and are more dense [3]. Ruszler and Carson suggest that bedding materials that hold moisture without caking are superior to those that cake [4]. This makes sense as longer particles tend to rise to the surface of a bedding material early, knitting together and caking over the course of grow-out.
Particle size also influences the incidences of footpad dermatitis [5], making footpad scores a good indicator of litter quality over the course of grow out. Younger birds are more susceptible to develop footpad dermatitis, but generally, wetter bedding materials increase the incidence of the disease [6] as well as higher levels of cake [5]. Cengiz et al. also indicated that footpad scores are an indicator of bird welfare, as pain can arise from severe footpad injury [6]. Litter ammonia levels may be another contributing factor with the incidence of footpad injury, since this gas is readily dissolved in higher moisture environments, leading to burning of the footpads through the alkaline solution created from this process [5].

Breast feather cleanliness is also considered an indicator of litter conditions in the house. More soiled breast feathers indicate that the feathers have been in contact with wet litter [7]. Because of the relationship between breast feather cleanliness and transient wetness of the litter, it can be deduced that there is a correlation between breast cleanliness and footpad scores, making breast cleanliness a valid parameter with which to evaluate bird welfare. Breast feather soiling is also of concern because of its potential to introduce bacteria and other foodborne organisms into the processing plant [8, 9]. Reducing the potential of soiling the feathers may aid in keeping the levels of these bacteria low.

At the end of its life, spent litter can be utilized as either a fertilizer or fuel. The inherent values of P and K in the bedding material influence the final concentration of these two nutrients, but N can vary, depending on bedding conditions. This holds especially true for ammonium N, which is volatile and may be held differently by beddings of varying characteristics. Higher litter moisture maintained over a longer period of time (1-2 weeks) is especially concerning, as the transfer of ammonia from litter to the air is greater [10]. The ratio of C to N in the litter also influences its efficacy as a source of N when applied as a fertilizer. A C:N ratio higher than 30:1 immobilizes the available N, reducing its efficacy as a fertilizer [11]. In this instance, if more litter is applied to a field to overcome the tied up N, an excess of P and K will likely be applied.
Phosphorous is a nutrient with the potential to cause environmental damage when it migrates from a field and into surface water. When applying poultry litter to the field for its N, care must be taken to ensure that P is not overapplied.

Combustion or gasification of the spent litter in a biomass burner may be a valid option for some broiler growers. By burning the litter, reliance on propane can be reduced, the mass of litter can be reduced by nearly 90% for ease of transport [12], and the N is eliminated, as most is volatilized to N₂ gas during the burning process instead of being released as a greenhouse gas.

Burning litter has been shown to reduce propane use by up to 90% on some farms when a single cycle litter system is utilized [12]. The resulting ash is rich in P, K, Ca, and micronutrients. Although availability of P has been documented, the other nutrients’ availability varies and need further evaluation at this time [13]. Another advantage of burning litter is the original litter mass is so far reduced (10% of the original), it can be economically transported at lower costs to areas where the nutrients can be properly utilized.

**Materials and Methods**

**Trial Design**

A 15.2 m x 61.0 m broiler house was utilized for this project. Cells were created by dividing the house with migration fences into 5 equal sections (15.2 m x 12.2 m). These cells remained through the middle of week 4, when the producer removed the fences, since the birds were migrating and pushing into it, compromising their welfare.

Bedding was placed to a depth of approximately 7.6 cm, where a softwood shaving/sawdust mixture (SS) was placed in the front of the house and chopped miscanthus grass
(MG) was placed in the rear of the house. The beddings met in the center of cell C, which was not utilized in the study as it allowed the two beddings to mix, leaving the two replicate cells of each bedding type to remain pure. A diagram of the divisions can be seen in Figure 3-1.

Thirteen thousand three hundred Heritage cockerels were placed in the whole house, with 2,660 placed per cell. Birds were placed on April 28th, 2015 and reared to 35 days of age. The flock was a single cycle conventional flock, placed to a density of 697 cm² per bird.

**Bedding Sampling and Analyses**

Bedding samples were taken before the birds were placed. The softwood sawdust/shaving was sampled from the covered bedding storage as well as miscanthus 1 (MG1). Miscanthus 2 (MG2) had already been placed in the house, so it was sampled from there. These two experimental beddings are denoted as separate products as well as combined, since they were delivered to the grower in two different loads and may have been harvested from different fields, and possibly with different equipment. They were placed in the house in layers of the same depth, with MG2 being placed first, topped with MG1.

All bedding samples were collected using a grab sample technique, where 10-15 representative sub-samples were taken and mixed to create each bedding replicate. Three replicates were taken per bedding type. The bedding samples were taken either from the bedding storage shed or from the floor of the barn before it was heated to brooding temperature. All samples were immediately closed in zipper lock bags to retain their moisture.

Three replicates were used for each bedding analysis. All analyses were conducted following collection, and were consistently stored in their respective zipper lock bags. Before any subsamples were taken from each replicate sample for any analysis, the whole samples were
gently mixed to evenly incorporate all grab samples from each subsample, with care taken not to break up the bedding particles.

Particle Size Determination

A sieve shaker (W.S. Tyler Company, Cleveland, OH) compliant with the ASAE S319.3 standard [14] was set with 13 - 30.48 cm screens and a bottom pan. The opening diameter of the screens used were as follows: 12.7 mm, 6.35 mm, 5.66 mm, 4 mm, 2.38 mm, 2 mm, 1.7 mm, 1.18 mm, 1 mm, 0.71 mm, 0.25 mm, 0.18 mm, 0.125 mm. A volume of bedding material was taken such that the top screen was filled to a depth of approximately 2.5 cm for each sample before shaking.

Once the screens were stacked in descending order of screen opening diameter, the sample was placed and the cover was secured. The machine was allowed to shake for 7.5 minutes. Each swing of the pendulum containing the screens was determined once the pendulum had hit both the front and rear plate once. It was determined that it performed 120 swings/minute.

At the end of each 7.5 minute session, the stack of screens was removed and the particles held on top of each screen collected. By adding the total mass from each screen, an overall sample mass was determined. Once this had been found, the following equation was used to determine the percentage of material within each particle size category using equation 3-1, where m= mass on a screen:

\[
\text{distribution (\%)} = \frac{m_{\text{screen}}}{\sum_{i=1}^{14} m_i} \times 100 \quad \text{Equation 3-1}
\]
**Percent Moisture**

The bedding moisture percentage was determined by placing representative replicates of the beddings into small, tared aluminum pans. These pans were then placed in forced-air oven set to 56 °C for 48 hours. The samples were removed and weighed again, where the following equation was used to determine the percent moisture of the sample.

\[
\% \text{ Moisture} = \frac{\text{Bedding "as-is"} - \text{Bedding Dry}}{\text{Bedding "as-is"}} \quad \text{Equation 3-2}
\]

**Moisture Holding Capacity**

The procedure for this evaluation followed that outlined by Brake et al. [15]. Bedding material taken directly from the sample bags was placed into a pre-weighed 1000 mL beaker to a depth of 10.2 cm. The mass of bedding was recorded (bm), then was filled to the 1000 mL mark with dH₂O. After sitting for 30 minutes at room temperature, the beaker was inverted onto a fine mesh screen, where it was allowed to drain for 3 minutes. All of the material was then removed from the screen and massed to determine the mass of the waterlogged sample (wm). Between each measurement, the screen was rinsed. The moisture holding capacity, expressed as the number of times the “as-is” material held its mass in water, was found using the equation below:

\[
\text{MHC} = \frac{\text{wm}}{\text{bm}} \quad \text{Equation 3-3}
\]
**Bulk Density**

Bulk density for each replicate sample was determined by dropping the bedding material gradually from a large plastic spoon from a height of 30.5 cm into a 1000 mL tared glass beaker. Once the level of the bedding was at the level of the 1000 mL mark, the beaker and material were again weighted to determine the mass of material within the beaker. Density was found as the “as-is” weight in the beaker divided by volume.

**Nutrient Analyses**

The same day of bedding sample collection, 3 replicates of each bedding type were delivered to the Agricultural Analytical Services Laboratory on Penn State University’s University Park campus. Each replicate was evaluated for total N, ammonium N, organic N, P in the form of P$_2$O$_5$, K in the form of K$_2$O, and total C.

Methods for determining values for total N and ammonium N were taken from, “Recommended methods of manure analysis”, published by University of Wisconsin Cooperative Extension Publishing. For those analyses requiring that the sample be dried first, the material was dried at 105 °C overnight [16]. Total N was found via combustion [17] and ammonium N [18] was determined by the specific ion electrode technique. Organic N was the calculated difference of total N and ammonium N.

Both P and K were determined using microwave-assisted acid digestion ICP [19], again using techniques published in “Recommended methods of manure analysis”. Total C was found by using a combustion method published by Pella in 1990 [20]. The C:N determination used total N and total C.
Litter Sampling and Analysis

Litter sampling took place at weeks 1, 3, and 5 over the course of the study using a grab sampling technique. The litter was collected in a representative core sample that extended from the litter surface to the floor of the barn. This sample was placed in a zipper lock bag to reduce moisture lost before analyses. As is seen in Figure 3-1, 3 sampling regions were utilized per cell. All regions were located in a straight line, centered between the feeder and drinker line just off center on the left side of the house to provide a more representative sample of the entire cell. Region 2 was located in the direct center of the cell while regions 1 and 3 were located halfway between region 2 and either the wall on cells A and E or the divider separating the current cell from the next. All litter parameters were tested before birds were captured for performance and welfare parameters.

At week 5, multiple litter grab samples were taken from each region within each cell to fill the volume of a 2 liter zipper lock bag. Before portioning for analyses, the samples were placed in a mixing bowl, with the cake broken up so that larger particles from the cake were evenly distributed among the smaller litter particles. Week 5 moisture, litter density, and nutrient analyses were determined from each replicate sample.

Each cell had three replicate measurements (one from each region) that were averaged per cell, resulting in an n of 2 per treatment.

Percent Moisture

Litter was collected at each region within each cell after the collection of data pertaining to ambient gasses and litter temperature as not to disrupt these measurements. Once at the lab, each sample was moved into a mixing bowl from its bag and thoroughly mixed, with cake broken
up to create a more homogenous mixture. From this point, the procedure to determine bedding moisture was followed.

**Litter Scores**

The length of each cell was walked twice to make observations and determine one litter score reflective of the entire cell. The scoring system was based on a scale of 0-3, with 0 representing new or slightly soiled litter. A score of 0 was slightly soiled litter without caking. Once some caking was observed in the cell, typically along the feeder and drinker lines, the score was a 1. A score of 2 indicated significant cake present, but covering a surface area ≤½ of the full cell, and a score of 3 represented severe caking over ≥¾ of the cell’s total surface.

**Litter Density**

The procedure for litter density was the same procedure as for bedding density.

**Litter Temperature**

Litter surface temperature was taken by using a model HHM290 SUPERMETER™ infrared thermometer (OMEGA Engineering, Inc., Stamford, CT), aimed at the litter surface at each region of each cell.
**Ambient Ammonia and CO₂**

The concentrations of both gasses were determined by utilizing a KWIK-DRAW Basic pump (MSA, Pittsburgh, PA). One-use glass ammonia Drager tubes (DragersafetyUSA.com) were used to test ammonia levels at each of the 3 regions within each cell. The number of pulls was dictated by the instructions for the tubes used. The style of tubes used was 2/A, which measured ammonia levels from 2-30 ppm. For ammonia levels below 2 ppm, estimates were taken for each quarter ppm. For levels above 2 ppm, measurements were estimated to the nearest 1 ppm. For those measurements that were under the detectable limit of the tube, the number assigned for statistical analysis was a 0. For each cell, the three regional measurements were averaged to get a representative measurement for that cell.

At the week 1 sampling date, it should be noted that cells B and D were each one measurement short due to a lack of tubes. Because of this, only two regional measurements were taken and averaged into the value for each of these cells.

Carbon dioxide measurements were also taken with the KWIK-DRAW basic pump, using style 100/A tubes, which had a measurement range of 100-3000 ppm. Measurements were estimated to the nearest 100 ppm. As was the case with the week 1 ammonia tests, cells B and D were each one measurement short, resulting in only two replicate measurements per cell.

**Ammonia Flux**

Ammonia flux was measured using the procedures outlined by Burley, 2009 [21]. A non-steady state recirculating flux chamber (volume = 0.07172 m³) was set on top of the litter surface in all regions within each cell (surface area = 0.1388 m²), attached to an INNOVA 1412 Photoacoustic Field Gas-Monitor (LumaSense Technologies, Santa Clara, CA). Equipment setup
specifications of the gas monitor were such that the normalization temperature was 20 °C, the time within the tubing was 11 seconds, and the water and cross interferences were turned on. A sampling interval of 1 minute was used, with a chamber flush time of 8 seconds before the new measurement was taken.

To get the value of the ambient air, the circulation chamber was held 54 cm above the litter surface, where it was allowed to recirculate air for at least 2 cycles (2 minutes) to ensure that the value for the ambient air was not influenced by the previous sample. Ambient air samples are denoted as \( C_0 \) for calculation purposes.

Once \( C_0 \) had been determined, the circulation chamber was lowered onto the litter surface to begin the measurements for minutes 1-5, denoted as \( C_1 - C_5 \). After five minutes of sampling had been completed, the chamber was removed from the litter surface, moved to the next region, and allowed to acclimate to get the next \( C_0 \).

To calculate flux, the measurements were first converted from ppm to mg/m\(^3\) via equation 3-4.

\[
[NH_3] \left( \frac{\text{mg}}{\text{m}^3} \right) = [NH_3] \ (\text{ppm}) \times 0.7 \quad \text{Equation 3-4}
\]

Ammonia emission or uptake was then determined by whether the chamber \( NH_3 \) concentration increased or decreased over the sampling period. If the value of \( [(C_2-C_0)/(C_4-C_2)] \) was greater than 1, reflecting a non-linear increase over time such that \( C_0 > C_2 > C_3 \), then the flux value was positive, meaning that over time, ammonia was released from the litter. However, if the measured \( NH_3 \) was shown to decrease non-linearly over time \( C_0 < C_2 < C_3 \), again using the comparison \( [(C_2-C_0)/(C_4-C_2)] > 1 \), the resulting value would be negative, meaning that ammonia was taken up by the litter instead of released.
In either above case, equation 3-5, taken from Wheeler et al. 2008 [22], was used to calculate flux. In this equation, V= flux chamber volume and A= surface area covered by the flux chamber. The letter C with a subscript was reflective of what minute’s measurement was used for each part of the equation. Times 0, 2, and 4 were used for this equation, reflected as C₀, C₂, and C₄, respectively.

\[
\text{NH}_3 \text{ flux (mg/m}^2\text{/min)} = \frac{(V/A) \times [(C_2 - C_0)^2]/[2(C_2 - C_4)\times t] \times \ln((C_2 - C_0)/(C_4 - C_2))}{t}
\]

Equation 3-5

**Nutrient Analyses**

Litter subsamples from each region were taken to the Agricultural Analytical Services Laboratory on Penn State’s University Park campus for the same analyses as outlined previously for the bedding nutrient analyses.

**Bird Performance and Welfare**

**Bodyweight**

At weeks 1, 3, and 5 after litter sampling and scoring, a group of 25 broilers were caught at random in a mobile wire pen in each cell for bodyweight determination and weighed using a hanging scale. Each weight was recorded individually, and bodyweight was calculated for each cell by taking the sum of all 25 bodyweights and dividing it by 25 birds.
Footpad Scores

After a bodyweight had been recorded for each bird, the footpads were evaluated for signs of lesions. Using the Global Animal Partnership’s 5-Step™ Animal Welfare Rating Standards for Chickens Raised for Meat\(^6\) v.2.0 [23], the average score of the combined footpads was assigned to each bird. The scoring system followed the guide such that a score of 0 represented a clean, intact foot pad while a score of 2 was indicative of a severe lesion that took up \(\geq 50\%\) of the central footpad with lesions that may or may not have spread to the pads of the toes. A score of 1 was in the middle and indicated the presence of a lesion, but one that took up \(< 50\%\) of the foot pad, with no lesions having spread to the pads of the toes. If only a small discoloration of the foot pad was present covering \(\leq 10\%\) of the surface area or if no lesion was present, that bird received a score of 0. The average foot pad score (FP) for the 25 birds evaluated per cell was found by dividing the number of birds evaluated by the number of pairs of feet evaluated.

Breast Cleanliness Scores

Breast feather cleanliness was scored after the food pad evaluations on each bird using the breast cleanliness scoring system of the Global Animal Partnership’s 5-Step™ Animal Welfare Rating Standards for Chickens Raised for Meat\(^6\) v.2.0 [23] with some slight modifications. Instead of scoring each bird’s breast feather cleanliness from 1-3, the scale was adjusted to reflect the footpad scoring system of 0-2. Soiling was not indicative of feather staining, but rather reflected the amount of dirt adhering to the breast feathers of the bird from the base of the keel to the thoracic inlet and then to either side of the breast to where the bottom edge of the wing met the bird’s body.
With this modification, 0 indicated a bird that was either clean or lightly soiled with ≤ 10% of the bird’s feathers having adhered organic matter. The score of 1 was reflective of a bird that had dirt adhering on between 10% and 49% of its breast feathers. A score of two indicated that ≥ 50% of the bird’s feathers had particles adhering. Once the score was recorded for each of the 25 birds evaluated, the average breast cleanliness score (BC) per cell was found by dividing the total number of birds by the number of breasts evaluated.

**Statistical Analysis**

Data were analyzed via a one-way ANOVA using the PROC MIXED procedure of SAS version 9.4 [24] with litter type as the independent variable (SAS). Significant values were noted at $P \leq 0.05$. Tukey’s Test for mean comparisons was used when differences among variables of interest were significant. Before analysis, percentage data was adjusted with an arcsine transformation to create a more even distribution of the data.

Bedding parameters always had an n of three for MG1, MG2, and SS. All of the parameters of interest were also run for MG with an n of 6, since MG1 and MG2 both made up the bedding material for MG. Although this may have resulted in a higher standard deviation and therefore higher chance of a type 1 error when the data were evaluated, it did not make sense to mix two of the same replicate of MG1 and MG2 to create three replicate MG beddings, since this would have run the risk of not accurately capturing the true composite bedding sample, making our statistical conclusions erroneous.

MG1 and MG2 were compared against each other to determine if differences existed between their particle distributions, percent moistures, moisture holding capacities, densities, and nutrient analyses, though these results were not used to compare directly to SS.
Before litter and bird data were analyzed with this program, means for each cell were determined from the 3 replicate measurements taken from each cell such that n=1 for each cell. Although having an n=2 for each treatment resulted in a lower power than would the n=6 if each individual replicate measurement were used, the results obtained from this project have a larger potential to not be replicated under identical conditions. However, it is still more representative of the results observed. It also eliminates pseudoreplication within parameters tested. Results must be interpreted with care as to account for the small n. Those numbers with P-values approaching significance \((P \leq 0.10)\) may have a trend associated with them from which conclusions can be drawn.

**Results and Discussion**

**Bedding**

One of the gross observations taken from the inside of the house during the first visit to the farm to collect bedding samples was the dusty nature of SS bedding during spreading by the grower. This observation was not seen with the MG. One of the reasons for this may have been the differences in particle size because although the percent moisture of the SS bedding was significantly lower, imparting somewhat to the dustiness, the two beddings only differed by a 2.62% moisture (Table 3-1).

The particle distribution of SS and MG revealed that SS had a much larger proportion of small particles as compared to MG. Nearly 48% of SS particles fell below 1mm whereas just fewer than 8% of MG particles fell within the same range. Figure 3-2 and Appendix A.1 illustrate the breakdown and significance of the particle separation.
These finer particles resulted in an increase in the amount of moisture absorbed by the SS bedding material and may have led to less matting and caking over the course of grow-out. The moisture holding capacity of these SS was nearly double that of MG (with values of 4.33 and 2.07 (Table 3-1). However, the density of SS was approximately half of the MG ($P = 0.0002$), meaning that the fineness of particles had a large influence on the amount of water the material was able to hold.

The nutrient evaluation of the two beddings revealed that there was no significant difference among them, as seen in Appendix A.2. As was expected from winter harvested miscanthus biomass, the moisture content of MG was less than 10%. However, the levels of P and K were not higher for the MG, as would be expected due to grasses high need for P and tendency to be a luxury consumer of K. On the other hand, because biomass grass crops tend to be grown on marginal ground and require little nutrient input over the course of their lifetime [1], an older stand of miscanthus may be a reason why these two nutrient values were not different from the softwood shaving control. If the field in which the MG was grown was of marginal land and the stand was older, it is likely that the concentrations of nutrients were not high enough to lead to a perceivable difference in these values as compared to SS.

Bedding organic N was the same as total N for both beddings, which is unusual. Typically, total N is the sum of the organic N and ammonium N, but the data reflects values that do not follow this pattern [18]. The reason for this is that organic N is a calculated value, where ammonium N is subtracted from total N. Since the ammonium values in all of the bedding materials tested were below the range of what the lab’s electrode could detect (ie values were < 1), they are technically reportable as “less than values”. “Less than values” are not used to calculate the nitrogen fractions, so inorganic N and organic N were the same value in this instance.
A striking feature of the beddings tested were the differences between the MG1 and MG2. When evaluating these two materials for differences in particle size, significance was present between many of the values, as seen in Appendix A.3. However, when evaluating the differences graphically (Figure 3-3), they appear to have similar distributions, which may indicate that the two fractions of miscanthus bedding were harvested with similar equipment.

As biomass grasses dry down in the field to lower moisture contents, the leaves of the plant are more prone to shattering, leaving harvesting time to influence the differences in particle size. This theory is further supported because MG2 has a significantly ($P < 0.0001$) lower moisture content than MG1, with values of 7.66% and 10.96%, respectively (Table 3-2). The lower moisture content of MG2 may have resulted in more shattering of the material upon harvest, resulting in the larger distribution of finer particles.

Table 3-2 also illustrates the differences between the two miscanthus fractions for densities and subsequent moisture holding capacities. Although the densities of these two miscanthus products were not significantly different (0.10 g/cm$^3$ for MG1 vs 0.09 g/cm$^3$ for MG2), the moisture holding capacities were. As was the pattern of the SS having a higher moisture holding capacity due to having a higher portion of smaller bedding particles than the MG, MG2 retained more moisture than MG1 ($P = 0.0004$) with MG 1 holding only 75% of the moisture of MG2.

When the nutrient analyses were compared amongst the miscanthus products (Table 3-3), significant differences were present for total N, organic N, P, K, and C. The total N present was higher for MG2. This may have been because this bedding was already in the house, and because of this, had contact with the floor. Due to the nature of a dirt broiler barn floor, the bedding may have absorbed some of the residual N, left over from the previous flock that had remained in the dirt, even after the previous flocks’ spent litter was removed. This would also explain the significant difference in Organic N, but the lack of a difference in ammonium N, since
ammonium N is a volatile compound and would have likely volatilized after the previously spent litter was cleaned out and before the new bedding was put down.

Table 3-3 also shows differences in P and K, which are likely attributed to where the two materials were grown. Grasses, being high P utilizers and luxury consumers of K, tend to absorb more of these nutrients if it is in their surrounding soil. Because the loads of MG1 and MG2 arrived at different times to the farm, there is a chance that they were not produced from the same field. To verify this assumption, the nutrients in these two beddings are similar as they would be, being the same species, but different enough to evoke significant differences due to where they were grown and how the fields were managed. The total carbon in each of these samples is reflected on an “as-is” basis, so because the moisture level of MG2 is higher, the carbon is effectively diluted, leading a level of 42.83% for MG2 vs 45.00% for MG1.

Being that both MG fractions were thought originally to have been nearly identical products, they had differences in characteristics, in particular particle size, which may have made them behave quite differently if they had been compared to each other rather than combined. This is a premise for future work, where a comparison of bedding materials of the same origin but different particle size with can shed light on if there is a difference in performance and if so, how much. The bedding, litter, and bird parameters measured in this project would be a complete analysis with the addition of evaporative loss as a complement to moisture holding capacity as well as bedding pH, which may change based on the bedding’s ability to hold moisture based on particle size.

**Litter**

Litter surface temperature results revealed that there were no differences at 1 week, but there were at week 5 (Table 3-4). The first week’s values indicate that the insulative properties of
the material for young birds is adequate for MG. Temperatures at 5 weeks indicate that miscanthus may be slightly better in terms of keeping the litter surface temperature cooler, which is better for the older birds, especially in the warmer weather, which was applicable with this project's early June finish. However, the lower litter surface temperature did not influence ambient ammonia (Appendix A.4) ammonia flux (Appendix A.4), or ammonium N content of the litter at 5 weeks (Table 3-5), as predicted by Li et al [10]. Even with the level of cake being higher for MG and the level of moisture higher for SS, these factors were not enough to make the ammonia released by these two beddings significantly different.

Gross observation of the litter at week 3 revealed tangible differences among the materials. Litter scores were not different between treatments (Appendix A.5) though MG had overall higher scores than SS. The SS bedding tended to appear damper, but had less cake. When the cake was moved, damp particles could be seen all the way to the floor of the house. The MG on the other hand was more caked, but once that cake was lifted, it revealed a layer of dry particles underneath that were separate from the cake. This shows that the cake limited the total utilization of the MG material. Reducing the particle size of the MG further in future trials may allow for a better utilization of all of the bedding placed into a house for a single-cycle flock.

Conversely, there is a slight advantage of this phenomenon in that for growers with litter burners; there is more dry carbon readily available for combustion than if all of the litter was wet all the way through. Another option would be to have the house caked out, with the cake used as a more nutrient dense material on the field while the remainder of material with a high carbon value could be incinerated.

Ambient CO₂ measurements shown in Appendix A.6 did not differ significantly between treatments over the course of the flock. The CO₂ levels experienced in this house were highest during the first week of brooding, decreased at week 3, then again increased at week 5. The low levels can be attributed to this grower’s use of a litter burner to supplement his farm’s propane
use by burning spent litter and heating the houses via a hot water heat exchange system. By concentrating his heating with this method throughout much of grow-out, he avoided excess CO₂ buildup from the propane heathers in the house during the brooding phase. Even at the end of the first week, where CO₂ levels would be expected to be the highest due to increased heating needs and decreased ventilation, the levels averaged 1,758 and 1,583 for MG and CON, respectively. This is well below the level of 3,000 ppm, which is the maximum suggested by the Cobb Management Guide [25].

Table 3-5 illustrates that the ending litter nutrient analyses indicating that this material is a good fertilizer as well as a fuel. The C:N was well below the threshold of 30:1, which means that if used as fertilizer, they have good N availability. However the softwood has a significantly lower C:N, so it would be better used as a fertilizer if the choice were between the two. Conversely, the higher C:N ratio alludes that the MG litter would be better utilized for a litter burner.

When considering the other nutrients for their fertilizer value, the SS exhibits significantly higher levels of total N, organic N, P, and K. Non-representative sampling is likely the cause of these differences, since there was no difference in the bedding materials’ initial nutrient analyses and all birds were fed the same diet and there were no differences in bodyweight. The layout of the experimental cells within the barn may have been a cause for these differences. Because SS was placed closer to the front of the house and MG to the rear, it is likely that as feed moved through the feed lines, it may have overfilled some feeders in the front of the house in order to keep the feeders filled at the rear. Either this or the feeders at the rear received a smaller volume of feed that was rapidly consumed by the birds, leading to less feed wastage in these cells than those at the front of the house.

This project’s experimental design was as is described at the beginning of the chapter due to constraints set by the grower. The number of replicates and house design were on the farther
end of what he was able to allow in his house. In future projects, the house design would have to be rearranged to ensure that the measurements taken are reflective of the beddings’ performance and based on house factors as little as possible. A suggestion is to have the house divided once lengthwise, and once again widthwise, with each of the bedding treatments tested placed along one half of the entire length of the house so that there would be two cells of each treatment on each side of the house. However this arrangement would only be appropriate if the number and arrangement of feeder and drinker lines on each side of the house was identical and if the grower was able to spread beddings in such a way for this design to work.

**Bird Performance and Welfare**

Bird performance and welfare both have the potential to be strongly influenced by the characteristics of the litter surface. Because MG1 was layered over MG2, the characteristics of MG1 may have had a larger impact on bird parameters over MG2. This being said, over the course of grow-out, broilers tend to mix the litter through dust bathing, scratching at the litter surface, and walking, so the influence of MG1 would be seen nearer the beginning of the trial whereas its effects would be muted by end.

Overall there were no significant differences among the two treatments at a level of $P \leq 0.05$ in terms of bodyweights, footpad scores, or breast cleanliness scores (Appendix A.7). However, at week 3, $P$-values for footpad scores and breast cleanliness scores approached significance, with both values of 0.0513.

The lack of differences in welfare parameters can be further verified by the lack of differences in either litter moisture (Appendix A.8) or scores (Appendix A.5). Typically, higher litter moisture will lead to an increase in the soiling of breast feathers, as there is a better potential for the wet material to adhere to the dry feathers [7]. The lack of differences in breast cleanliness
scores over the grow-out correspond well with the lack of differences seen in litter moisture. Litter scores on the other hand tend to influence the footpad scores of broiler type chickens because when the material has a higher level of cake, there is a larger proportion of manure in direct contact with the footpads, resulting in ammonia burns, which can be the start of lesions on the footpad. This reasoning is verified through the results of this trial in that there were no significant differences either in litter scores or footpad scores. Because the birds were in an environment that didn’t lead to much footpad injury and the bedding types were similar, there is no obvious reason why the bodyweights would have been different, which was the result in this trial.
Literature Cited

1. Wurzbacher, S. 2014. Alternative markets for dedicated grass energy crops. Ag Communications and Marketing, Penn State University, University Park, PA.


Figure 3-1. Broiler house cell divisions (A-E) and sampling regions (1-3) within each cell.
Figure 3-2. Miscanthus grass and softwood shaving bedding particle size distributions.
Table 3-1. Moisture (%)$^1$, moisture holding capacity (expressed in g of water held per g of dry bedding material), and density of bedding materials

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Moisture (%)$^1$</th>
<th>Moisture holding capacity</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus</td>
<td>6</td>
<td>9.31$^a$</td>
<td>2.07$^b$</td>
<td>0.10$^a$</td>
</tr>
<tr>
<td>Softwood</td>
<td>3</td>
<td>6.69$^b$</td>
<td>4.33$^a$</td>
<td>0.06$^b$</td>
</tr>
<tr>
<td>SEM$^2$</td>
<td>---</td>
<td>0.65</td>
<td>0.39</td>
<td>0.00</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.0393</td>
<td>&lt;0.0001</td>
<td>0.0002</td>
</tr>
</tbody>
</table>

$^a$,$^b$ Means within a column that do not share common superscripts differ significantly ($P \leq 0.05$).

$^1$ Percentage data evaluated with an arcsine transformation.

$^2$ SEM = pooled standard error of the means.
Figure 3-3. Miscanthus 1 and miscanthus 2 bedding particle size distributions.
Table 3-2. Moisture, moisture holding capacity (expressed in g of water held per g of dry bedding material), and density of miscanthus 1 and miscanthus 2

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Moisture (%)&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Moisture holding capacity</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus 1</td>
<td>3</td>
<td>10.96&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.77&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.10</td>
</tr>
<tr>
<td>Miscanthus 2</td>
<td>3</td>
<td>7.66&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.37&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.09</td>
</tr>
<tr>
<td>SEM&lt;sup&gt;2&lt;/sup&gt;</td>
<td>---</td>
<td>0.74</td>
<td>0.14</td>
<td>0.00</td>
</tr>
<tr>
<td>P-Value</td>
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<td>&lt;0.0001</td>
<td>0.0004</td>
<td>0.2461</td>
</tr>
</tbody>
</table>

<sup>a</sup>-<sup>b</sup> Means within a column that do not share common superscripts differ significantly (<i>P</i> ≤ 0.05).

<sup>1</sup> SEM = pooled standard error of the means.

<sup>2</sup> Percentage data evaluated with an arcsine transformation.
Table 3-3. Nutrient analyses\(^1\) of Miscanthus 1 and Miscanthus 2 bedding materials on an “as-is” basis

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Moisture (%)(^2)</th>
<th>Total N (g/kg)</th>
<th>Ammonium N (g/kg)</th>
<th>Organic N (g/kg)</th>
<th>P(_2)O(_5) (g/kg)</th>
<th>K(_2)O (g/kg)</th>
<th>Carbon (%)</th>
<th>C:N Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus 1</td>
<td>3</td>
<td>7.45(^b)</td>
<td>1.16(^b)</td>
<td>0.04</td>
<td>1.16(^b)</td>
<td>0.12(^b)</td>
<td>0.77(^b)</td>
<td>45.00(^*)</td>
<td>437.27</td>
</tr>
<tr>
<td>Miscanthus 2</td>
<td>3</td>
<td>11.62(^a)</td>
<td>2.06(^a)</td>
<td>0.03</td>
<td>2.06(^a)</td>
<td>1.99(^a)</td>
<td>2.33(^a)</td>
<td>42.83(^b)</td>
<td>209.40</td>
</tr>
<tr>
<td>SEM(^3)</td>
<td>---</td>
<td>0.94</td>
<td>0.24</td>
<td>0.00</td>
<td>0.24</td>
<td>0.42</td>
<td>0.35</td>
<td>0.01</td>
<td>70.47</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>&lt;0.0001</td>
<td>0.0430</td>
<td>0.2171</td>
<td>0.0430</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.1045</td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) Analyzed by the Agriculture Analytical Laboratory (University Park, Pa).

\(^2\) Percentage data evaluated with an arcsine transformation.

\(^3\) SEM = pooled standard error of the means.
### Table 3-4. Surface litter temperatures at weeks 1 and 5 (°C)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Week 1</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus</td>
<td>2</td>
<td>25.83</td>
<td>24.81b</td>
</tr>
<tr>
<td>Softwood</td>
<td>2</td>
<td>25.33</td>
<td>28.15a</td>
</tr>
<tr>
<td>SEM(^1)</td>
<td>---</td>
<td>0.55</td>
<td>0.98</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.7379</td>
<td>0.0151</td>
</tr>
</tbody>
</table>

\(^a\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) SEM = pooled standard error of the means.
Table 3-5. Litter nutrient analyses\(^1\) after 5 weeks of use on an “as-is” basis

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Moisture (%)(^2)</th>
<th>Total N (g/kg)</th>
<th>Ammonium N (g/kg)</th>
<th>Organic N (g/kg)</th>
<th>P(_2)O(_5) (g/kg)</th>
<th>K(_2)O (g/kg)</th>
<th>Carbon (%)</th>
<th>C:N Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus</td>
<td>6</td>
<td>32.15</td>
<td>21.18(^b)</td>
<td>2.82</td>
<td>18.37(^b)</td>
<td>14.04(^b)</td>
<td>10.15(^b)</td>
<td>48.93</td>
<td>23.03</td>
</tr>
<tr>
<td>Softwood</td>
<td>6</td>
<td>36.17</td>
<td>24.08(^a)</td>
<td>3.11</td>
<td>20.97(^a)</td>
<td>17.59(^a)</td>
<td>11.54(^a)</td>
<td>39.67</td>
<td>16.52</td>
</tr>
<tr>
<td>SEM(^3)</td>
<td>---</td>
<td>1.13</td>
<td>0.60</td>
<td>0.17</td>
<td>0.64</td>
<td>0.61</td>
<td>0.26</td>
<td>0.03</td>
<td>1.25</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.0720</td>
<td>0.0070</td>
<td>0.4040</td>
<td>0.0337</td>
<td>0.002</td>
<td>0.0013</td>
<td>0.0665</td>
<td>0.0025</td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) Analyzed by the Agriculture Analytical Laboratory (University Park, Pa).

\(^2\) Percentage data evaluated with an arcsine transformation.

\(^3\) SEM = pooled standard error of the means.
Chapter 4

Switchgrass versus Softwood Shavings for Bedding Red Broilers Reared at an Organic Stocking Density in a Pen-Scale Trial

Summary

The second trial in this series was conducted with the intention of determining if particle size of switchgrass influenced litter quality, bird performance, and bird welfare of commercial red broilers reared to 8 weeks of age. A forage harvester was used to harvest the switchgrass directly from the field and create three distinct bedding treatments (5.3 mm, 31.4 mm, and 62.8 mm), which were compared against themselves as well as to a baled kiln-dried softwood shaving control. The smallest switch treatment had a particle distribution that was most similar to the softwood shavings. The two longest treatments had particle distributions most similar to each other. Although water holding and evaporative loss were indicative of differences between the treatments, the results were not replicated in bedding moisture at the time periods tested. Litter moisture was highest for the longest switch particles at 8 weeks, though litter moisture did not appear to directly impact footpad scores. Litter scores were significantly different only at week 6, where the 31.4 mm switch treatment performed the best. Footpad scores, breast cleanliness, and bird performance parameters did not differ significantly between treatments at 35 and 56 days. All bedding nutrient parameters excluding K₂O were higher for switchgrass on an “as-is” basis, though ammonium N was the only remaining difference at 8 weeks of age. The results indicate that processing switchgrass to lengths between 5.3 mm and 62.8 mm influences its physical parameters and subsequent performance as poultry bedding though they have no impact on bird performance or welfare.
Description of Problem

With the increasing use of alternative bedding materials over traditional softwood shavings, more research must be conducted to determine if these materials are efficacious. Switchgrass is a material that is gaining popularity and has been tested as a bedding material in both pen trials and commercial facilities [1, 2, 3]. However, it has been noted that particle size can influence its performance.

Switchgrass is native to much of the United States, including Pennsylvania [4]. It grows 0.9-1.5 m in height [4] and once established, can produce continuously for 20 years [5]. This species can be planted in marginal soils with great success, as it is tolerant of poorly drained soils, flooding, high water tables, and produces well on soils that are low in fertility [5]. The biomass is typically harvested from late winter to early spring at rates between 6.69 and 10.46 Mg/ha [6]. Harvesting in the fall will yield the highest amount of product, since the moisture in the biomass is still high and the leaves have not shattered from the stems due to drying over the winter [6]. Contrariwise, to produce a product comparable to kiln-dried shavings in terms of moisture, the biomass should be allowed to dry down in the field for the longest time possible, resulting in biomass with 10% moisture by the end of winter in the Northeastern U.S. [7].

Processing switchgrass can have a large influence on how it will perform as a bedding material. An optimal bedding will wick moisture away from the litter surface and birds yet also release it in a timely manner so that the moisture can be taken up by the ventilation system and removed from the house, decreasing house humidity. Although bedding type strongly influences this property, particle size within a bedding type may be just as influential. Smaller particles of the same material will absorb more liquid per unit mass [8], though switchgrass as a material overall tends to absorb a similar amount of moisture compared with pine shavings that have similar bulk densities [9].
These innate properties have the potential to play a large role in how the litter will cake and allow ammonia to volatilize. Caking tends to occur with longer particle lengths, as these rise to the surface of the litter, effectively creating a suspended surface where caking can begin. Areas of excessively wet litter, such as those found under severe cake create anaerobic conditions which can suppress ammonia volatilization. Larger particles allow for more air pockets in the litter, creating an environment in which aerobic uric acid decomposing bacteria can thrive, leading to higher levels of ammonia [10]. Miles et al. also argued against differences in particle size leading to varying rates of ammonia volatilization because volatilization is mainly affected by temperature, rather than litter moisture [10]. Increases in pH are associated with increases in litter moisture, which in turn can also influence the release of ammonia over grow-out [11].

Factors such as these have the potential to influence poultry welfare and performance. The amount of moisture held in litter can increase the incidence of footpad dermatitis in broilers, with birds younger than 14 days of age experiencing a higher incidence of lesions with wetter litter [12]. If the situation does not improve by later ages, this could further aggravate and perpetuate lesions [12]. The literature to date only identifies this as a concern for the paw market and chicken welfare, as there has been little evidence of an effect of footpad dermatitis on live performance [13]. Litter caking is a factor in the incidence of footpad lesions [13], as is high litter moisture [14]. Breast feather cleanliness is also indicative of house litter moisture, with higher moisture leading to a greater attachment of material to the breast feathers [15]. This can be used as an additional gauge to relate footpad lesions and litter wetness.

To date, switchgrass has not been shown to impact mortality [2, 3], and performance of birds reared on switchgrass has been most commonly found to be equal when compared to birds reared on softwood shavings [1, 3]. One study did note a slight difference early on in performance parameters, but these differences were not evident by processing age [2].
Materials and Methods

Bedding Processing and Sample Collection

On March 3, 2016 a switchgrass field at The Pennsylvania State University located at the corner of Fox Hollow and Big Hollow roads was harvested to obtain the material needed for this study. This mature stand was allowed to complete its annual growth cycle and dry down naturally in the field over the winter. Because the grassy biomass is harvested from the field annually, the only product in the field was from the 2015 growing season. Using standard cutting and raking equipment, the grass was cut and raked into rows the day before it was picked up with the forage harvester.

A John Deere 6750 self-propelled forage harvester outfitted with a 630-A 48-knife cutterhead and 4 length-of-cut transmission settings was used to pick up the raked grass, chop it, and blow it into a dump truck before being transported to the Poultry Education and Research Center on Penn State’s University Park campus. Cutter head knives were removed and transmission settings changed to attain treatment particle lengths (Table 4-1). As knives were removed, the average particle length increased. The 1st and slowest transmission speed resulted in the smallest particle for the number of knives present, while the 4th and fastest setting resulted in the largest particles. Knife number and transmission speeds were adjusted in order to attain the largest, smallest, and middle sized particle that this particular harvester could produce. The average particle size was realized for each treatment, with S1 representing an average particle size of 5.3 mm, S2 an average particle size of 31.4 mm, and S3 an average particle size of 62.8 mm.

After harvesting, the chopped product was moved to the Poultry Education and Research Center, where three replicate samples of the combined treatments were taken using a random grab
sampling technique with 15 subsamples per replicate to test for the moisture content of the product from the field. The bedding materials for the trial were stored in large piles indoors according to treatment before they were spread in the assigned trial pens within a week after the grass’s arrival at the facility.

The control used for this study was compressed baled softwood shavings (SS), procured from a local supplier. This treatment was spread into the control pens approximately one week after the switchgrass treatments.

**Trial Design**

This pen trial was conducted at the Poultry Education and Research Center in the Meat Bird Building (P-2) on Penn State’s University Park Campus. Two wings in this building were dedicated to the trial, with each wing having 24 - 2.51 m² pens. Two extra pens on each side at both the front and rear of the wings were used for the storage of the extra switchgrass, resulting in 16 pens per wing used for the trial. Each wing had individual controllers set to the same environmental parameters. The layout of the wings can be seen in Figure 4-1.

The four treatments were distributed evenly among the two wings, with 2 pens of each bedding treatment on each side of each wing, totaling 4 pens of each bedding treatment per wing. Each pen was equipped with a nipple drinker line and hanging feeder. To ensure that each pen received the same amount of bedding, one pen was bedded to a depth of 10 centimeters. This amount was then removed and weighed. The same amount of bedding was then added to the remaining pens of that treatment. The same technique was employed for all treatments.

Three days before chick placement, the temperature in both wings was increased to brooding temperature in order to flash off any excess moisture from the bedding and prepare the wings for the arrival of the chicks. Day old, straight run Hubbard Red Bro chicks were placed on
April 11, 2016. The pens had 27 birds placed per each at a density of 930 cm$^2$ per bird. The birds were reared to 8 weeks of age.

**Bedding Sampling and Analyses**

One day before the start of the trial, a sample of bedding was removed from the same area in each pen and stored in a gallon zipper-lock bag using a grab sample technique. The amount of bedding removed from each pen was recorded for later calculations. The recorded bedding samples taken from each pen were pooled and mixed to create 3 replicate samples for each treatment. This was done to get a more accurate representation of the bedding materials used.

**Particle Size Determination**

A sieve shaker (W.S. Tyler Company, Cleveland, OH) compliant with the ASAE standard S319.3 [16] was set with 13 screens and a bottom pan. The opening diameter of the screens (W.S. Tyler, Mentor, OH) were 12.7 mm, 6.35 mm, 5.66 mm, 4 mm, 2.38 mm, 2 mm, 1.7 mm, 1.18 mm, 1 mm, 0.71 mm, 0.25 mm, 0.18 mm, and 0.125 mm. A volume of bedding material was taken such that the top screen was filled to a depth of approximately 2.5 cm with each sample to ensure a uniform shake across all samples tested.

Before the addition of the sample, the screens were stacked in descending order of screen opening diameter. The sample was added on the top screen followed by a lid, and the stack of screens was secured to the shaker. The machine was allowed to shake for 10 minutes with a pendulum that swung at a rate of 120 swings/minute.
At the end of each 10 minute session, the stack of screens was removed and the particles held on top of each screen were weighed. The sum of all screens was the total sample mass. The following equation was used to determine the percent of material within each particle size category using equation 4-1, where \( m \) = mass on a screen:

\[
\text{distribution (\%)} = \frac{m_{\text{screen}}}{\sum m_i} \times 100 \quad \text{Equation 4-1}
\]

**Percent Moisture**

Percent moisture of the switchgrass on the day of harvest and the percent moisture of bedding before bird placement were determined using this procedure. Equal volumes of bedding material was placed in a small aluminum loaf pan to a depth of 3.8 cm and transferred into a forced air drying oven set at 56 °C for 48 hours. The bedding was weighed before placement in the oven and then again after being in the oven to determine the moisture initially in the beddings using equation 4-2.

\[
\% \text{ Moisture} = \frac{\text{Bedding "as-is"} - \text{Bedding Dry}}{\text{Bedding "as-is"}} \quad \text{Equation 4-2}
\]

**pH**

The procedure to determine pH was that outlined by Benabdellil and Ayachi [17]. Six representative grams of each bedding sample were placed in a tared glass breaker. To this, 60 mL of ddH\(_2\)O was added. Both the samples and water were at room temperature before the start of the analysis. Using a spoon, the sample was compressed gently so that the bedding material was
below the water’s surface. The sample was allowed to set for 30 minutes undisturbed, and then was stirred constantly for 5 minutes, with care taken not to break up the particles. After stirring, the liquid was removed and read with an accumet™ AB 150 pH meter (Fisher Scientific™, Pittsburgh, PA).

**Moisture Holding and Evaporative Loss**

The purpose of this measurement was to determine the ability of the bedding types to absorb and release moisture over time in a controlled laboratory setting. The techniques used in this analysis followed those outlined by Spiels et al. [18].

Mesh satchels were made from 100% nylon stockings to hold the samples for both the moisture holding and evaporative loss analyses. The leg of each stocking was tied using overhand knots at 4 equivalent points along its length, starting at the toe and ending approximately 11 cm before the body of the stocking where the reinforcement region started. Each satchel was 11 cm long with a knot at the bottom and trimmed to a mass of 1 g. Using a wire, a label was affixed to each satchel and their combined mass was added to the mass of the satchel for later reference (SWL).

Representative subsamples of the same volume were placed into the satchel with care taken not to break the particles. The open top was then tied using two overhand knots to secure the bedding material and form it gently into a spherical mass, with care taken again as to not break the fibers. Three replicates for each time period were created, resulting in a total of 15 samples per bedding type.

The samples were placed in a forced air drying oven at 56 °C for 72 hours to remove all moisture. Samples were weighed after this initial drying period to later calculate the grams of water absorbed per gram of dry matter. Moisture holding capacity was determined at times 0, 6,
12, 24, 48, and 72 hours. The same three replicate samples were used for the measurements at 0 and 72 hours. All other hour measurements had their own set of 3 replicate samples.

Five- four hundred milliliter beakers were filled with enough dH\textsubscript{2}O to allow room for the samples to be fully submerged, but not touch the bottom of the vessel. A separate beaker was used for each water holding capacity measurement time, excluding hour 0. The water was allowed to sit in the beakers overnight prior to analysis to ensure that water absorption assays occurred at room temperature.

At time 0, all samples were submerged in their respective beakers. A weight was added to the top of each group of bedding samples to keep them fully submerged for each period. At the end of each time period, the samples were lifted from the water by their wires and allowed to drip for 30 minutes under the cover of a plastic sheet, which minimized surface moisture evaporation. After this time, the knots at the bottom of each satchel were gently squeezed until water no longer dripped from them upon application of gentle pressure. Each sample was weighed, with the value used to calculate water holding capacity.

It was noted before the assay that the nylon mesh retained a small amount of water. To account for the water held by the nylon, an adjustment factor (Adj\textsubscript{Hold}) was calculated using the following procedure. Three pre weighed cylindrical plastic containers measuring approximately 5 cm by 7.6 cm were placed inside of pre weighed satchels with wire and labels, and were dried at 56 °C for 72 hours, where a dry weight of the nylon, wire, and tag was taken. The plastic container was assumed to be at 0% moisture. After their time in the oven, the reference samples were then immersed in room temperature distilled water for 6 hours, after which time were allowed to drip and were weighed using the same procedure as was used for the bedding samples. The adjustment factor utilized equation 4-3, where Ref\text{Dry} = mass of the cup, wire, satchel, and tag, Cup= mass of cup only, and Ref\text{Wet}= mass of soaked cup, satchel, wire, and tag at 6 hours.
After the measurements were taken, moisture holding capacity, represented as the fraction of grams of water absorbed per gram of dry bedding was calculated with equation 4-4, where BedWet\(_H\) is the mass of wet bedding, satchel, tag, and wire at a set time point (hour 2, 6, etc.), TagWireSatchel\(_H\) is the mass of the tag, wire, and satchel for the hour and replicate sample evaluated, and BedDry\(_{72}\) is the mass of the wet bedding, satchel, tag, and wire after having been dried 72 hours before immersion in the dH\(_2\)O.

\[
MHC = \frac{\text{BedWet}_H - \text{TagWireSatchel}_H - \text{Adj}_{\text{Held}}}{\text{BedDry}_{72} - \text{TagWireSatchel}_H}
\]

Equation 4-4

The samples that were used for the 72 hour measurement for moisture holding capacity were then used for the evaporative loss analysis. After having been immersed in water for 72 hours, these samples were weighed and then moved to a forced air drying oven, set at 56 °C. Hot weights of all samples were taken at 0, 2, 4, 6, 12, 24, 48, and 72 hours. From these measurements, evaporative water loss was calculated using equation 4-5 and represented as grams of water released per gram of the dry bedding at 72 hours. It should be noted that at 72 hours of the analysis (BedDry\(_{72A}\)), the samples had less mass than the samples originally at 72 hours before immersion in the water. The discrepancy is likely due to loss of particles through the nylon mesh. Because of this, the dry weight at 72 hours of analysis was used to calculate evaporative water loss in lieu of the original 72 hour dry measurement before immersion.

Similar to the moisture holding capacity, another adjustment was created to account for the water left in the nylon satchel at each hour interval. The same reference samples for MHC
were placed back in the forced air drying oven and hot massed at 2, 4, 6, and 12 hours, or until the mass of the samples did not change over two consecutive measurements. Using equation 4-5, the adjustments for each hour were found, with RefWet₆ representing the weight of the wet references at 6 hours, and RefDryₙ represent the dry mass of the sample at each hour evaluated.

\[
\text{Adj}_{\text{HeldH}} = \text{Avg} ((\text{RefWet}_6 - \text{Cup}) - (\text{RefDry}_n - \text{Cup}))
\]

**Equation 4-5**

Once the adjustment factors had been found, evaporative loss, represented in the number of grams moisture retained per gram of dry matter bedding was determined using equation 4-6.

\[
\text{EWL} = \frac{(\text{BedWet}_H - \text{TagWireSatchel}_H - \text{Adj}_{\text{HeldH}}) - (\text{BedDry}_{72A} - \text{TagWireSatchel}_H)}{\text{BedDry}_{72A} - \text{TagWireSatchel}_H}
\]

**Equation 4-6**

**Density**

Bulk density for each replicate sample was determined by dropping the bedding material gradually from a height of 30.5 cm into a 1000 mL tared glass beaker. Once the level of the bedding was at the level of the 1000 mL mark, the mass of material was determined. The density was calculated from these two values.
Nutrient Analyses

On the same day of bedding sample collection, 3 replicates of each bedding type were delivered to the Agricultural Analytical Services Laboratory on Penn State University’s University Park campus. Each replicate was evaluated for total N, ammonium N, organic N, P in the form of $P_2O_5$, K in the form of $K_2O$, and total C.

The methods for determining total N and ammonium N were taken from “Recommended Methods of Manure Analysis”, by University of Wisconsin Cooperative Extension Publishing. For those analyses requiring that the sample be dried first, the material was dried at 105 °C overnight [19]. Total N was found via combustion [20] and ammonium N was determined by the specific ion electrode technique [21]. Organic N was the calculated difference between total N and ammonium N.

Both P and K were determined using microwave-assisted acid digestion ICP [22], using techniques published in “Recommended Methods of Manure Analysis”. Total C was found by using a combustion method published by Pella in 1990 [23]. The C:N determination used total N and total C.

Litter Sampling and Analyses

Litter observations and sampling occurred on the first day of weeks 4, 6, and 8. Grab samples for moisture and pH analyses were taken from the middle of each pen, centered between the hanging feeder and rear wall of the pen as well as between the hanging drinker line and the side wall of the pen. Care was taken to get a representative sample from each area, including both caked and friable matter. All litter removed was accounted for in the final litter weight calculation. Enough sample was removed to fill half of a 946mL zipper lock bag at weeks 4 and
6. At week 8, the volume increased to fill two 950 mL bags in order to have enough to send for nutrient analyses as well as the moisture and pH analyses. Litter depth measurements were the only measurements that were taken on the first day of each week throughout the 8 week grow-out period.

One measurement was taken for each of the analyses below for each pen, resulting in 8 total replicates per treatment. The exception are the litter nutrient analyses, where one sample was taken from each pen but only 4 replicates per treatment were sent in for analyses.

**Percent Moisture**

Litter was sampled as mentioned above from each pen after the collection of data pertaining to ambient gases and litter temperature so as not to influence these measurements. Using a grab sampling technique, litter was collected in a representative core sample that extended from the litter surface to the floor of each pen. This sample was placed in a zipper lock bag to reduce moisture loss before analyses.

Once at the lab, each sample was placed into a mixing bowl and thoroughly combined, with cake broken up to create a more homogenous mixture. From this mixture, the procedure to determine bedding moisture was followed.

**pH**

The remaining sample in the mixing bowl was used for the pH analysis. Six representative grams of each litter sample were placed in a glass beaker per replicate. From there, the procedure outlined for bedding pH was followed.
**Litter Scores**

Each pen was evaluated to obtain a litter score representative of each entire pen. The scores ranged from 0-3, with 0 indicating new bedding and 3 referring to severe wet and/or caking across the entire pen. A score of 1 indicated some slight caking around the feeder and drinker line, while a 2 suggested that the pen had significant cake, extending 0.61 m from the drinker line, with cake present along the edges of the pen as well. A median score of 1.5 was representative of significant cake under the drinker line only. These scores increased by half point increments.

**Litter Depth**

Litter depth was taken on the first day of each week using a ruler to measure to the nearest centimeter. These measurements were taken 0.3 m from the rear wall and side opposite the drinker in each pen. Taking these measurements at this location in each pen allowed for the most representative sample of litter depth; the front portion of the pen was stepped on by farm staff who fed the birds and collected mortalities, the cake was thicker around the drinker line, making measurements more difficult, and the area around the feeder would have received more traffic than the rear region measured. The measurement is reflective of how much compression a bedding material in the open region of a house would receive within the confines of a 2.51 m\(^2\) pen.

Before the birds were placed, the litter depth was measured to document a true starting depth, since the pens were bedded by weight rather than by depth. All weekly bedding depths were taken at the start of each week. To determine each week’s value as a percent of the original bedding depth, equation 4-7 was used:
\[
\text{\% of Original Bedding Depth} = \frac{\text{BedDepth}_{\text{week}}}{\text{BedDepth}_{\text{initial}}} \quad \text{Equation 4-7}
\]

**Litter Weight Gain**

At the end of the study, all litter was removed from the pens and weighed with corrections made for the samples removed for bedding and litter analyses to arrive at the adjusted initial and final litter weights. By finding the difference between the two, the weight gain of the litter was determined.

**Ammonia Flux**

Ammonia flux was measured using the procedures outlined by Burley, 2009 [24]. A non-steady state recirculating flux chamber (volume = 0.07172 m\(^3\)) was attached to an INNOVA 1412 Photoacoustic Field Gas-Monitor (LumaSense Technologies, Santa Clara, CA). The specifications of the gas monitor were set such that the normalization temperature was 20 °C, the time within the tubing was 11 seconds, and the water and cross interferences were on. A sampling interval of 1 minute was used, with a chamber flush time of 8 seconds before the new measurement was taken. All litter gasses were monitored, though only the ammonia values had flux determined from them.

Flux measurements were taken after the birds and hanging feeders had been removed from the pens to reduce gaseous interference from the birds in the pen being evaluated or adjoining pens.

To measure the ammonia value of the ambient air, the circulation chamber was held 54 cm above the floor in front of each pen’s entrance. The chamber was allowed to recirculate air for
2 cycles (2 minutes) to ensure that the value for the ambient air, determined at the end of the 2 minute cycle, was not influenced by the previous sample. Ambient air samples are denoted as $C_0$ for calculation purposes.

Once $C_0$ had been determined, the circulation chamber was lowered onto the litter surface (surface area = 0.1388 m$^2$) in the center of the pen to begin the measurements for minutes 1-5, denoted as $C_1 - C_5$. After five minutes of sampling, the chamber was removed from the litter surface, moved to the next pen, and allowed to acclimate to get the next $C_0$.

To calculate flux, the measurements were first converted from ppm to mg/m$^3$ via equation 4-8.

$$[\text{NH}_3] \left( \frac{\text{mg}}{\text{m}^3} \right) = [\text{NH}_3] \ (\text{ppm}) \times 0.7 \quad \text{Equation 4-8}$$

Equation 4-9, taken from Wheeler et al. 2008 [25], was used to calculate flux. In this equation, $V =$ flux chamber volume and $A =$ surface area covered by the flux chamber. The letter $C$ with a subscript representing what minute’s measurement was used for each part of the equation. Times 0, 2, and 4 were used for this equation and represented by $C_0$, $C_2$, and $C_4$, respectively.

$$\text{NH}_3 \text{ flux (mg/m}^2/\text{min}) = \frac{(V/A) \times [(C_2 - C_0)^2]/(2(C_2 - C_4 - C_0)t)}{\ln[(C_2 - C_0)/(C_4 - C_2)]}$$

$$\text{Equation 4-9}$$

**Nutrient Analyses**

Not all pens had replicate samples sent for litter analyses. Instead, two representative pens from each wing were selected. Many birds had suffered from *E. coli* related issues from the
hatchery, resulting in some pens with higher mortality than others. Those pens with the highest mortalities were excluded from the analyses. Pens 81 and 82 were also excluded because they experienced a waterline leak at some point during the trial. From those pens that matched the criteria outlined above, two were removed from each treatment per wing. Samples of the 8 week litter were sent to the Agricultural Analytical Services Laboratory on Penn State’s University Park campus for the same nutrient analyses as outlined above in the bedding nutrient analyses section.

**Bird Performance and Welfare**

Performance was evaluated over three periods, marked by a feed transition (days 1-18, 18-35, and 35-56). These periods were used to evaluate livability, bodyweight, feed intake, and feed conversion ratios. Since welfare parameters are more litter than performance dependent, all birds were evaluated for breast cleanliness and footpad scores at weeks 4, 6, and 8 with the other litter parameters, which were determined individually for all birds in each pen.

**Livability**

A running total of mortalities and culls per pen by day were kept. Both mortalities and culls were denoted as “mortalities” to simplify the data for analysis. The sum of mortalities per pen was found for each period and using equation 4-10, the percentage of mortalities per period was found.
% Mortality = \left( \frac{\text{# live birds at beginning of period} - \text{# live birds at end of period}}{\text{# live birds at the beginning of period}} \right) \times 100

\text{Equation 4-10}

\textit{Bodyweight}

All birds were weighed as a group by pen at each of the specified sampling periods. The average bodyweight per bird (BW) at each period was found by dividing the total weight of the birds within a pen by the total number of birds present in the pen.

\textit{Feed Intake and Feed Conversion}

Three phases of commercial broiler diets were offered to the birds ad libitum. A mash starter was provided for days 1-18, a crumble grower was provided for days 18-35, and a pelleted finisher was provided for days 35-56. The feed transitions marked the start and end of each period. The macronutrient densities for the starter and finisher are provided in Appendix B.1. All feed was weighed into the feeders at the beginning of each period and weighed out at the end, with the difference used to calculate feed intake per bird (FI, equation 4-11) and feed conversion per bird (FCR, equation 4-12), where “kgfeed” was the kg of feed consumed per period and “#birds” was the number of birds per pen at the end of the period evaluated. The FCR equation is specific to each period evaluated, where a subscript of “dy” indicates the values at the end of the period being evaluated and “dx” indicates the values determined at the end of the previous period. Overall feed intake per bird and feed conversion per bird were also calculated using this method.

\[
\text{FI} = \frac{\text{kgfeed}}{\text{#birds}} \quad \text{Equation 4-11}
\]
Footpad Scores

Each bird in each pen was evaluated for signs of footpad lesions individually using the Global Animal Partnership’s 5-Step™ Animal Welfare Rating Standards for Chickens Raised for Meat® v.2.0 [26]. This resulted in two footpad scores per bird that were used to find the average footpad score per pen. A score of 0 represented a clean, intact foot pad while a score of 2 was indicative of a severe lesion that took up ≥ 50% of the central footpad with lesions that may or may not have spread to the pads of the toes. A score of 1 was in the middle and indicated the presence of a lesion, but one that took up < 50% of the foot pad, with no lesions having spread to the pads of the toes. If only a small discoloration of the foot pad was present covering ≤ 10% of the surface area or if no lesion was present, that foot received a score of 0. The average foot pad score (FP) for all birds evaluated per pen was found by dividing the sum of footpad scores by the number of individual feet scored.

Breast Cleanliness Scores

Breast feather cleanliness was scored for each bird. The scoring was adapted from standards set by the Global Animal Partnership’s 5-Step™ Animal Welfare Rating Standards for Chickens Raised for Meat® v.2.0 [26]. While scores taken directly from the Global Animal Partnership range from 1-3, our scores ranged from 0-2 to match the scoring guidelines set in place for scoring footpads. Scores ranged in whole increments from 0, which was given to birds
with very little to no soiling on their feathers, to 2, which represented severe soiling of their breast feathers. This system did not take into account feather loss, only the amount of litter and other material adhering to the feathers.

With this modification, 0 indicated a bird that was either clean or lightly soiled with ≤ 10% of the bird’s feathers having adhering organic matter. A score of two indicated that ≥ 50% of the bird’s feathers had adhering particles. The score of 1 was reflective of a bird that had adhering particles on between 10% and 49% of its breast feathers. Once the score was recorded for all birds in each pen, the average breast cleanliness score (BC) per pen was found by summing the breast cleanliness scores for a pen and dividing by the number of birds scored.

Statistical Analysis

At the end of the study, it was observed as litter was being removed from pens 81 (S2) and 82 (S3) that they had been subjected to a significant water leakage. The welfare scores and litter parameters were noticeably influenced by this. Because there was no indication of when the leaking started, these pens’ litter, bird performance, and bird welfare parameters were removed from the trial, leaving S2 and S3 with 7 replicates of each treatment, rather than 8.

Data were analyzed via a one-way ANOVA using the PROC GLM procedure of SAS® version 9.4 with litter type as the independent variable [27]. The data were blocked by wing in order to account for any variation between the two and to remove that nuisance variable. Tukey’s Test for mean comparisons was used when differences among variables of interest were significant \(P \leq 0.05\). Before analysis, percentage data was adjusted with an arcsine transformation to create a more even distribution of the data.

Bedding parameters always had three replicate samples for SS, S1, S2, and S3. The only parameter that did not follow this was the initial bedding moisture from the field, which had 3
replicate samples, but was representative of the combined switch treatments. Bird data did not have a specific number per pen, as all birds were analyzed and this number varied by pen due to natural mortality. Before bird data were analyzed via this program, means for each pen were created from the replicate measurements, which were used in the analysis rather than the individual data collected from each bird. This technique was used to avoid pseudoreplication.

**Results and Discussion**

There were some significant differences between the wings, most of which can be attributed to small temperature and ventilation differences (leading to differing levels of humidity) between them. Because the same number of treatments were assigned per wing and equally weighted, the differences were not expounded upon in this section.

**Bedding**

Evaluation of the particle size distribution revealed significance between the treatments at all sizes in-between except 4.75 mm, 0.063 mm and < 0.063 mm, as seen in Table 4-2. The general pattern was that SS and S1 tended to follow the same distribution trend, while S2 and S3 followed another, which was markedly different from the SS/S1 trend. S2 and S3 had the greatest number of large particles at 12.7 mm and 6.35 mm, while from 2.8 mm – 0.125 mm they had the smallest proportion of small particles. SS and S1 had a greater number of small particles from 2.8 mm - 0.125 mm than S2 and S3. This pattern is depicted in Appendix B.2. After realizing this trend, it was thought that the remainder of the bedding characteristics and subsequent litter and bird characteristics would follow a similar pattern. The pattern was noted in some lab and field results, though there were some that had no relationship with this pattern.
Moisture of the switchgrass from the field was 16.34%, which was higher than expected, since moisture for switchgrass is around 20% by winter’s start and steadily decreases toward the end of winter, with values seen as low as 10-12.6% [7, 28]. However, this decrease is highly weather dependent. Because the switchgrass for this project was cut and raked the day prior to its pick up early the following morning, it is possible that the dew on the grass resulted in a higher than expected moisture content.

The switchgrass bedding moisture before chick placement after two days of being subjected to the brooding heat before chick arrival, moisture was 4.16% and less (Table 4-3). There was no difference between any of the switchgrass bedding treatment moistures and the SS before chick placement.

The pH between the switchgrass bedding treatments were not different, but were significantly higher than SS as seen in Table 4-3. Switchgrass tended to have a pH that was more neutral, while SS had a more acidic nature. From these results, it can be concluded that although the fineness of chop has no influence over pH, material type does make a difference.

Particle size did influence the beddings’ ability to retain and release moisture, as seen numerically in Table 4-4 and graphically in Appendices B.3 and B.4. The only differences in water holding capacity were noted at hours 24 and 48, when S2 held the least water and S1 the most. SS was close to S1 in terms of the grams of moisture held per gram of dry bedding material and held the same amount as S1 at 48 hours. The ability of S3 to hold water at these time points was in-between S2 and SS. As was the case with the particle distribution, SS and S1 tracked together, while S2 and S3 tended to track together.

When it came to evaporative loss, however, differences were noted at hours 4, 6, and 12, with S2 and S3 releasing their moisture quickest, while S1 released moisture the slowest of the treatments. This makes sense, as larger particles compact together less so than smaller ones, allowing air to circulate better around the particles, leading to faster drying. Softwood retained
the same amount of moisture as S2 and S3 at hour 4, but at hours 6 and 12 retained an amount that was in-between the largest and smallest switch particles. By hour 24, all of the beddings were effectively at their 72 hour dry weights. The pattern from the moisture holding and particle size evaluations were not as well maintained in this analysis.

Particle size not only played a role in moisture holding and evaporative loss, but also greatly impacted density (Table 4-3.). When dropped from an identical height, large particles tend to fall randomly, creating large air pockets in a volume of bedding material. This phenomenon occurs among smaller particles, but those pockets are smaller since the particles themselves are smaller, leading to a higher density. It was no surprise therefore that SS and S1 had the highest densities (0.0731 g/cm$^3$ and 0.0659 g/cm$^3$, respectively), which were significantly different from the densities of S2 and S3. Although S2 and S3 had similar particle size distributions, the greater number of larger particles in S3 caused the formation of more air pockets, giving it a lower density of 0.0306 g/cm$^3$ when compared to 0.0417 g/cm$^3$ for S2.

Before the bedding was exposed to the birds, the nutrient values between the switch and softwood were different in all parameters, save K$_2$O, illustrated in Table 4-5. Switchgrass was higher in total N, ammonium N, organic N, and P$_2$O$_5$. These values are representative, to a large degree, of the nutrient levels in the soil. The switchgrass harvested for this project was from an 8-year old stand that did not receive fertilization. Annual removal of biomass material leaves the soil with a low nutrient profile, which is reflective of the nutrients in switchgrass bedding.

**Litter**

Although the beddings had no significant differences in moisture upon placement, differences were noted by weeks 6 and 8, though not at week 4, with a $P$-value of 0.0552. Table 4-6 illustrates this significance where S3 has the highest litter moisture while SS, S1, and S2 have
the lowest. This finding was not reflective of the moisture holding capacity results, suggesting that there is another factor that influenced litter moisture.

Because S1 has the highest moisture holding capacity at hours 12 and 24 and is one of the slowest to release said moisture, it would have been expected that it would have had the highest litter moisture over grow-out. Contrariwise, S2 held a middle to lower amount of moisture and released it fastest, so it would be reasoned that this treatment would have the lowest moisture over the course of the trial. Litter moisture did not accurately reflect these predictions. The disagreement between the analysis and litter performance indicate that the test for moisture holding and evaporative loss are not good predictors of bedding performance.

A possible explanation is that if a pen experienced a high level of cake, the moisture would have stayed on the litter surface rather than penetrating to the pen floor, so a grab sample that includes material below the cake would have included more dry material, lowering the moisture values. If this was true, then the levels of cake per treatment would have been $S3 \geq S2 > S1 \geq SS$ based on the particle size distribution. However, this reasoning could not be verified in this trial, since litter scores differed significantly by treatment only at week 6 (Table 4-7) while litter moisture differed significantly at weeks 6 and 8. Additionally, higher litter scores are not related to higher moistures at week 6 except for S2.

Litter pH was not significantly different between the litters at the time points evaluated (Appendix B.5). This is surprising since there was such a large difference between the bedding materials at the onset, with the SS being more acidic. However, the pH of the birds’ waste overwhelmed the bedding material, leading to similar litter results over time. Because litter pH is one of the parameters associated with ammonia generation [11], this contributes to the observation that no statistical differences in ammonia flux were observed (Appendix B.6).

Particle size and subsequent bedding density did not accurately predict how the beddings compressed over time, but did accurately predict their final compaction at week 8. Because SS
and S1 had similar particle distributions and were more dense to begin with, they were predicted to have compacted the least, followed by S2 and then S3. The results in Table 4-8 show that litter depth, expressed as a percent of the original bedding depth, was significantly different at weeks 2, 3, 4, and 7. Softwood compacted the most for weeks 2, 3, and 4, whereas S2 consistently compacted the least. At week 8, this trend was replaced the trend that was anticipated, but the differences between values were not significant. A graphical representation of these differences is seen in Appendix B.7.

No differences in final litter weight or weight gain between the two treatments was found at the end of the 8-week grow out period, indicating that the compaction of the bedding did not influence moisture retention or release. Although differences between the initial bedding weights were present, the lack of differences between final weights and weight gain may be indicative of bedding moisture retention (Table 4-9). It would appear differences were diluted by the amount of moisture and feces imparted to the litter by the birds.

When removing the spent litter from the pens, some of the pens had dry, unused litter that presented itself as a distinguishable layer underneath the dirty litter. Although this may have aided in cushioning the birds, it is not necessary for a single cycle flock, as this unused portion is effectively wasted, especially if the litter isn’t going to be burned to take advantage of the remaining carbon. Tilling after each flock if the litter was to be reused would also allow for use of the unused bedding material. However, if a grower is only rearing one flock per cycle of bedding and not planning on burning the litter, the recommendation would be to put less than 10.16 cm of bedding down to reduce the amount of bedding used, which would save the farmer money and would not likely impact bird performance or welfare parameters.

Litter nutrients at the conclusion of the trial indicated that there was a significant difference only in ammonium N between treatments, where S2 exhibited the highest value at 5.86 g/kg, and SS exhibiting the least, at 5.20 g/kg (Table 4-10). Because this value is represented on
an “as-is” basis, the amount of moisture in the sample has influence on the nutrient densities. Therefore, S2 and S3, which have the highest moisture values from the lab’s analysis, exhibit the greatest dilution of nutrients. Even with this consideration, S3 still has the highest ammonium N value.

This data is not reinforced by the level of ammonia flux present at the end of the flock cycle, as there were no significant differences between the treatments, but it does relate to higher litter moisture at week 8 (Table 4-6). Alternatively, softwood had one of the lowest litter moistures, which related to its low ammonium N value, though again there was not a significantly lower flux to correspond to the higher ammonium N and moisture values. The lack of differences in nutrient values other than ammonium N between the switchgrass and pine shavings is typical when comparing these two beddings after only one flock of use [2].

The total N and organic N values between the beddings were approaching, but never reached significance ($P = 0.0777$ and $P = 0.0589$, respectively). These values could be influenced if a significant difference in mortality resulted in different numbers of birds present in each treatment. All nutrient values would be affected if this was the case, though, especially those that are not influenced by environmental factors, such as P and K. The lack of differences between P and K by treatments lends to the conclusion that bird factors did not influence the amount of N between the treatments. This is further confirmed by the lack of significant differences in all bird performance parameters, meaning one treatment did not consume more feed (and effectively defecate more) than another. Because bird factors were ruled out from being a cause of the N differences between treatments, they can therefore only be due to litter parameters. Nonetheless, looking at the data for litter, there are no other overt reasons as to why these values would have been distributed the way that they are. If this difference shows up in other trials, there may be a reason for its occurrence that will have to be identified.
Bird Performance and Welfare

Livability was the same among treatments through all time points evaluated, though the overall mortality (8.85-12.48%) was higher than the U.S. average for the broiler industry. The 4-5% national average [29] mortality was surpassed by day 18 due to an antibiotic resistant strain of E. coli found to be present as a hatchery-origin problem in the chicks. This resulted in most of the 1-18 day mortalities that occurred by day 7. When evaluating the mortality numbers for this time period, the mean values have a substantial range of 3.28-8.00%. In cases other than this one, this may be enough to evoke significance between treatments, but because some pens experienced higher mortality rates than others, the standard deviation between treatments was too great to define significance.

Mortalities were high for all treatments over the course of the study due to heavy culling. After the E. coli incident, there were a number of birds that did not grow after having been severely stunted by the disease challenge. Most of these were culled during the 1-18 day period, as they could not reach the feeder or drinker lines and were not representative of the average bird in the pen if allowed to remain. The majority of the culling that took place from days 18-56 was due to bad legs, pendulous crops, and lack of gain. Only birds that were not able to support themselves on their own legs, had an obvious distention of the crop, or could not reach the water and feed lines were culled. The birds exhibiting the aforementioned problems were not from only one treatment; Appendix B.8 and Appendix B.9 show that there were no significant differences between treatments for mortality at these time periods.

Bodyweights were not different at the time points evaluated, though they approached significance at the day 35 ($P = 0.0572$) and day 56 ($P = 0.0646$), seen in appendices B.9 and B.10, respectively. At both of these time points, the trend was such that the birds on S2 had the lowest bodyweight, while birds on the other treatments were not different from each other.
However, feed intake during these periods showed no significance, nor did the feed conversion ratio. The same was true for the overall values (Appendix B.11), even though overall feed intake was approaching significance, with the S2 treatment again having the lowest feed intake. This matched the low bodyweight for this treatment, leading to a value for overall feed conversion that did not approach significance when compared to the other treatments. Therefore, these trends are unfounded. It can therefore be concluded that there was no significance among treatments for bird performance parameters.

Footpad scores (Appendix B.12) and breast cleanliness scores (Appendix B.13) showed no differences among treatments for the time periods evaluated. This was not expected, especially in weeks 6 and 8 where litter moisture was highest for S3 and the lowest for all other treatments. From these differences, it was predicted that both footpad and breast cleanliness scores would have been higher for the S3 treatment. Because litter scores were significant at week 6, where SS, S1, and S3 had the highest levels of cake, it was anticipated that, at least in the S3 treatment, birds would show higher footpad and/or breast cleanliness scores reflecting the wetter, caked environment. Because this was not the case, it is thought that the low bird density as a result of the initial organic stocking density and aforementioned mortality and morbidity problems could have diluted the effects of the beddings on these welfare parameters.

Because of the high mortality in the pens, the density of birds per pen was well below a standard organic stocking density, meaning that the pressure of birds on the litter was reduced, possibly muting the effects that would have otherwise become apparent with a higher density. For this reason, litter and bird parameters should be evaluated in another similar trial. The first part would be to look into performance and welfare parameters because even though there were no significant differences in these parameters, there were some periods at which the values approached significance (bodyweight at days 35 and 56 and overall feed intake). Second, the expected differences in welfare parameters were not present, even though the litter did express
some differences that would predispose the birds to either footpad lesions or dirty breast feathers.

For these reasons, it would be pertinent to replicate this study at a commercial scale to see if the differences are either exacerbated or diminished.
Literature Cited


Table 4-1. Switchgrass treatment assignments based on forage harvester\(^1\) knife number and transmission speed

<table>
<thead>
<tr>
<th>Number of knives</th>
<th>Transmission speed(^2)</th>
<th>Average particle size (mm)</th>
<th>Treatment assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>48</td>
<td>1</td>
<td>5.3</td>
<td>S1</td>
</tr>
<tr>
<td>24</td>
<td>4</td>
<td>31.4</td>
<td>S2</td>
</tr>
<tr>
<td>12</td>
<td>4</td>
<td>62.8</td>
<td>S3</td>
</tr>
</tbody>
</table>

\(^1\) All switchgrass was harvested with a John Deere 6750 forage harvester with a 48-knife cutterhead

\(^2\) Transmission speed 1 is the slowest feed; transmission speed 4 is the fastest feed
Figure 4-1. Diagram of the pens within the two wings of the PSU Poultry Education and Research Center with grey boxes indicating pens that were not used in the study.
Table 4-2. Bedding particle size (mm) distribution as a percentage of the total mass

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>12.7</th>
<th>6.35</th>
<th>4.75</th>
<th>4</th>
<th>2.8</th>
<th>2</th>
<th>1.41</th>
<th>1</th>
<th>0.71</th>
<th>0.5</th>
<th>0.25</th>
<th>0.125</th>
<th>0.063</th>
<th>&lt;0.063</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood</td>
<td>3</td>
<td>1.16</td>
<td>10.22</td>
<td>9.26</td>
<td>7.47</td>
<td>20.77</td>
<td>12.70</td>
<td>11.88</td>
<td>10.78</td>
<td>6.80</td>
<td>3.93</td>
<td>3.71</td>
<td>0.90</td>
<td>0.28</td>
<td>0.14</td>
</tr>
<tr>
<td>S1</td>
<td>3</td>
<td>3.66</td>
<td>6.94</td>
<td>10.49</td>
<td>4.36</td>
<td>19.07</td>
<td>13.54</td>
<td>12.51</td>
<td>13.61</td>
<td>6.74</td>
<td>3.81</td>
<td>4.15</td>
<td>0.86</td>
<td>0.20</td>
<td>0.07</td>
</tr>
<tr>
<td>S2</td>
<td>3</td>
<td>10.23</td>
<td>20.82</td>
<td>22.43</td>
<td>9.09</td>
<td>16.09</td>
<td>8.76</td>
<td>4.07</td>
<td>4.00</td>
<td>2.27</td>
<td>0.78</td>
<td>0.94</td>
<td>0.20</td>
<td>0.23</td>
<td>0.10</td>
</tr>
<tr>
<td>S3</td>
<td>3</td>
<td>21.42</td>
<td>17.74</td>
<td>14.41</td>
<td>9.06</td>
<td>16.06</td>
<td>7.38</td>
<td>5.56</td>
<td>3.44</td>
<td>2.07</td>
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<td>1.06</td>
<td>0.26</td>
<td>0.56</td>
<td>0.05</td>
</tr>
<tr>
<td>SEM ‡</td>
<td>---</td>
<td>2.42</td>
<td>2.03</td>
<td>2.31</td>
<td>0.68</td>
<td>0.77</td>
<td>0.90</td>
<td>1.14</td>
<td>1.33</td>
<td>0.72</td>
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<td>0.48</td>
<td>0.12</td>
<td>0.06</td>
<td>0.03</td>
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<tr>
<td>P-Value</td>
<td>---</td>
<td>&lt;0.0001</td>
<td>0.0079</td>
<td>0.1965</td>
<td>0.0049</td>
<td>0.0421</td>
<td>0.0092</td>
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<td>0.0005</td>
<td>0.0013</td>
<td>0.0275</td>
<td>0.2019</td>
<td>0.6025</td>
</tr>
</tbody>
</table>

* Means within a column that do not share common superscripts differ significantly (P ≤ 0.05).
1 Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.
2 Percentage data analyzed with an arcsine transformation.
3 SEM = pooled standard error of the means.
Table 4-3. Initial bedding moisture (％)², pH, and density

<table>
<thead>
<tr>
<th>Treatment¹</th>
<th>(n)</th>
<th>Moisture</th>
<th>pH</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood</td>
<td>3</td>
<td>4.04</td>
<td>4.83ᵇ</td>
<td>0.0731ᵃ</td>
</tr>
<tr>
<td>S1</td>
<td>3</td>
<td>4.16</td>
<td>6.56ᵃ</td>
<td>0.0659ᵃ</td>
</tr>
<tr>
<td>S2</td>
<td>3</td>
<td>3.94</td>
<td>6.43ᵃ</td>
<td>0.0417ᵇ</td>
</tr>
<tr>
<td>S3</td>
<td>3</td>
<td>3.91</td>
<td>6.50ᵃ</td>
<td>0.0306ᶜ</td>
</tr>
<tr>
<td>SEM³</td>
<td>---</td>
<td>---</td>
<td>0.04</td>
<td>0.22</td>
</tr>
<tr>
<td>P-Value</td>
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<td>0.1051</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

⁎⁎ Means within a column that do not share common superscripts differ significantly (P ≤ 0.05).
¹ Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.
² Percentage data analyzed with an arcsine transformation.
³ SEM = pooled standard error of the means.
Table 4-4. Water holding capacity and evaporative water loss of all bedding treatments

Water holding capacity (g), expressed in g of water absorbed per g of dry bedding material

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
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<th>12</th>
<th>24</th>
<th>48</th>
<th>72</th>
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<tbody>
<tr>
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</tr>
<tr>
<td>S3</td>
<td>3</td>
<td>2.67</td>
<td>3.23</td>
<td>2.79</td>
<td>3.26</td>
<td>3.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEM</td>
<td>---</td>
<td>0.13</td>
<td>0.10</td>
<td>0.23</td>
<td>0.39</td>
<td>0.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.2898</td>
<td>0.9416</td>
<td>0.0208</td>
<td>0.0399</td>
<td>0.7226</td>
</tr>
</tbody>
</table>

Evaporative water loss (g), expressed in g of water retained per g of dry bedding material

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>12</th>
<th>24</th>
<th>48</th>
<th>72</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood</td>
<td>3</td>
<td>4.00</td>
<td>1.21</td>
<td>0.66</td>
<td>0.39</td>
<td>0.04</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>S1</td>
<td>3</td>
<td>4.09</td>
<td>1.62</td>
<td>1.18</td>
<td>0.81</td>
<td>0.23</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>S2</td>
<td>3</td>
<td>4.07</td>
<td>1.29</td>
<td>0.60</td>
<td>0.32</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>S3</td>
<td>3</td>
<td>4.51</td>
<td>1.41</td>
<td>0.67</td>
<td>0.23</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>SEM</td>
<td>---</td>
<td>0.09</td>
<td>0.06</td>
<td>0.09</td>
<td>0.08</td>
<td>0.03</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.1413</td>
<td>0.00579</td>
<td>0.00466</td>
<td>0.0128</td>
<td>0.0174</td>
<td>0.4341</td>
<td>0.2422</td>
<td>---</td>
</tr>
</tbody>
</table>

*a,b* Means within a column that do not share common superscripts differ significantly (*P* ≤ 0.05).

1 Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

2 SEM = pooled standard error of the means.
Table 4-5. Nutrient analyses\(^2\) of bedding treatments on an “as-is” basis.

<table>
<thead>
<tr>
<th>Treatment(^1) (n)</th>
<th>Moisture (%)(^3)</th>
<th>Total N (g/kg)</th>
<th>Ammonium N (g/kg)</th>
<th>Organic N (g/kg)</th>
<th>P(_2)O(_5) (g/kg)</th>
<th>K(_2)O (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood 3</td>
<td>5.04</td>
<td>1.05(^b)</td>
<td>0.04(^b)</td>
<td>1.05(^b)</td>
<td>0.15(^b)</td>
<td>0.65</td>
</tr>
<tr>
<td>Switchgrass 3</td>
<td>4.87</td>
<td>4.47(^a)</td>
<td>0.06(^a)</td>
<td>4.41(^a)</td>
<td>1.24(^a)</td>
<td>0.63</td>
</tr>
<tr>
<td>SEM(^4)</td>
<td>--</td>
<td>0.05</td>
<td>0.77</td>
<td>0.00</td>
<td>0.76</td>
<td>0.25</td>
</tr>
<tr>
<td>P-Value</td>
<td>--</td>
<td>0.0922</td>
<td>&lt;0.0001</td>
<td>0.0086</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

\(^a\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

\(^2\) Analyzed by the Agriculture Analytical Laboratory (University Park, Pa).

\(^3\) Percentage data evaluated with an arcsine transformation.

\(^4\) SEM = pooled standard error of the means.
Table 4-6. Litter moisture (%)\(^2\) by treatment for weeks 4, 6, and 8

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Week 4</th>
<th>Week 6</th>
<th>Week 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding(^1)</td>
<td>Softwood</td>
<td>8</td>
<td>24.16</td>
<td>26.46(^b)</td>
<td>30.74(^b)</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>8</td>
<td>21.84</td>
<td>29.63(^b)</td>
<td>33.01(^b)</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>7</td>
<td>18.35</td>
<td>30.22(^b)</td>
<td>34.63(^b)</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>7</td>
<td>25.25</td>
<td>33.79(^a)</td>
<td>37.56(^a)</td>
</tr>
<tr>
<td>Wing</td>
<td>1- Pens 49-72</td>
<td>16</td>
<td>23.13</td>
<td>30.90</td>
<td>34.07</td>
</tr>
<tr>
<td></td>
<td>2- Pens 73-96</td>
<td>14</td>
<td>21.67</td>
<td>29.20</td>
<td>33.90</td>
</tr>
<tr>
<td>SEM(^3)</td>
<td>Bedding</td>
<td>---</td>
<td>0.96</td>
<td>0.78</td>
<td>0.73</td>
</tr>
<tr>
<td>P - value</td>
<td>Bedding</td>
<td>---</td>
<td>0.0552</td>
<td>0.0081</td>
<td>0.0105</td>
</tr>
<tr>
<td></td>
<td>Wing</td>
<td>---</td>
<td>0.4008</td>
<td>0.2209</td>
<td>0.9053</td>
</tr>
<tr>
<td></td>
<td>Bedding*Wing</td>
<td>---</td>
<td>0.3854</td>
<td>0.7484</td>
<td>0.9409</td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

\(^2\) Percentage data evaluated with an arcsine transformation.

\(^3\) SEM = pooled standard error of the means.
Table 4-7. Litter scores\(^2\) by treatment for weeks 4, 6, and 8

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Week 4</th>
<th>Week 6</th>
<th>Week 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding(^1)</td>
<td>Softwood</td>
<td>8</td>
<td>1.38</td>
<td>1.56(^a)</td>
<td>1.94</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>8</td>
<td>1.44</td>
<td>1.69(^a)</td>
<td>1.69</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>7</td>
<td>1.06</td>
<td>1.42(^b)</td>
<td>1.65</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>7</td>
<td>1.38</td>
<td>1.85(^a)</td>
<td>2.00</td>
</tr>
<tr>
<td>Wing</td>
<td>1- Pens 49-72</td>
<td>16</td>
<td>1.38</td>
<td>1.72</td>
<td>1.78</td>
</tr>
<tr>
<td></td>
<td>2- Pens 73-96</td>
<td>14</td>
<td>1.25</td>
<td>1.54</td>
<td>1.85</td>
</tr>
<tr>
<td>SEM(^3)</td>
<td>Bedding</td>
<td>---</td>
<td>0.07</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td>P - value</td>
<td>Bedding</td>
<td>---</td>
<td>0.0965</td>
<td>0.0251</td>
<td>0.2307</td>
</tr>
<tr>
<td></td>
<td>Wing</td>
<td>---</td>
<td>0.2571</td>
<td>0.0692</td>
<td>0.6102</td>
</tr>
<tr>
<td></td>
<td>Bedding*Wing</td>
<td>---</td>
<td>0.0027</td>
<td>0.6187</td>
<td>0.6116</td>
</tr>
</tbody>
</table>

\(^a\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

\(^2\) Litter was scored on a scale of 0-3, with 0 referring to new bedding and 3 referring to the whole pen being severely wet and/or caked. Scores increased by half point increments.

\(^3\) SEM = pooled standard error of the means.
Table 4-8. Litter depth, expressed as a percentage\(^2\) of the original bedding depth, by treatment and wing at weeks 1-8

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding(^1)</td>
<td>Softwood</td>
<td>8</td>
<td>64.70</td>
<td>52.54(b)</td>
<td>54.40(b)</td>
<td>55.82(b)</td>
<td>58.40</td>
<td>59.67</td>
<td>68.52(ab)</td>
<td>72.07</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>7</td>
<td>68.24</td>
<td>60.15(ab)</td>
<td>66.37(a)</td>
<td>66.11(a)</td>
<td>61.54</td>
<td>66.94</td>
<td>75.70(a)</td>
<td>75.57</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>7</td>
<td>75.51</td>
<td>66.31(a)</td>
<td>66.14(a)</td>
<td>65.56(a)</td>
<td>65.08</td>
<td>61.24</td>
<td>66.75(ab)</td>
<td>66.57</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>7</td>
<td>73.90</td>
<td>60.84(ab)</td>
<td>60.72(b)</td>
<td>58.84(b)</td>
<td>55.05</td>
<td>58.03</td>
<td>60.86(a)</td>
<td>61.46</td>
</tr>
<tr>
<td>Wing</td>
<td>1- Pens 49-72</td>
<td>15</td>
<td>67.18</td>
<td>57.22</td>
<td>58.79(b)</td>
<td>59.55</td>
<td>58.72</td>
<td>60.31</td>
<td>65.08</td>
<td>68.14</td>
</tr>
<tr>
<td></td>
<td>2- Pens 73-96</td>
<td>14</td>
<td>73.99</td>
<td>62.70</td>
<td>65.02(a)</td>
<td>63.62</td>
<td>61.32</td>
<td>62.62</td>
<td>70.84</td>
<td>69.70</td>
</tr>
<tr>
<td>SEM(^3)</td>
<td>Bedding</td>
<td>---</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>P - value</td>
<td>Bedding</td>
<td>---</td>
<td>0.2225</td>
<td>0.0182</td>
<td>0.0203</td>
<td>0.0471</td>
<td>0.2984</td>
<td>0.1917</td>
<td>0.0351</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wing</td>
<td>---</td>
<td>0.0990</td>
<td>0.0647</td>
<td>0.0403</td>
<td>0.1669</td>
<td>0.4446</td>
<td>0.4061</td>
<td>0.0716</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bedding*Wing</td>
<td>---</td>
<td>0.5615</td>
<td>0.7701</td>
<td>0.1357</td>
<td>0.7260</td>
<td>0.9413</td>
<td>0.1786</td>
<td>0.3195</td>
</tr>
</tbody>
</table>

\(^a\)\(^b\) Means within a column that do not share common superscripts differ significantly (P \(\leq\) 0.05).

\(^1\) Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

\(^2\) Percentage data evaluated with an arcsine transformation.

\(^3\) SEM = pooled standard error of the means.
Table 4-9. Initial bedding weight, final litter weight, and litter weight gain, by Treatment and wing

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Initial Bedding Wt (kg)</th>
<th>Final Litter Wt (kg)</th>
<th>Weight Gain (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding¹</td>
<td>Control</td>
<td>8</td>
<td>14.97</td>
<td>59.66</td>
<td>44.69</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>8</td>
<td>18.14</td>
<td>62.55</td>
<td>44.40</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>7</td>
<td>15.88</td>
<td>59.45</td>
<td>43.58</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>7</td>
<td>13.61</td>
<td>58.93</td>
<td>45.32</td>
</tr>
<tr>
<td>Wing</td>
<td>1- Pens 49-72</td>
<td>16</td>
<td>15.65</td>
<td>60.81</td>
<td>45.16</td>
</tr>
<tr>
<td></td>
<td>2- Pens 73-96</td>
<td>14</td>
<td>15.65</td>
<td>59.48</td>
<td>43.83</td>
</tr>
<tr>
<td>SEM²</td>
<td>Bedding</td>
<td>---</td>
<td>0.31</td>
<td>0.71</td>
<td>0.67</td>
</tr>
<tr>
<td>P - value</td>
<td></td>
<td>---</td>
<td>&lt;0.0001</td>
<td>0.2610</td>
<td>0.8587</td>
</tr>
<tr>
<td></td>
<td>Wing</td>
<td>---</td>
<td>0.3509</td>
<td>0.3509</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bedding*Wing</td>
<td>---</td>
<td>0.3135</td>
<td>0.3135</td>
<td></td>
</tr>
</tbody>
</table>

¹ Means within a column that do not share common superscripts differ significantly (*P* ≤ 0.05).
² Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.
³ SEM = pooled standard error of the means.
### Table 4-10. Litter nutrient analyses of litter samples after 8 weeks of use on an “as-is” basis.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Moisture (%)</th>
<th>Total N (g/kg)</th>
<th>Ammonium N (g/kg)</th>
<th>Organic N (g/kg)</th>
<th>P₂O₅ (g/kg)</th>
<th>K₂O (g/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Softwood</td>
<td>4</td>
<td>32.18ᵇ</td>
<td>28.29</td>
<td>5.20ᵇ</td>
<td>23.10</td>
<td>16.23</td>
<td>19.38</td>
</tr>
<tr>
<td>S1</td>
<td>4</td>
<td>31.22ᵇ</td>
<td>30.38</td>
<td>5.39ᵇ</td>
<td>24.98</td>
<td>17.58</td>
<td>20.55</td>
</tr>
<tr>
<td>S2</td>
<td>4</td>
<td>35.85ᵃ</td>
<td>26.65</td>
<td>5.86ᵃ</td>
<td>20.79</td>
<td>16.73</td>
<td>19.91</td>
</tr>
<tr>
<td>S3</td>
<td>4</td>
<td>36.20ᵇ</td>
<td>26.20</td>
<td>5.77ᵇ</td>
<td>20.42</td>
<td>16.39</td>
<td>19.66</td>
</tr>
<tr>
<td>SEM⁴</td>
<td>---</td>
<td>---</td>
<td>0.78</td>
<td>0.65</td>
<td>0.10</td>
<td>0.71</td>
<td>0.32</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.0278</td>
<td>0.0777</td>
<td>0.0359</td>
<td>0.0589</td>
<td>0.4967</td>
<td>0.6023</td>
</tr>
</tbody>
</table>

**Means within a column that do not share common superscripts differ significantly \( P \leq 0.05 \).**

1. Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

2. Analyzed by the Agriculture Analytical Laboratory (University Park, Pa).

3. Percentage data evaluated with an arcsine transformation.

4. SEM = pooled standard error of the means.
Chapter 5
Commercial Application of Switchgrass as a RenewableAlternative Bedding for Broilers in a Single-Cycle Production System

Summary

The third trial applied the results of the replicate pen trial from the second project to a commercial broiler house. Two switchgrass beddings processed to short and long particle lengths similar to S1 and S2 from the previous study, respectively, were used as the bedding treatments. Organic broilers were reared to 46 days of age on the litter treatments determine if particle size influenced litter performance, bird performance, and bird welfare. The most reliable analyses to determine litter performance were bedding density and particle size, whereas moisture holding and release, pH, and initial litter moisture were not. Over the course of grow out, litter moisture was not significant between treatments, but particle size influenced the level of caking, with the longer treatment (S2) caking over quicker and to a greater degree than the shorter (S1). Although litter temperature and ammonia levels (ambient and flux) are typically reflective of each other, these did not differ by treatment. Performance was not affected by particle size of the beddings, nor was breast cleanliness. However, the high level of cake of the long switchgrass bedding led to poorer foot pad scores. Bedding nutrients were not different, but litter differences between the treatments were observed for carbon level and the carbon nitrogen ratio, which were higher for the shorter treatment (S1). This project shows that processing switchgrass to shorter particle lengths increases its success as an alternative, renewable bedding material.
Description of the Problem

Softwood shavings, a traditional bedding material for broiler chickens in Pennsylvania, is still the preferred product on which to grow broilers, but instability in the market has prompted growers to look into other sources of bedding materials. One option is to use switchgrass, a renewable, alternative bedding source that can be produced locally. This native grass species is prolific, producing 6.69 to 10.46 Mg/ha annually once established [1], and will continue to produce for 20 years [2]. The material, if allowed to dry naturally in the field over the winter months, is typically less than 20% moisture, with levels around 10% near the end of the winter [3] given the proper set of weather conditions.

It has been documented that switchgrass can perform as well as a softwood shaving bedding for broilers [4, 5, 6], but to date the differences in performance and welfare between birds reared on the same material that varies in average particle size have not been categorized. One of the most important characteristics of bedding is its availability to hold moisture. Bedding that has a higher moisture holding capacity will readily wick water away from the birds. Switchgrass has been found to hold a similar amount of moisture compared to a pine shaving [7]. However, the capacity to release that moisture so that the ventilation system can draw it out of the house is another preferred characteristic and should be considered in concert with moisture holding capacity [8].

Particle size has been documented to influence footpad dermatitis [9], mainly because smaller particles are able to hold more water [9, 10]. The more moisture retained by a bedding material, the greater opportunity there is to develop footpad lesions and increase the severity of said lesions over the course of grow out [11]. Higher litter moisture can also lead to a greater amount of dissolved ammonium N in the litter, resulting in more ammonia gas, which has the potential to burn footpads [9]. Soiled breast feathers are also typically a result of high house
moisture, where wetter litter material has a greater potential to adhere to the breast feathers [12]. It can therefore be reasoned that litter quality can greatly influence the house environment and bird welfare.

The condition of the litter may also influence its volatilization of ammonia [13]. High levels of ammonia are a concern within the house because they can lead to increased susceptibility to respiratory diseases, including Newcastle disease virus [14]. Continuous exposure to ammonia at levels of 20 ppm can induce pulmonary congestion, edema, and hemorrhage [14] while a rate of 25 ppm or greater has been shown to impact performance [15]. In young birds at one week of age, ammonia levels can impact chick weight gains by 20% [16]. Ammonia release should be considered mostly toward the end of grow-out in the summer when temperatures are higher [17]. Without the consideration of the effects of ventilation, temperature is classified as the leading cause of ammonia volatilization, followed by pH and litter moisture [18]. If the house is kept drier by using bedding materials that can readily release moisture to the air, the amount of ammonia volatilization can be reduced. This is only accurate if the ventilation rate is higher to allow for the moisture released from the bedding material to be moved out of the house. In times when ventilation is low (ie winter months), the litter’s ability to retain and release moisture may be muted.

Caking is a concern in houses, mainly because it allows for birds’ footpads to be in direct contact with manure but also because it can maintain high moisture on the litter surface. Longer particles been shown to cake over with straw, which is similar to the dried biomass grasses. A collection of poultry producer recommendations from work done at Oregon State University concluded that straw bedding should be less than an inch in length, with longer particles have a greater potential to mat over quicker [19]. Additional recommendations made note that the length of the chop is more important than the type of straw itself [19].
Spent litter has the potential to be used as a fertilizer or fuel source for agricultural use. There are some limitations to both of these practices, however. High moisture in the house may lead to ammonia loss to the air, reducing the nitrogen content of the litter for fertilizer use [18]. If the litter C:N ratio, is greater than 30:1, the higher amount of carbon can tie up available N [20], and if less than 10:1, cannot be readily composted without additional C [20, 21]. If burned in a biomass burner or gasifier specifically designed to handle poultry litter, the mass of material can be reduced by up to 90% [22], with the heat used to reduce a farmer’s dependence on propane. Depending on the nutrient needs of the grower’s farm, the resulting ash can be transported off the farm or used as a fertilizer, with concentrated P, K, Ca, and microminerals [9].

**Materials and Methods**

**Bedding Processing**

The switchgrass used for this project was the Cave-in-Rock variety, grown in Greenwood Township, near Meadville, PA. It was established July 7, 2007. On November 3, 2015, it was mowed and left in the field in windrows over the winter, after which point it was round baled on May 19, 2016. After harvest, but before processing, the bales were left in the field stacked end to end to limit degradation of fibers. Two separate loads of switchgrass, each of a distinct particle size were processed, with the smaller treatment processed on November 22, 2016 and the larger processed on November 23, 2016.

Both treatments were run through a bale chopper, outfitted with round hole screens in order to make the two bedding treatments. The smaller of the two treatments (S1) was created using a 1.27cm down and a 2.54cm up screen configuration. The larger of the two treatments was created using a 2.54cm down and 5.08cm up screen configuration.
**Trial Design**

Two similar broiler houses measuring 13.4 m x 152.4 m each were used for this study. Because the grower half-house brooded, only half of each house was utilized (13.4 m x 76.2 m). Each brooding end was further divided into 6 equal cells measuring 6.7 m x 25.4 m, as depicted in Figure 5-1. In addition to cell divisions, the colored horizontal lines indicate feed (red) and water (blue) lines. A brood curtain divided the house in half, with our experimental cells on one side and reused softwood shaving litter on the other.

Bedding was placed to a depth of 8.26 cm using a bedding spreader, which allowed for bedding placement in one half of the house to the experimental depth at a time. A pen divider spanning the central length of the brood cell was placed to separate the two bedding treatments. Horizontal dividers were then placed to create three cells of each bedding treatment. The second barn was set up the same way, except the sides on which the bedding treatments were spread were reversed.

Straight run Ross x Ross chicks were placed at a density of 3,400 birds per cell on December 6, 2016. On day 10 of age, half of the birds from each experimental cell were manually moved to the non-trial region of the house to leave a density of 0.09 m² per bird for the remainder of the trial. Flock records for mortality were kept through day 9 and the flocks were reared to 44 days of age.

**Bedding Sampling and Analyses**

Bedding was sampled from each house the same day of chick placement before arrival of the birds, since the bedding had already been distributed in the houses. The houses had been heated for three days prior to the arrival of the chicks to bring them up to temperature. Using a
grab sample technique to the floor of the house, bedding samples from each treatment were taken from three regions in each house to attain the three replicates per treatment needed for analyses. Bedding pH and moisture were performed on the bedding samples in each house, since the environment in the house prior to placement may have affected these parameters. These parameters had an n of 3 per house, with an n of 6 per treatment. All other bedding parameters tested used a 50/50 blend of the two replicate from each house as a single replicate (n=3 per treatment), as house environment would not have had an effect on parameters other than pH and moisture.

**Particle Size Determination**

Particle size was measured using a sieve shaker (W. S. Tyler Company, Cleveland, OH) compliant with the ASAE standard S319.3 [23] set up with 13-30.48 cm screens and a bottom pan. The opening diameter of the screens utilized were as follows: 12.7 mm, 6.35 mm, 5.66 mm, 4 mm, 2.38 mm, 2 mm, 1.7 mm, 1.18 mm, 1 mm, 0.71 mm, 0.25 mm, 0.18 mm, 0.125 mm. The volume of bedding material used to make the determination was such that the top screen was filled to a depth of approximately 2.5 cm with each sample to ensure a uniform shake across all samples tested.

Before the addition of the sample, the screens were stacked in descending order of screen opening diameter. The sample was added on the top screen followed by a lid, and the stack of screens was secured to the shaker. The machine was allowed to shake for 10 minutes, after which time the stack of screens was removed and the particles held on top of each screen were weighed. By adding the weights of bedding from each of the screens, a total sample mass was determined. Then the following equation was used to determine the percent of material within each particle size category using equation 4-1, where \( m \) is the mass on a screen:
distribution (%) = \frac{m_{\text{screen}}}{\sum_{i} m_{i}} \times 100 \quad \text{Equation 5-1}

**Percent Moisture**

The moisture percentage of the switchgrass on the day of harvest and the moisture of new bedding were determined using this procedure. Bedding material was placed in a small aluminum loaf pan to a depth of 3.8 cm and transferred into a forced air drying oven set at 56 °C. The bedding was weighed before placement in the oven and then again after 48 hours to determine the percent moisture retained.

\[
\% \text{ Moisture} = \frac{\text{Bedding "as-is"} - \text{Bedding Dry}}{\text{Bedding "as-is"}} \quad \text{Equation 5-2}
\]

**pH**

The procedure to determine pH was taken from that outlined by Ben Abdeljelil and Ayachi [24]. Although the ratio of water to bedding was the same, 6 grams of bedding to 60 mL of ddH\_2O was used. The desiccant was read by an accumet\textsuperscript{TM} AB 150 pH meter (Fisher Scientific\textsuperscript{TM}, Pittsburgh, PA).

**Moisture Holding Capacity and Evaporative Loss**

This analysis was used to determine the ability of the beddings to absorb and release moisture over time in a controlled setting. Techniques used in this analysis followed those
outlined by Spiehs [25]. Instead of testing all of the time periods in this paper, water holding capacity was evaluated at 0, 6, 12, 24, 48, and 72 hours, while evaporative losses were evaluated at 0, 2, 4, 6, 12, 24, 48, and 72 hours.

**Bulk Density**

Bulk density for each replicate sample was determined by dropping the bedding material gradually from a large spoon from a height of 30.5 cm into a 1000 mL tared glass beaker. Once the level of the bedding was at the 1000 mL mark, the mass of material was determined. The density was calculated from these numbers.

**Nutrient Analyses and Energy Density**

Three replicates of each bedding type were delivered to the Agricultural Analytical Services Laboratory on Penn State University’s University Park campus for nutrient analyses including total N, ammonium N, organic N, P in the form of P$_2$O$_5$, K in the form of K$_2$O, and total C. Another three replicates were sent to Barrow Agee Laboratories, LLC (Memphis, TN) for gross energy determination by bomb calorimetry.

Methods for determining values for total N and ammonium N were taken from “Recommended Methods of Manure Analysis”, by University of Wisconsin Cooperative Extension Publishing. For those analyses requiring that the sample be dried first, the material was dried at 105 °C overnight [26]. Total N was found via combustion [27] and ammonium N [28] was determined by the specific ion electrode technique. Organic N was the calculated difference of total N and ammonium N.
Both P and K were determined using microwave-assisted acid digestion ICP [29], again using techniques published in “Recommended Methods of Manure Analysis”. Total C was found by using a combustion method published by Pella [30]. The C:N determination used total N and total C.

**Litter Sampling and Analyses**

Litter samples collected for percent moisture and pH were taken from 3 regions within each cell of each house, centered between the drinker line closest to the central divider and the feed line and located at regions ¼ (A), ½ (B), and ¾ (C) of the distance down the cell. The sampling regions were marked to ensure samples were staggered over the course of the project to get the most representative sample from each region from period to period. Litter was sampled on days 12, 35, and 44. A grab sampling technique was employed to remove a representative core of litter for testing.

At week 5, litter was also sent out for nutrient analyses and energy density. The samples used for this were different than those for moisture and pH. To get more representative samples for these analyses, the aforementioned grab sampling technique was used, but 5 core samples were taken and mixed together for each replicate rather than 1. These samples were taken at regions A, B, and C in the following locations: 0.3 m from the wall, 0.3 m away from the drinker line closest to the wall, centered in-between the drinker line closest to the wall and the feed line, between the drinker line closest to the center divider and the feed line, and centered in-between the drinker line closest to the central divider and the central divider.
**Percent Moisture**

Litter was sampled as mentioned above, but after gasses and litter temperature were measured so that disturbing the litter surface would not influence these measurements. Before the analysis, each sample was mixed to break up the cake and better incorporate it into the more friable fraction of the litter for more representative subsamples.

**pH**

The analysis for pH followed the same methods outlined for bedding pH, although sample was taken from the mixed sample from which litter moisture was taken.

**Litter Scores**

Litter was scored by cell in both houses by walking the length of the entire cell and determining a score which depicted the average condition of litter. The scoring system ranged from 0-3, where 0 represented new litter and 3 represented severe cake covering ≥ 80% of the litter surface. Scores increase by half-point increments and each score had the potential also include either a ‘+’ or ‘-‘, indicating a quarter point deviation from each half point interval. For statistical purposes, the presence of a ‘+’ indicated an addition of .25 and a ‘-‘ indicated a subtraction of .25 from each half or whole score increment.

The whole point scoring system is illustrated below:

0: New bedding

1: Some cake extending between 0.3 m and 0.61 m from under and around < 75% all
feed/drinker lines, small amounts of continuous cake present along the outside edges of the cell.

2: Significant cake extending $\geq 0.61$ m from $\geq 75\%$ of feed/drinker lines and some continuous cake present along outside edges of cell

3: Significant cake extending $\geq 0.61$ m from $\geq 75\%$ of feed/drinker lines and significant cake present around outside of cell; $\geq 80\%$ of cell is continuously caked

**Litter Temperature**

Litter temperature was taken with an infrared thermometer at regions A, B, and C in both barns before disruption of the litter surface by sampling. The thermometer model number was C0805061961, but a company could not be identified.

**Ambient Ammonia**

Ambient ammonia was taken at days 12, 35, and 45 using utilizing a KWIK-DRAW Basic pump (MSA, Pittsburgh, PA). One-use glass ammonia Drager tubes (DragersafetyUSA.com) were used to test ammonia levels at regions A, B, and C within each cell in both barns. The number of pulls per tube was dictated by each individual tube’s instructions. The style of tubes used on day 12 was 2/a, which measured ammonia levels from 2-30 ppm. Because the values from the first period were higher than what was expected, 5/b tubes which measured ammonia values between 5 and 100 ppm were used for the final two sampling days.
**Ammonia Flux**

Ammonia flux was measured in each cell of House 10 only. Measurements took place at each of the three regions within each cell at 46 days. A non-steady state recirculating flux chamber (volume = 0.07172 m$^3$) was attached to an INNOVA 1412 Photoacoustic Field Gas-Monitor (LumaSense Technologies, Santa Clara, CA). The specifications of the gas monitor were set such that the normalization temperature was 20 °C, the time within the tubing was 11 seconds, and the water and cross interferences were on. A sampling interval of 1 minute was used, with a chamber flush time of 8 seconds before the new measurement was taken.

To get the value of the ambient air, the circulation chamber was held 54 cm above the litter surface at each region. The chamber was allowed to recirculate air for 2 cycles (2 minutes) to ensure that the value for the ambient air, determined at the end of the 2 minute cycle, was not influenced by the previous sample. Once set on the litter surface (surface area = 0.1388 m$^2$), 4 measurements were taken in order to calculate flux, with calculations following those outlined by Burley [31].

**Nutrient Analyses and Energy Density**

A subsample taken from each region in each cell of the house was taken to the Agricultural Analytical Services Laboratory and Barrow-Agee Laboratories, LLC, for the same analyses outlined above in the bedding nutrient and energy density analyses.
Bird Performance and Welfare

A brood curtain divided the house until birds reached 10 days of age, at which point the curtain was removed and half of the birds in each cell were removed to the non-experimental grow-out end out of the house. Livability was recorded by the grower from days 1-9 by cell. Bird bodyweights, footpad scores, and breast cleanliness scores were taken at 12, 35, and 45 days.

Livability d 1-9

Once daily, each cell in each house was walked by the grower to pick up the mortalities and culls. These two categories were combined to create one category, mortality, which was recorded by cell for days 1-9.

Bodyweight

At days 12, 35, and 45, a random sample of birds was collected in a small pen from each cell in each barn. Twenty-five birds were then randomly selected from this pen and weighed and recorded individually. An average bodyweight (BW) was calculated for each cell by dividing the total weight of the birds by the total number of birds measured.

Footpad Scores

Footpads were scored individually using a ranking system based on the one presented by the Global Animal Partnership’s 5-Step™ Animal Welfare Rating Standards for Chickens Raised for Meat [32]. This scoring system uses a scale of 0-2, with 0 representing intact, uninjured footpads and a 2 representing footpads with severe lesions. However, this was not specific
enough to encompass the wide range of lesions seen in this flock. Therefore, each score had the option of the addition of either + or ++, resulting in 7 possible scores instead of 3. In addition to allowing a better representation of footpad scores among birds, these scores were converted to numeric values to allow the data to be analyzed more like ratio data for a more thorough statistical analysis. The scores of both feet for each bird were noted. When evaluating the data for statistical significance, scores were made numeric, where whole numbers remained as whole numbers, but a ‘+’ held an added value of 0.33 and a ‘++’ held an added value of 0.66.

The range of scores that used to evaluate footpads is detailed below:

0: No lesions present; footpad is clean and intact

0+: Papillae are enlarged with minimal soil adhesion

0++: Papillae are enlarged with severe soil adhesion

1: A lesion is present on main foot pad and may or may not have enlarged papillae; some soiling present

1+: Lesion present on main foot pad that covers ≥ 50% of pad’s surface area

1++: Lesion present on main foot pad covers ≥ 50% of pad’s surface area and is cracked, raw, and/or bleeding

2: Lesions are present on toe pads in addition to being present on main foot pad

Both footpads were evaluated separately per bird, leading to a total of 50 footpads evaluated per cell. The average footpad score per cell was then found by taking the sum of all of the scores and dividing it by the number of individual footpads evaluated.
Breast Cleanliness Scores

Breast cleanliness of the birds was evaluated with a system based on the standard scoring system of such by the Global Animal Partnership [32]. However, instead of the discreet scores of 1-3, our scoring system was modified to a 0-2 as to keep consistent with the scoring system used to evaluate foot pads. Like the foot pad scoring system, each score could have an additional + or ++, which allowed for a more descriptive evaluation of the soiling present and a better statistical evaluation of the data. Breast cleanliness scores did not take into account lack of feathers, level of staining, or presence of lesions on the breast. The amount of soil adhered based on the number of feathers present was all that was considered, with the region of the breast identified as the area from thoracic inlet to the bottom of the keel and from the line of the left wing to the line of the right wing. The breast skin itself was not evaluated because soil typically didn’t adhere without the presence of feathers. The average breast cleanliness score for each cell was found by taking the total sum of all breast cleanliness scores and dividing it by the total number of birds evaluated.

The range of scores used to evaluate breast cleanliness is detailed below:

0: Clean breast feathers without any soil adhesion
0+: Adhesion of very few bedding or manure particles covering < 10% of combined breast surface area
0++: Adhesion of some bedding or manure particles which combined surface area is between 10% and 25% of entire breast surface
1: Adhesion of bedding or manure particles which cover a combined breast surface area of between 25% and 50%
1+: Adhesion of bedding or manure particles covering a combined breast surface area between 50% and 60%
1++: Adhesion of bedding or manure particles on combined breast surface area between 60% and 75%

2: Breast feathers soiled severely. Adhesion of manure or bedding on > 75% of feathers

Statistical Analyses

Data were analyzed using the one-way ANOVA, and the mixed procedure of SAS® version 9.4 [33], with data blocked by house where significant values were realized ($P \leq 0.05$). Tukey’s test for mean comparisons was used to define the differences among variables of interest.

All bedding parameters were evaluated with 3 replicates per treatment (S1 and S2). Litter and bird parameters were averaged to one replicate per cell, resulting in an n of 6 per treatment and house. This experimental design was created after a power analysis, which determined that an n of 6 would yield a higher power than a replicate of 3 (if only one house had been used for this project).

Results and Discussion

Bedding

When processing warm season grasses, most of the grinding occurs on the “downward” side of the screen, as it is here where it is in direct contact with the hammers which drag the fibers from the bale into the grinder [34]. Therefore, the average size of the overall grind tends to be influenced more by the smaller down screen than the larger up screen. This was reflected in the particle analysis, as S2 had a greater proportion of larger particles ranging from >12.7 mm – 2.8 mm, and 1.41 mm ($P \leq 0.0236$) while S1 had a greater number of smaller particles, ranging from
0.71 mm - < 0.063 mm \((P \leq 0.048, \text{ Table 5-1})\). Although these beddings did not have the exact distributions of S1 and S2 from the previous trial, they had enough differences in their distributions that if there were to be differences amongst the treatments, they would come to light in this trial.

The graphical particle distribution in Appendix C.1 makes it easier to visualize the differences between the two treatments, but is slightly confounding. It was expected that there would have been a greater number of particles classified as dust (0.125 mm-0.063 mm) [35] for S1, and this amount would greatly exceed this classification for S2 since the screen sizes for S1 were half that of S2. Although there were more particles between 0.125 mm and <0.063 mm for S1, the distributions at this size between the treatments were relatively close. This can be explained by the weather on days of treatment processing. On the day of S1 processing, a steady wind of 4.47 meters per second continuously blew smaller particles from the processing area. Because dust is classified as small, dry particles between 1 \(\mu\)m and 100 \(\mu\)m [36], it can be reasoned that many of the S1 bedding particles between 0.125 mm and < 0.063 mm were removed from the treatment by the wind, making the difference between the two treatments in this region smaller than it would have been had all the particles made it through processing. To add to this, the day that S2 was processed experienced no wind, so the particles seen in this profile are more representative of what the bale chopper can produce with a 2.54 cm down and 5.08 cm up screen configuration.

The sieving technique employed in this trial gave information used for comparisons between treatments, but does not accurately represent the true particle distribution, since the standard used for this analysis was for square (sides ratio of 1:1) or circular particles [23]. Because biomass grasses are processed into more rectangular particles, the particles are prone to the “fall through” effect, where long particles can still make it through a sieve opening if their width is less than said opening [37]. It would have therefore been more appropriate to use a sieve
with deeper walls and openings similar to those illustrated in ASABE Standard S424.1 [38]. However, because of the lack of number of screens available that match that suggested ASABE standard, definition between some of the particle sizes evaluated would have been lost, especially on the finer end of the range.

Not surprisingly, the density between the two bedding materials was different for S1 (0.1039 g/cm$^3$) and S2 (0.0728 g/cm$^3$) ($P < 0.0001$). This can be attributed to the greater percentage of fine particles in S1, which filled in the spaces between the larger particles in the cylinder, resulting in the higher density. Higher density bedding material has the capacity to hold more water and release that water at a slower rate than bedding of lower density. However, this was not entirely the case. The two treatments showed no difference in the moisture held, however at 4, 6, and 12 hours, S2 released more moisture than S1, which corresponds to the aforementioned hypothesis (Table 5-2). The relatively small difference between the smaller range of the particle size distribution may have caused the lack of difference in the moisture holding capacity. However, the larger number of larger particles in S2 would have resulted in a greater number of air pockets per volume of material, allowing for more air circulation between the particles in the drying oven, leading to faster drying. Graphical representations of water holding and evaporative loss are in appendices C.2 and C.3.

As expected, there were no differences in nutrients or energy (Appendix C.4) between the two treatments, since both were harvested from the same site, were of the same variety, and were harvested on the same day. This reasoning also accounts for the lack of differences ($P > 0.05$) between bedding moisture (11.09% vs 11.18%, $P = 0.8268$) and pH (7.79 vs 8.03, $P = 0.0997$) by treatment.
Litter

Litter moisture over the course of grow-out was not different between the two treatments (Appendix C.5), which correlates with the results obtained from the moisture holding capacity, but not the moisture release. This may have been because as the birds walked on the bedding, it compressed, crushing the large air pockets initially present in the bedding, reducing the ability of S2 to release moisture.

Although particle size did not affect litter moisture, it significantly affected litter scores at all time periods tested (Table 5-3). The higher proportion of longer particles in S2 was the primary factor contributing to the difference between the caking of these two materials. Litter scores were significantly higher for S2 though the overall litter scores were higher than what is typically observed in poultry houses. This was in part due to the trial taking place in the winter where decreased ventilation resulted both in higher house moisture and slower drying of the litter. It is interesting that litter scores, which reflected levels of caking in the house, did not impact litter moisture, since theoretically higher levels of cake retain moisture in the physical cake as well as keep the moisture below the cake from being released effectively, allowing it to accumulate.

Ambient ammonia levels were not affected by treatment but at days 35 and 45 were much higher than expected, as noted in Table 5-4. The levels ranging from 40.11 for S1 on day 45 to 58.22 ppm for S1 on day 35 exceed the maximum acceptable level of 25 ppm, set in place by the Ross Broiler Management Handbook [15]. That being said, the ammonia levels experienced in the houses were in part due to the trial being conducted in winter with a lack of sufficient ventilation as well as due to house management. The grower noted that the nipple drinker lines were not regulated properly, leading them to leak over the course of the grow-out, resulting in high humidity in both houses. Additional problems were likely due to the organic regulations
limiting the litter amendments which can be added to effectively reduce ammonia levels in the house. Part of the ammonia levels could be from the dirt floors of these older houses holding ammonia from previous flocks, since birds had been organically produced in these houses for years prior to our trial.

Table 5-4 shows that day 35 ammonia levels differed by house, where house 9 experienced levels that were 15.22 ppm higher than house 10. This matches what Wheeler et al. found in that emissions tend to vary across houses, even those on the same site [13]. Because there was no difference in litter moisture between the houses at this time, the significant differences in ammonia levels were likely in part due to house management. Significantly higher temperatures in house 9 (Appendix C.6) were the likely cause, since it has been shown that temperature is a larger contributing factor to ammonia volatilization than is litter pH (Appendix C.7) or litter moisture [18], in which there was no differences between houses. The findings of Miles et al. that particle size does not influence ammonia volatilization is verified through the results from this observation [18].

No treatment differences in litter moisture, temperature, or pH resulted in a lack of differences in ammonia flux (Appendix C.8) between treatments at 46 days. Unfortunately comparisons could not be made between houses, since measurements could only be taken for house 10.

Table 5-5 shows that litter nutrients were generally not different among treatments, which is not surprising considering that the same bedding source was used for both treatments, the same number of birds were reared in each experimental cell, and the diets were the same for all birds. That being said, K differs significantly ($P = 0.0155$) between the two treatments. Because of the lack of significant differences between the bedding treatments and bird density, the difference would be reasoned to have stemmed from conditions in the house. However, this phenomenon was not seen in chapter 4 of this thesis, which also determined nutrient values for different
particle lengths of switchgrass after 8 weeks of use. Additionally, there are no other results from the current trial that would support this finding.

The difference in C between the two treatments was significant ($P = 0.0149$), where S1 had more carbon than S2. This can tied back to the bedding density, since a volume of material was spread in the houses rather than a mass. Because S1 had a greater density, a greater mass of carbon-rich switch particles were placed in those experimental cells. The same ranking is reflected in the C:N ($P = 0.0257$), since there was no difference in nitrogen values and carbon was greater for S1.

This ratio of carbon to nitrogen is appropriate for a direct applied fertilizer, since the C:N ratio is far under the 30:1 maximum recommendation for best nitrogen release from the organic material, and closer to the lower end of 10:1 [20]. If this material was to be composted in order to eliminate disease carrying pathogens, weed seeds, and other materials before field application, it would require a great deal of additional carbon to properly complete the process, as the C:N at the start of composting process should be closer to 30:1 [21].

Although significant differences were present for carbon, the energy value of this material is not significantly different ($P = 0.0786$). With the lower C:N and high moisture content of both switchgrass litters, it would not be recommended for incineration, as it would be inefficient to do so without a specially designed burner that would handle the corrosive nature of nitrogen and the high moisture of poultry manure. That being said, using the standard energy value for propane [39], between 2.6 and 2.9 kg of single-cycle switchgrass litter with an original bedding depth of 8.26 cm would have the same amount of energy as one liter of propane. However, a product with a higher level of C would have a greater energy potential.
Bird Performance and Welfare

Livability of chicks through day 9 of age did not differ by treatment (Table 5-6) from days 2-9 and overall. Bodyweights were, however, affected by treatment at day 12, where S1 had an average bodyweight of 0.25 kg, while S2 had an average bodyweight of 0.26 kg ($P = 0.0056$) (Table 5-7). This early difference was unrealized by days 35 and 45. The significance found at day 12 may have been due to the small standard deviation among the cells, resulting in significant data. Furthermore, since broilers are typically processed at 5 weeks of age or older, it is concluded that the particle sizes of the switchgrass beddings tested do not affect bodyweight by processing age.

Of the two welfare parameters measured, footpad scores were more indicative of differences between treatments than were breast cleanliness scores as seen in Tables 5-8 and 5-9, respectively. Footpad scores were not significant at day 12, but became significant by day 35 and continuing through day 45, where S2 experienced significantly higher footpad scores than S1 ($P = 0.0013$ and $P = 0.0087$, respectively). The footpads seen at day 45 had scores much closer to the highest end of the scale, where many birds experienced severe lesions in both treatments. This again comes back to the high levels of moisture and cake in both houses, which resulted in more manure coming in direct contact with the footpads, creating an environment where footpad lesions could begin and rapidly progress in severity. This reflects the conclusions made by Cengiz et al [11]. However, because litter moisture was not different between the two treatments, the cause of the lesions was directly impacted by the amount of caking by treatment, reflected in the litter scores at days 35 and 45.

Breast cleanliness scores were not different among treatments, though by day 45, these scores were approaching the higher end of our range for both treatments at 1.24 (S1) and 1.43 (S2). The lack of differences shown in Table 5-9 was likely in part due to high levels of caking in
both treatments as well as high overall house moisture. These scores did not follow differences in bedding performance or footpad scores and may not be as sensitive a parameter for litter evaluation.
Literature Cited


Figure 5-1. Experimental layout of the two broiler houses used in this project.
### Table 5-1. Bedding particle size (mm) distribution as a percentage\(^1\) of the total mass

<table>
<thead>
<tr>
<th>Treatment</th>
<th>n</th>
<th>12.7</th>
<th>6.35</th>
<th>4.75</th>
<th>4</th>
<th>2.8</th>
<th>2</th>
<th>1.41</th>
<th>1</th>
<th>0.71</th>
<th>0.5</th>
<th>0.25</th>
<th>0.125</th>
<th>0.063</th>
<th>&lt;0.063</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>3</td>
<td>0.27(^a)</td>
<td>0.39(^b)</td>
<td>0.93(^*)</td>
<td>1.37(^*)</td>
<td>9.85(^a)</td>
<td>11.21</td>
<td>18.48(^a)</td>
<td>11.46</td>
<td>11.17(^*)</td>
<td>10.53(^a)</td>
<td>14.64(^a)</td>
<td>6.95(^a)</td>
<td>2.21(^*)</td>
<td>0.54(^a)</td>
</tr>
<tr>
<td>S2</td>
<td>3</td>
<td>3.77(^b)</td>
<td>8.83(^a)</td>
<td>10.15(^*)</td>
<td>5.53(^b)</td>
<td>20.58(^b)</td>
<td>8.60</td>
<td>10.40(^b)</td>
<td>6.64</td>
<td>7.53(^b)</td>
<td>5.56(^b)</td>
<td>7.81(^b)</td>
<td>3.36(^b)</td>
<td>0.91(^b)</td>
<td>0.31(^b)</td>
</tr>
<tr>
<td>SEM(^2)</td>
<td>---</td>
<td>0.90</td>
<td>1.97</td>
<td>2.12</td>
<td>1.09</td>
<td>2.90</td>
<td>1.41</td>
<td>2.06</td>
<td>1.49</td>
<td>1.03</td>
<td>1.19</td>
<td>1.57</td>
<td>0.91</td>
<td>0.36</td>
<td>0.07</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.0064</td>
<td>0.0005</td>
<td>0.0003</td>
<td>0.0154</td>
<td>0.0400</td>
<td>0.4569</td>
<td>0.0236</td>
<td>0.0966</td>
<td>0.0480</td>
<td>0.0098</td>
<td>0.0012</td>
<td>0.0164</td>
<td>0.0439</td>
<td>0.0421</td>
</tr>
</tbody>
</table>

\(^1\) Means within a column that do not share common superscripts differ significantly ($P \leq 0.05$).

\(^2\) Percentage data analyzed with an arcsine transformation.

\(\) SEM = pooled standard error of the means.
**Table 5-2. Water holding capacity and evaporative water loss**

Water holding capacity (g), expressed in g of water absorbed per g of dry bedding material

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>6</th>
<th>12</th>
<th>24</th>
<th>48</th>
<th>72</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>3</td>
<td>4.26</td>
<td>4.22</td>
<td>5.35</td>
<td>5.30</td>
<td>5.07</td>
</tr>
<tr>
<td>S2</td>
<td>3</td>
<td>3.95</td>
<td>4.46</td>
<td>4.83</td>
<td>5.10</td>
<td>4.62</td>
</tr>
<tr>
<td>SEM</td>
<td>---</td>
<td>0.26</td>
<td>0.18</td>
<td>0.16</td>
<td>0.11</td>
<td>0.23</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.6075</td>
<td>0.5577</td>
<td>0.0863</td>
<td>0.4013</td>
<td>0.3937</td>
</tr>
</tbody>
</table>

Evaporative water loss expressed in g of water retained per g of dry bedding material

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>0</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>12</th>
<th>24</th>
<th>48</th>
<th>72</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>3</td>
<td>4.25</td>
<td>1.69</td>
<td>1.21</td>
<td>0.80</td>
<td>0.37</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
</tr>
<tr>
<td>S2</td>
<td>3</td>
<td>3.80</td>
<td>0.74</td>
<td>0.58</td>
<td>0.23</td>
<td>0.00</td>
<td>0.00</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>SEM</td>
<td>---</td>
<td>0.26</td>
<td>0.27</td>
<td>0.15</td>
<td>0.14</td>
<td>0.09</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.4481</td>
<td>0.0573</td>
<td>0.0091</td>
<td>0.0041</td>
<td>0.0090</td>
<td>0.2597</td>
<td>0.4651</td>
<td>---</td>
</tr>
</tbody>
</table>

\( ^{a,b} \) Means within a column that do not share common superscripts differ significantly \( (P \leq 0.05) \).

\(^1\) SEM = pooled standard error of the means.
Table 5-3. Litter scores\(^1\) by treatment and by house

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Day 12</th>
<th>Day 35</th>
<th>Day 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>S1</td>
<td>6</td>
<td>0.67(^b)</td>
<td>2.38(^b)</td>
<td>2.75(^b)</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>6</td>
<td>1.33(^a)</td>
<td>2.79(^a)</td>
<td>2.96(^a)</td>
</tr>
<tr>
<td>House</td>
<td>House 9</td>
<td>6</td>
<td>1.04</td>
<td>2.58</td>
<td>2.92</td>
</tr>
<tr>
<td></td>
<td>House 10</td>
<td>6</td>
<td>0.96</td>
<td>2.58</td>
<td>2.79</td>
</tr>
<tr>
<td>SEM(^2)</td>
<td>--</td>
<td>---</td>
<td>0.12</td>
<td>0.08</td>
<td>0.05</td>
</tr>
<tr>
<td>P-value</td>
<td>Bedding</td>
<td>---</td>
<td>0.0017</td>
<td>0.0035</td>
<td>0.0203</td>
</tr>
<tr>
<td></td>
<td>House</td>
<td>---</td>
<td>0.5796</td>
<td>1.0000</td>
<td>0.1215</td>
</tr>
<tr>
<td></td>
<td>Bedding*House</td>
<td>---</td>
<td>0.5796</td>
<td>0.4379</td>
<td>0.5796</td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly (P ≤ 0.05).

\(^1\) Litter was scored on a scale of 0-3, with 0 referring to new bedding and 3 referring to ≥80% cell being continuously caked. Scores increased by quarter point increments.

\(^2\) SEM = pooled standard error of the means.
Table 5-4. Ambient ammonia\(^1\) (ppm) by treatment and by house

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Day 12</th>
<th>Day 35</th>
<th>Day 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>S1</td>
<td>6</td>
<td>11.78</td>
<td>58.22</td>
<td>40.11</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>6</td>
<td>11.94</td>
<td>56.33</td>
<td>42.39</td>
</tr>
<tr>
<td>House</td>
<td>House 9</td>
<td>6</td>
<td>12.89</td>
<td>64.89(^a)</td>
<td>39.39</td>
</tr>
<tr>
<td></td>
<td>House 10</td>
<td>6</td>
<td>10.83</td>
<td>49.67(^b)</td>
<td>43.11</td>
</tr>
<tr>
<td>SEM(^2)</td>
<td>--</td>
<td>---</td>
<td>1.14</td>
<td>2.67</td>
<td>1.47</td>
</tr>
<tr>
<td>P - value</td>
<td>Bedding</td>
<td>---</td>
<td>0.9496</td>
<td>0.5611</td>
<td>0.4545</td>
</tr>
<tr>
<td></td>
<td>House</td>
<td>---</td>
<td>0.4448</td>
<td>0.0012</td>
<td>0.2349</td>
</tr>
<tr>
<td></td>
<td>Bedding*House</td>
<td>---</td>
<td>0.8499</td>
<td>0.7051</td>
<td>0.3393</td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) Measurements taken at 15cm above the litter surface.

\(^2\) SEM = pooled standard error of the means.
Table 5-5. Litter nutrient\(^1\) and energy\(^2\) analyses 46 days by treatment and by house

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Moisture (%)(^3)</th>
<th>Total N (g/kg)</th>
<th>NH(_4) (g/kg)</th>
<th>Organic N (g/kg)</th>
<th>P(_2)O(_5) (g/kg)</th>
<th>K(_2)O (g/kg)</th>
<th>Carbon (g/kg)</th>
<th>C:N</th>
<th>GJ/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>S1</td>
<td>6</td>
<td>36.21</td>
<td>20.99</td>
<td>4.81</td>
<td>16.18</td>
<td>14.40</td>
<td>12.91(^b)</td>
<td>273.67(^a)</td>
<td>13.23(^a)</td>
<td>20.05</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>6</td>
<td>39.35</td>
<td>22.77</td>
<td>5.43</td>
<td>17.34</td>
<td>16.73</td>
<td>16.52(^a)</td>
<td>247.20(^b)</td>
<td>10.91(^b)</td>
<td>18.08</td>
</tr>
<tr>
<td></td>
<td>House 10</td>
<td>6</td>
<td>38.17</td>
<td>21.99</td>
<td>5.08</td>
<td>16.91</td>
<td>15.15</td>
<td>14.57</td>
<td>259.18</td>
<td>12.03</td>
<td>18.40</td>
</tr>
</tbody>
</table>

| SEM\(^4\) | --    | --- | 1.02                | 0.47           | 0.24           | 0.41             | 0.69              | 0.79           | 5.53          | 0.52 | 0.62 |

| P – value | Bedding | --- | 0.1713              | 0.0734         | 0.2378         | 0.2072           | 0.0888            | 0.0155         | 0.0149        | 0.0257 | 0.0786 |
|           | House   | --- | 0.7231              | 0.8003         | 0.8773         | 0.7286           | 0.5053            | 0.8072         | 0.7772        | 0.9241 | 0.2090 |
|           | Bedding*House | --- | 0.9104              | 0.3987         | 0.4622         | 0.6528           | 0.1786            | 0.1692         | 0.4241        | 0.3334 | 0.0889 |

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly (P ≤ 0.05).

1 Analyzed by the Agricultural Analytical Services Lab (University Park, PA).
2 Analyzed by Barrow Agee Labs (Memphis, TN).
3 Percentage data analyzed with an arcsine transformation.
4 SEM = pooled standard error of the means.
Table 5-6. Mortality (%)\(^1\) by day and overall through day 9 by treatment and by house

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>S1</td>
<td>6</td>
<td>0.06(^b)</td>
<td>0.06</td>
<td>0.22</td>
<td>0.16</td>
<td>0.10</td>
<td>0.04</td>
<td>0.07</td>
<td>0.02</td>
<td>0.01</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>6</td>
<td>0.10(^a)</td>
<td>0.05</td>
<td>0.17</td>
<td>0.15</td>
<td>0.04</td>
<td>0.08</td>
<td>0.02</td>
<td>0.04</td>
<td>0.01</td>
<td>0.67</td>
</tr>
<tr>
<td>House</td>
<td>House 9</td>
<td>6</td>
<td>0.10</td>
<td>0.06</td>
<td>0.13(^b)</td>
<td>0.13</td>
<td>0.09</td>
<td>0.03(^b)</td>
<td>0.05</td>
<td>0.02</td>
<td>0.01</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>House 10</td>
<td>6</td>
<td>0.06</td>
<td>0.05</td>
<td>0.26(^a)</td>
<td>0.18</td>
<td>0.04</td>
<td>0.09(^a)</td>
<td>0.04</td>
<td>0.04</td>
<td>0.01</td>
<td>0.80</td>
</tr>
<tr>
<td>SEM(^2)</td>
<td>--</td>
<td>---</td>
<td>0.01</td>
<td>0.01</td>
<td>0.03</td>
<td>0.03</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
<td>0.06</td>
</tr>
<tr>
<td>P - value</td>
<td>Bedding</td>
<td>---</td>
<td>0.0447</td>
<td>0.8783</td>
<td>0.2999</td>
<td>0.8580</td>
<td>0.1507</td>
<td>0.1076</td>
<td>0.1366</td>
<td>0.3288</td>
<td>1.0000</td>
<td>0.4134</td>
</tr>
<tr>
<td></td>
<td>House</td>
<td>---</td>
<td>0.0664</td>
<td>0.8517</td>
<td>0.0164</td>
<td>0.2883</td>
<td>0.1068</td>
<td>0.0157</td>
<td>0.8607</td>
<td>0.2254</td>
<td>1.0000</td>
<td>0.1433</td>
</tr>
<tr>
<td></td>
<td>Bedding*House</td>
<td>---</td>
<td>0.1375</td>
<td>0.7139</td>
<td>0.3501</td>
<td>0.0799</td>
<td>0.5062</td>
<td>0.3001</td>
<td>0.3945</td>
<td>0.8628</td>
<td>0.0805</td>
<td>0.7272</td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) Percentage data evaluated with an arcsine transformation.

\(^2\) SEM = pooled standard error of the means.
Table 5-7. Average bird bodyweight\(^1\) (kg) for days 12, 35, and 45 by treatment and by house

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Day 12</th>
<th>Day 35</th>
<th>Day 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>S1</td>
<td>6</td>
<td>0.25(^b)</td>
<td>1.71</td>
<td>2.42</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>6</td>
<td>0.26(^a)</td>
<td>1.68</td>
<td>2.35</td>
</tr>
<tr>
<td>House</td>
<td>House 9</td>
<td>6</td>
<td>0.26</td>
<td>1.70</td>
<td>2.43</td>
</tr>
<tr>
<td></td>
<td>House 10</td>
<td>6</td>
<td>0.26</td>
<td>1.69</td>
<td>2.35</td>
</tr>
<tr>
<td>SEM(^2)</td>
<td>--</td>
<td>---</td>
<td>0.00</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>P - value</td>
<td>Bedding</td>
<td>---</td>
<td>0.0056</td>
<td>0.3265</td>
<td>0.1232</td>
</tr>
<tr>
<td></td>
<td>House</td>
<td>---</td>
<td>0.2142</td>
<td>0.8749</td>
<td>0.0790</td>
</tr>
<tr>
<td></td>
<td>Bedding*House</td>
<td>---</td>
<td>0.0776</td>
<td>0.9254</td>
<td>0.6481</td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) 25 birds scored per cell. The average of these scores was used as the value for each replicate cell.

\(^2\) SEM = pooled standard error of the means.
Table 5-8. Footpad scores\(^{1,2}\) for days 12, 35, and 45 by treatment and by house

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Day 12</th>
<th>Day 35</th>
<th>Day 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>S1</td>
<td>6</td>
<td>0.09</td>
<td>0.48(^{b})</td>
<td>1.22(^{b})</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>6</td>
<td>0.17</td>
<td>1.16(^{a})</td>
<td>1.64(^{a})</td>
</tr>
<tr>
<td>House</td>
<td>House 9</td>
<td>6</td>
<td>0.11</td>
<td>0.84</td>
<td>1.47</td>
</tr>
<tr>
<td></td>
<td>House 10</td>
<td>6</td>
<td>0.15</td>
<td>0.80</td>
<td>1.40</td>
</tr>
<tr>
<td>SEM(^{3})</td>
<td>--</td>
<td>---</td>
<td>0.04</td>
<td>0.12</td>
<td>0.09</td>
</tr>
<tr>
<td>Bedding</td>
<td>---</td>
<td>0.3425</td>
<td>0.0013</td>
<td>0.0087</td>
<td></td>
</tr>
<tr>
<td>House</td>
<td>---</td>
<td>0.5968</td>
<td>0.8162</td>
<td>0.5932</td>
<td></td>
</tr>
<tr>
<td>Bedding*House</td>
<td>---</td>
<td>0.0263</td>
<td>0.2675</td>
<td>0.0911</td>
<td></td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

1 Footpads scored on a scale of 0-2, with 0 representing a perfectly intact footpad and 2 representing a footpad with a lesion that covered the main pad and extended to the pads of the toes. Scores increased in increments of 0.33.

2 Footpads scored individually, resulting in n=2 per bird, with 25 birds sampled per cell. The individual scores in each cell have been averaged to one score, which has been used as the value for each replicate cell.

3 SEM = pooled standard error of the means
Table 5-9. Breast cleanliness scores\(^1\)\(^2\) for days 12, 35, and 45 by treatment and by house

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Day 12</th>
<th>Day 35</th>
<th>Day 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>S1</td>
<td>6</td>
<td>0.27</td>
<td>0.72</td>
<td>1.24</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>6</td>
<td>0.23</td>
<td>0.77</td>
<td>1.43</td>
</tr>
<tr>
<td>House</td>
<td>House 9</td>
<td>6</td>
<td>0.26</td>
<td>0.80</td>
<td>1.47(^a)</td>
</tr>
<tr>
<td></td>
<td>House 10</td>
<td>6</td>
<td>0.24</td>
<td>0.69</td>
<td>1.20(^b)</td>
</tr>
<tr>
<td>SEM(^3)</td>
<td>--</td>
<td>---</td>
<td>0.01</td>
<td>0.03</td>
<td>0.08</td>
</tr>
<tr>
<td>P - value</td>
<td>Bedding</td>
<td>---</td>
<td>0.2522</td>
<td>0.3893</td>
<td>0.1446</td>
</tr>
<tr>
<td></td>
<td>House</td>
<td>---</td>
<td>0.6591</td>
<td>0.1000</td>
<td>0.0406</td>
</tr>
<tr>
<td></td>
<td>Bedding*House</td>
<td>---</td>
<td>0.7621</td>
<td>0.2388</td>
<td>0.1151</td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) Breasts were scored on a scale of 0-2, with 0 representing clean or <10% adhering particles and 2 representing >75% of the breast feathers had adhering particles. Scores increased in increments of 0.33.

\(^2\) Each bird in each pen scored individually, with a total of 25 birds per cell. The individual scores in each pen have been averaged to one score, which has been used as the value for each replicate pen.

\(^3\) SEM = pooled standard error of the means
Chapter 6
Conclusions and Future Work

Overall, grass biomass bedding materials will perform similarly to kiln-dried softwood bedding materials when processed to a particle size below that which does not allow it to rapidly cake over. For the biomass used in these trials, this refers to particles no longer than approximately 6.35 cm. It was found that some lab analyses used to predict how the bedding would perform once put down in a house are more telling than others. Density of bedding as it relates to particle size is also telling of a grass beddings’ performance, as larger particles tend to float to the surface of bedding and mat, while smaller particles allow the bedding to stay friable longer. Density is telling of litter moisture over the life of the flock. However, moisture holding and release, which identify differences among the beddings due to their particle size, do not accurately reflect what is seen in a commercial production scenario. Because the beddings are exposed to a great deal of equipment, bird, and human traffic, the resulting compression of materials leaves the materials may lead to the similarities in moisture percent over the course of the trials. Although initial bedding pH and moisture can show differences between treatments, these differences impart are overwhelmed by fecal material, especially as a flock ages.

The biomass grass particle sizes used in these studies were found to have more of an impact on performance (litter and bird) and welfare parameters more than bedding type (grass vs softwood shavings). Neither switchgrass nor miscanthus showed differences in performance when compared to softwood, though there was a difference in bodyweight in the earliest time period tested in the commercial application of switchgrass. This was unfounded, as the difference disappeared by processing age.
Although switchgrass litter moisture differed by treatment later in grow-out between the switchgrass treatments and softwood shavings in the replicate pen trial, this difference was not realized once the beddings were tested in a commercial facility. This is attributed to the management of the commercial house and how much larger a commercial house is than a pen-style setting. Differences in ambient ammonia and ammonia flux were also found to not be influenced by bedding material or the particle sizes tested over the course of these three projects, meaning that all are appropriate to use in a house taking only this into consideration.

Footpad scores and breast cleanliness scores for birds reared on miscanthus or switchgrass also have the potential to be no different when compared to softwood shavings. That being said, the potential difference in footpad scores between longer and shorter particles of switchgrass on a commercial scale is a real phenomenon, in which birds reared on litter with longer bedding particles can be subject to poorer footpad scores than those reared on shorter bedding particles. Even in a situation where footpad scores are so obviously different between two bedding treatments, breast cleanliness scores did not differ and do not relate well with footpad differences. In the future, parameters such as breast blister incidence or breast feather loss may be used to better determine if beddings have an impact on breast condition.

It was observed in all three trials that time of year significantly influences how the beddings will perform. Spring into summer allows for higher ventilation rates, keeping ammonia and moisture levels in the house lower than they are in the winter. It may be for this reason that the higher litter moisture, caking, litter scores, ammonia, foot pad scores, and breast cleanliness scores were present in the commercial scale switchgrass study, since the trial of the commercial application of switchgrass was performed over the winter. This can also be seen when comparing these values to those found in the commercial miscanthus trial.

The differences between particle distributions of switchgrass in the commercial scale house yielded much more significant results than those of the pen trial. This was likely due to the
aforementioned differences between the housing environments between summer and winter, but may have also had to do with the high mortality experienced in the pen trial, resulting in a lower density of birds per pen at the later weeks evaluated. A lower bird density would have allowed for a better moisture release, lower overall litter scores, lower cake, and lower ammonia levels.

Nutrient compositions between bedding materials are relatively the same between switchgrass and softwood, but these values are highly dependent on where the biomass grasses were grown, as they tend to take up nutrients available to them and some fields are more strictly managed for nutrients than others. This being said, any of the nutrient differences between the bedding materials are diluted by the birds’ feces, so no differences in the litter are typically seen.

Proper sampling the litter materials is important to ensuring that the levels of nutrients of spent litter are accurately represented, as was discovered during the miscanthus trial. If sampling is representative and consistent as it was in the other two trials, nutrient values should be approximately the same between beddings of the same species as well as between switchgrass and softwood shavings. Something to keep in mind for future trials is that it appears that there is potential for the acidic nature of softwood shavings to reduce ammonium N contents in the litter, especially if the bedding is initially placed to a depth of 8.3-10.16 cm.

The most striking difference between switchgrass particle sizes in terms of bedding nutrients is carbon. Because litter is placed by volume rather than weight, more dense bedding with a corresponding smaller average particle size will have a larger portion of carbon in the spent litter. Although this difference is present and affects the carbon nitrogen ratio, it does not translate into the energy value of more dense litter. However, differences in energy density between the two beddings used in the commercial switchgrass trial were approaching significance, which means that a very finely ground product has the potential to have a higher energy density than a more coarsely ground one.
From the particle distributions between the switchgrasses tested in the two trials, it becomes apparent that processing method greatly influences the number of long and fine particles within a given biomass species. Future work in this area should be to develop standard particle distributions for different types of processing equipment readily available to PA growers so they can arrange for a processing method that makes the most appropriately sized bedding for their production scenario. Using the information gained from these trials, a reference could be compiled which rates the potential bedding efficacy of each of the products produced from the different pieces of equipment.

Utilizing biomass grasses as poultry bedding is part of a larger picture. Growing bedding locally or producing it on one’s own farm can reduce transportation costs while allowing for a more reliable source of bedding. After its use, the spent litter can be composted, incinerated on an on-farm litter burner, or spread directly onto crop fields, depending on the grower’s nutrient management goals and the concentrations of moisture, nutrients, and fuel values of the litter material.

With this in mind, further research efforts can explore the potential for a carbon neutral poultry farm in which biomass for bedding can be grown on farm, used as litter, and then burned to reduce propane use on the farm. The idea would encompass aspects of production including the amount of carbon sequestered by biomass produced on the farm that will be used as bedding, the reduction in propane, the amount of CO₂ released by the birds themselves over their life cycle, less fuel consumed with transporting the material to the farm, and the amount of carbon used in on-farm biomass processing, just to name a few. With these factors, an ideal carbon neutral farm plan can be proposed. To further this, research into nutrient neutral concepts can also be explored to help determine how to further reduce the footprint of these large-scale production facilities.
## Appendix A

### Chapter 3 Summary Tables

#### Appendix A.1. Bedding particle size (mm) distribution as a percentage of total mass

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>12.7</th>
<th>6.35</th>
<th>5.66</th>
<th>4</th>
<th>2.38</th>
<th>2</th>
<th>1.7</th>
<th>1.18</th>
<th>1</th>
<th>0.71</th>
<th>0.25</th>
<th>0.18</th>
<th>0.125</th>
<th>&lt;0.125</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus</td>
<td>6</td>
<td>6.12</td>
<td>8.98</td>
<td>9.08</td>
<td>13.47</td>
<td>29.47</td>
<td>10.93</td>
<td>5.99</td>
<td>8.07</td>
<td>2.52</td>
<td>2.52</td>
<td>2.33</td>
<td>0.24</td>
<td>0.23</td>
<td>0.06</td>
</tr>
<tr>
<td>Softwood</td>
<td>3</td>
<td>1.88</td>
<td>9.26</td>
<td>5.37</td>
<td>9.73</td>
<td>13.65</td>
<td>2.52</td>
<td>3.52</td>
<td>5.87</td>
<td>2.34</td>
<td>5.96</td>
<td>19.34</td>
<td>5.53</td>
<td>7.22</td>
<td>7.83</td>
</tr>
<tr>
<td>SEM2</td>
<td>---</td>
<td>0.96</td>
<td>1.15</td>
<td>1.12</td>
<td>1.77</td>
<td>2.79</td>
<td>1.57</td>
<td>0.85</td>
<td>1.24</td>
<td>0.33</td>
<td>0.66</td>
<td>2.85</td>
<td>0.88</td>
<td>1.17</td>
<td>1.34</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.0099</td>
<td>0.0826</td>
<td>0.0994</td>
<td>0.3871</td>
<td>&lt;0.0001</td>
<td>0.0003</td>
<td>0.1921</td>
<td>0.5289</td>
<td>0.9327</td>
<td>0.0052</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

* Means within a column that do not share common superscripts differ significantly (\( P \leq 0.05 \)).
1 Percentage data analyzed with an arcsine transformation.
2 SEM = pooled standard error of the means.
Appendix A.2. Nutrient analyses results\(^1\) of bedding materials on an “as-is” basis

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Moisture (%)(^2)</th>
<th>Total N (g/kg)</th>
<th>Ammonium N (g/kg)</th>
<th>Organic N (g/kg)</th>
<th>P(_2)O(_5) (g/kg)</th>
<th>K(_2)O (g/kg)</th>
<th>Carbon (%)</th>
<th>C:N Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus</td>
<td>6</td>
<td>9.53</td>
<td>1.61</td>
<td>0.03</td>
<td>1.61</td>
<td>1.05</td>
<td>1.55</td>
<td>43.81</td>
<td>323.33</td>
</tr>
<tr>
<td>Softwood</td>
<td>3</td>
<td>8.15</td>
<td>1.56</td>
<td>0.03</td>
<td>1.56</td>
<td>0.48</td>
<td>2.03</td>
<td>43.48</td>
<td>282.06</td>
</tr>
<tr>
<td>SEM(^3)</td>
<td>---</td>
<td>0.65</td>
<td>0.16</td>
<td>0.00</td>
<td>0.16</td>
<td>0.29</td>
<td>0.24</td>
<td>0.00</td>
<td>46.39</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.3661</td>
<td>0.9017</td>
<td>0.7858</td>
<td>0.9017</td>
<td>0.3812</td>
<td>0.3836</td>
<td>0.7708</td>
<td>0.7032</td>
</tr>
</tbody>
</table>

\(^{a-b}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) Analyzed by the Agriculture Analytical Laboratory (University Park, Pa).

\(^2\) Percentage data evaluated with an arcsine transformation.

\(^3\) SEM = pooled standard error of the means.
### Appendix A.3. Bedding particle size (mm) distribution as a percentage\(^1\) of the total mass for two types of miscanthus beddings

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>12.7</th>
<th>6.35</th>
<th>5.66</th>
<th>4</th>
<th>2.38</th>
<th>2</th>
<th>1.7</th>
<th>1.18</th>
<th>1</th>
<th>0.71</th>
<th>0.25</th>
<th>0.18</th>
<th>0.125</th>
<th>&lt;0.125</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus 1</td>
<td>3</td>
<td>4.85</td>
<td>12.14(^a)</td>
<td>11.84(^a)</td>
<td>18.90(^b)</td>
<td>30.34</td>
<td>8.63(^b)</td>
<td>3.47(^b)</td>
<td>4.03(^b)</td>
<td>1.43(^b)</td>
<td>1.57(^a)</td>
<td>2.02</td>
<td>0.31</td>
<td>0.36</td>
<td>0.12(^a)</td>
</tr>
<tr>
<td>Miscanthus 2</td>
<td>3</td>
<td>7.39</td>
<td>5.83(^b)</td>
<td>6.32(^b)</td>
<td>8.04(^b)</td>
<td>28.60</td>
<td>13.23(^a)</td>
<td>8.51(^b)</td>
<td>12.11(^b)</td>
<td>3.60(^a)</td>
<td>3.46(^b)</td>
<td>2.64</td>
<td>0.17</td>
<td>0.10</td>
<td>0.00(^b)</td>
</tr>
<tr>
<td>SEM(^2)</td>
<td>---</td>
<td>0.90</td>
<td>1.54</td>
<td>1.45</td>
<td>2.56</td>
<td>1.41</td>
<td>1.09</td>
<td>1.15</td>
<td>1.84</td>
<td>0.50</td>
<td>0.48</td>
<td>0.39</td>
<td>0.06</td>
<td>0.08</td>
<td>0.03</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.1565</td>
<td>0.0081</td>
<td>0.0213</td>
<td>0.0025</td>
<td>0.6096</td>
<td>0.0050</td>
<td>0.0008</td>
<td>0.0003</td>
<td>0.0025</td>
<td>0.0168</td>
<td>0.4223</td>
<td>0.4196</td>
<td>0.1384</td>
<td>0.0142</td>
</tr>
</tbody>
</table>

\(^a\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) Percentage data analyzed with an arcsine transformation.

\(^2\) SEM = pooled standard error of the means.
### Appendix A.4

Ambient ammonia levels (ppm) at 1, 3, and 5 weeks and ammonia flux (mg/m²/min) at 5 weeks

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Week 1</th>
<th>Week 3</th>
<th>Week 5</th>
<th>Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus</td>
<td>2</td>
<td>0.29</td>
<td>8.00</td>
<td>20.66</td>
<td>12.76</td>
</tr>
<tr>
<td>Softwood</td>
<td>2</td>
<td>0.54</td>
<td>7.33</td>
<td>17.77</td>
<td>16.12</td>
</tr>
<tr>
<td>SEM&lt;sup&gt;1&lt;/sup&gt;</td>
<td>---</td>
<td>0.11</td>
<td>0.72</td>
<td>2.06</td>
<td>1.67</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.3064</td>
<td>0.7327</td>
<td>0.5963</td>
<td>0.4187</td>
</tr>
</tbody>
</table>

<sup>a</sup>-<sup>b</sup> Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

<sup>1</sup> SEM = pooled standard error of the means.
### Appendix A.5. Litter scores at 1, 3, and 5 weeks

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Week 1</th>
<th>Week 3</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus</td>
<td>2</td>
<td>0.00</td>
<td>1.50</td>
<td>1.50</td>
</tr>
<tr>
<td>Softwood</td>
<td>2</td>
<td>0.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>SEM</strong>(^1)</td>
<td>---</td>
<td>0.00</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td><strong>P-Value</strong></td>
<td>---</td>
<td>---</td>
<td>0.4226</td>
<td>0.4226</td>
</tr>
</tbody>
</table>

\(^{ab}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) SEM = pooled standard error of the means.
**Appendix A.6.** Ambient CO$_2$ levels (ppm) at 1, 3, and 5 weeks at the level of the birds

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Week 1</th>
<th>Week 3</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus</td>
<td>2</td>
<td>1758</td>
<td>1067</td>
<td>1351</td>
</tr>
<tr>
<td>Softwood</td>
<td>2</td>
<td>1583</td>
<td>1100</td>
<td>1314</td>
</tr>
<tr>
<td>SEM$^1$</td>
<td>---</td>
<td>319.89</td>
<td>79.93</td>
<td>84.84</td>
</tr>
<tr>
<td>$P$-Value</td>
<td>---</td>
<td>0.8421</td>
<td>0.8796</td>
<td>0.8723</td>
</tr>
</tbody>
</table>

$^a$ Means within a column that do not share common superscripts differ significantly ($P \leq 0.05$).

$^1$ SEM = pooled standard error of the means.
Appendix A.7. Bird performance data including body weights, footpad scores\(^1\), and breast cleanliness scores\(^2\) for weeks 1, 3, and 5.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Body Weight (kg)</th>
<th>Foot Pad Score</th>
<th>Breast Cleanliness Score</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Week 1</td>
<td>Week 3</td>
<td>Week 5</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>2</td>
<td>0.17</td>
<td>0.95</td>
<td>2.22</td>
</tr>
<tr>
<td>Softwood</td>
<td>2</td>
<td>0.17</td>
<td>0.93</td>
<td>2.27</td>
</tr>
<tr>
<td>SEM(^3)</td>
<td>---</td>
<td>0.00</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.9298</td>
<td>0.2539</td>
<td>0.3155</td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) Foot pads were scored on a scale of 0-2, with 0 representing intact footpads and 2 representing those with severe lesions.

\(^2\) Breast cleanliness was scored on a scale of 0-2 with 0 representing clean feathers and 2 representing severely soiled feathers.

\(^3\) SEM = pooled standard error of the means.
Appendix A.8. Percent² moisture of litter at 1, 3, and 5 weeks.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Week 1</th>
<th>Week 3</th>
<th>Week 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miscanthus</td>
<td>6</td>
<td>13.53</td>
<td>26.96</td>
<td>29.96</td>
</tr>
<tr>
<td>Softwood</td>
<td>3</td>
<td>22.28</td>
<td>30.13</td>
<td>34.78</td>
</tr>
<tr>
<td>SEM¹</td>
<td>---</td>
<td>2.71</td>
<td>1.59</td>
<td>2.39</td>
</tr>
<tr>
<td>P-Value</td>
<td>---</td>
<td>0.0641</td>
<td>0.4242</td>
<td>0.4178</td>
</tr>
</tbody>
</table>

¹² Means within a column that do not share common superscripts differ significantly (P ≤ 0.05).

¹ SEM = pooled standard error of the means.

² Percentage data analyzed with an arcsine transformation.
### Appendix B

**Chapter 4 Summary Tables**

**Appendix B.1.** Nutrient composition for the starter and finisher diets fed to all birds

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Moisture (%)</th>
<th>Fat</th>
<th>Protein</th>
<th>Fiber</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starter</td>
<td>3</td>
<td>3.77</td>
<td>3.55</td>
<td>21.83</td>
<td>3.00</td>
<td>5.31</td>
</tr>
<tr>
<td>Finisher</td>
<td>3</td>
<td>11.51</td>
<td>5.25</td>
<td>18.30</td>
<td>2.93</td>
<td>4.60</td>
</tr>
</tbody>
</table>
Appendix B.2. Particle size distribution of the four bedding materials tested.
Appendix B.3. Graphical representation of the water holding capacity expressed in grams of water absorbed per gram of dry matter.
Appendix B.4. Graphical representation of the evaporative water loss represented as g water retained per g of bedding material.
**Appendix B.5.** Litter pH by treatment for weeks 4, 6, and 8

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Week 4</th>
<th>Week 6</th>
<th>Week 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>Softwood</td>
<td>8</td>
<td>6.96</td>
<td>8.51</td>
<td>8.91</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>8</td>
<td>7.12</td>
<td>8.93</td>
<td>8.96</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>7</td>
<td>6.73</td>
<td>8.75</td>
<td>9.03</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>7</td>
<td>7.22</td>
<td>8.81</td>
<td>8.99</td>
</tr>
<tr>
<td>Wing</td>
<td>1- Pens 49-72</td>
<td>16</td>
<td>7.14</td>
<td>8.85</td>
<td>8.95</td>
</tr>
<tr>
<td></td>
<td>2- Pens 73-96</td>
<td>14</td>
<td>6.87</td>
<td>8.66</td>
<td>8.98</td>
</tr>
<tr>
<td>SEM²</td>
<td>---</td>
<td>---</td>
<td>0.08</td>
<td>0.06</td>
<td>0.02</td>
</tr>
<tr>
<td>P - value</td>
<td>Bedding</td>
<td>---</td>
<td>0.1798</td>
<td>0.0764</td>
<td>0.0885</td>
</tr>
<tr>
<td></td>
<td>Wing</td>
<td>---</td>
<td>0.0997</td>
<td>0.0999</td>
<td>0.2333</td>
</tr>
<tr>
<td></td>
<td>Bedding*Wing</td>
<td>---</td>
<td>0.2510</td>
<td>0.6074</td>
<td>0.3321</td>
</tr>
</tbody>
</table>

*Means within a column that do not share common superscripts differ significantly (P ≤ 0.05).

1 Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

2 SEM = pooled standard error of the means.
Appendix B.6. Litter ammonia flux measurements (mg/m²/min) at 8 weeks by treatment and by wing

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding¹</td>
<td>Softwood</td>
<td>8</td>
<td>36.52</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>8</td>
<td>37.47</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>7</td>
<td>41.43</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>7</td>
<td>34.00</td>
</tr>
<tr>
<td>Wing</td>
<td>1- Pens 49-72</td>
<td>16</td>
<td>35.11</td>
</tr>
<tr>
<td></td>
<td>2- Pens 73-96</td>
<td>14</td>
<td>39.60</td>
</tr>
<tr>
<td>SEM²</td>
<td>---</td>
<td>---</td>
<td>0.23</td>
</tr>
<tr>
<td>P-value</td>
<td>Bedding</td>
<td>---</td>
<td>0.3957</td>
</tr>
<tr>
<td></td>
<td>Wing</td>
<td>---</td>
<td>0.1387</td>
</tr>
<tr>
<td></td>
<td>Bedding*Wing</td>
<td>---</td>
<td>0.9174</td>
</tr>
</tbody>
</table>

Means within a column that do not share common superscripts differ significantly (P ≤ 0.05).

¹ Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

² SEM = pooled standard error of the means.
Appendix B.7. Litter depth changes expressed as a percent of the original bedding depth
### Appendix B.8. BW, FI, FC, and Mortality for days 1-18 by treatment and by wing

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>BW Day 1 (g/bird)</th>
<th>BW Day 18 (kg/bird)</th>
<th>FI (kg/bird) Days 1-18</th>
<th>FC Days 1-18</th>
<th>Mortality (%) Days 1-18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding¹</td>
<td>Softwood</td>
<td>8</td>
<td>48.18</td>
<td>0.40</td>
<td>0.60</td>
<td>1.69</td>
<td>6.04</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>8</td>
<td>49.10</td>
<td>0.40</td>
<td>0.59</td>
<td>1.68</td>
<td>3.28</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>7</td>
<td>47.50</td>
<td>0.39</td>
<td>0.57</td>
<td>1.70</td>
<td>7.49</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>7</td>
<td>49.95</td>
<td>0.39</td>
<td>0.58</td>
<td>1.71</td>
<td>8.00</td>
</tr>
<tr>
<td>Wing</td>
<td>1- Pens 49-72</td>
<td>16</td>
<td>47.84</td>
<td>0.41³</td>
<td>0.60³</td>
<td>1.68</td>
<td>5.79</td>
</tr>
<tr>
<td></td>
<td>2- Pens 73-96</td>
<td>14</td>
<td>49.53</td>
<td>0.38³</td>
<td>0.57³</td>
<td>1.71</td>
<td>6.45</td>
</tr>
<tr>
<td>SEM³</td>
<td>---</td>
<td>---</td>
<td>0.84</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.18</td>
</tr>
<tr>
<td>P-value</td>
<td>Bedding</td>
<td>---</td>
<td>0.8160</td>
<td>0.2452</td>
<td>0.1182</td>
<td>0.7650</td>
<td>0.3328</td>
</tr>
<tr>
<td></td>
<td>Wing</td>
<td>---</td>
<td>0.3746</td>
<td>.00027</td>
<td>0.0008</td>
<td>0.1292</td>
<td>0.8210</td>
</tr>
<tr>
<td></td>
<td>Bedding*Wing</td>
<td>---</td>
<td>0.9985</td>
<td>0.4905</td>
<td>0.2991</td>
<td>0.8603</td>
<td>0.3571</td>
</tr>
</tbody>
</table>

³ Means within a column that do not share common superscripts differ significantly (P ≤ 0.05).
¹ Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.
² Percentage data evaluated with an arcsine transformation.
³ SEM = pooled standard error of the means.
Appendix B.9. BW, FI, FC, and mortality for days 18-35 by treatment and by wing

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>BW Day 35 (kg/bird)</th>
<th>FI Days 18-35 (kg/bird)</th>
<th>FC Days 18-35 (kg/kg)</th>
<th>Mortality (%)²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>Softwood</td>
<td>8</td>
<td>1.18</td>
<td>1.57</td>
<td>2.01</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>8</td>
<td>1.18</td>
<td>1.56</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>7</td>
<td>1.14</td>
<td>1.49</td>
<td>1.99</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>7</td>
<td>1.16</td>
<td>1.55</td>
<td>2.02</td>
</tr>
<tr>
<td>Wing</td>
<td>1- Pens 49-72</td>
<td>16</td>
<td>1.17</td>
<td>1.54</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>2- Pens 73-96</td>
<td>14</td>
<td>1.16</td>
<td>1.55</td>
<td>2.01</td>
</tr>
<tr>
<td>SEM</td>
<td>---</td>
<td>---</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>P-value</td>
<td>Bedding</td>
<td>---</td>
<td>0.0572</td>
<td>0.1176</td>
<td>0.8005</td>
</tr>
<tr>
<td></td>
<td>Wing</td>
<td>---</td>
<td>0.1413</td>
<td>0.6677</td>
<td>0.7176</td>
</tr>
<tr>
<td></td>
<td>Bedding*Wing</td>
<td>---</td>
<td>0.2638</td>
<td>0.0622</td>
<td>0.1327</td>
</tr>
</tbody>
</table>

Means within a column that do not share common superscripts differ significantly (P ≤ 0.05).

1 Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

2 Percentage data evaluated with an arcsine transformation.

3 SEM = pooled standard error of the means.
### Appendix B.10. BW, FI, FC, and mortality for day 56, by treatment and by wing

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>BW Day 56 (kg/bird)</th>
<th>FI Days 35-56 (kg/bird)</th>
<th>FC Days 35-56 (kg/kg)</th>
<th>Mortality (%)&lt;sup&gt;2&lt;/sup&gt; Days 35-56</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Softwood</td>
<td>8</td>
<td>2.27</td>
<td>2.99</td>
<td>2.00</td>
<td>4.00</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>8</td>
<td>2.28</td>
<td>2.97</td>
<td>1.98</td>
<td>2.42</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>7</td>
<td>2.20</td>
<td>2.89</td>
<td>1.99</td>
<td>3.36</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>7</td>
<td>2.25</td>
<td>2.95</td>
<td>1.99</td>
<td>1.73</td>
</tr>
<tr>
<td>Wing</td>
<td>1- Pens 49-72</td>
<td>16</td>
<td>2.24</td>
<td>2.92</td>
<td>1.98</td>
<td>2.50</td>
</tr>
<tr>
<td></td>
<td>2- Pens 73-96</td>
<td>14</td>
<td>2.26</td>
<td>2.97</td>
<td>2.00</td>
<td>3.26</td>
</tr>
<tr>
<td>SEM&lt;sup&gt;3&lt;/sup&gt;</td>
<td>---</td>
<td>---</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>0.59</td>
</tr>
<tr>
<td>P - value</td>
<td>Bedding</td>
<td>---</td>
<td>0.0646</td>
<td>0.3645</td>
<td>0.8854</td>
<td>0.7517</td>
</tr>
<tr>
<td></td>
<td>Wing</td>
<td>---</td>
<td>0.5049</td>
<td>0.2522</td>
<td>0.3747</td>
<td>0.7403</td>
</tr>
<tr>
<td></td>
<td>Bedding*Wing</td>
<td>---</td>
<td>0.6531</td>
<td>0.7165</td>
<td>0.7141</td>
<td>0.4351</td>
</tr>
</tbody>
</table>

<sup>a-b</sup> Means within a column that do not share common superscripts differ significantly (<i>P</i> ≤ 0.05).

<sup>1</sup> Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

<sup>2</sup> Percentage data evaluated with an arcsine transformation.

<sup>3</sup> SEM = pooled standard error of the means.
## Appendix B.11. Overall FI, FC, and mortality by treatment and by wing

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Overall FI (kg/bird)</th>
<th>Overall FC (kg/kg)</th>
<th>Overall Mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding¹</td>
<td>Softwood</td>
<td>8</td>
<td>5.15</td>
<td>2.32</td>
<td>13.48</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>8</td>
<td>5.13</td>
<td>2.30</td>
<td>8.85</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>7</td>
<td>4.95</td>
<td>2.30</td>
<td>11.74</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>7</td>
<td>5.08</td>
<td>2.31</td>
<td>11.12</td>
</tr>
<tr>
<td>Wing</td>
<td>1- Pens 49-72</td>
<td>16</td>
<td>5.06</td>
<td>2.31</td>
<td>9.94</td>
</tr>
<tr>
<td></td>
<td>2- Pens 73-96</td>
<td>14</td>
<td>5.09</td>
<td>2.31</td>
<td>12.66</td>
</tr>
<tr>
<td>SEM³</td>
<td>---</td>
<td>---</td>
<td>0.03</td>
<td>0.01</td>
<td>1.05</td>
</tr>
<tr>
<td>P - value</td>
<td>Bedding</td>
<td>---</td>
<td>0.0927</td>
<td>0.7719</td>
<td>0.5557</td>
</tr>
<tr>
<td></td>
<td>Wing</td>
<td>---</td>
<td>0.5819</td>
<td>0.9955</td>
<td>0.2090</td>
</tr>
<tr>
<td></td>
<td>Bedding*Wing</td>
<td>---</td>
<td>0.3004</td>
<td>0.4223</td>
<td>0.4999</td>
</tr>
</tbody>
</table>

⁠¹⁶⁷ Mean within a column that do not share common superscripts differ significantly (P ≤ 0.05).

¹ Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

² Percentage data evaluated with an arcsine transformation.

³ SEM = pooled standard error of the means.
Appendix B.12. Individual footpad scores\(^{1,2,3}\) by treatment and by wing for weeks 4, 6, and 8

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Week 4</th>
<th>Week 6</th>
<th>Week 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding(^1)</td>
<td>Softwood</td>
<td>8</td>
<td>0.02</td>
<td>0.05</td>
<td>0.07</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>8</td>
<td>0.04</td>
<td>0.09</td>
<td>0.04</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>7</td>
<td>0.05</td>
<td>0.10</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>7</td>
<td>0.03</td>
<td>0.08</td>
<td>0.16</td>
</tr>
<tr>
<td>Wing</td>
<td>1- Pens 49-72</td>
<td>16</td>
<td>0.05</td>
<td>0.11(^a)</td>
<td>0.11</td>
</tr>
<tr>
<td></td>
<td>2- Pens 73-96</td>
<td>14</td>
<td>0.02</td>
<td>0.04(^b)</td>
<td>0.08</td>
</tr>
<tr>
<td>SEM(^4)</td>
<td>---</td>
<td>---</td>
<td>0.01</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
<td>P - value</td>
<td>Bedding</td>
<td>---</td>
<td>0.7888</td>
<td>0.6333</td>
<td>0.1022</td>
</tr>
<tr>
<td></td>
<td>Wing</td>
<td>---</td>
<td>0.2377</td>
<td>0.0418</td>
<td>0.3267</td>
</tr>
<tr>
<td></td>
<td>Bedding * Wing</td>
<td>---</td>
<td>0.7862</td>
<td>0.8538</td>
<td>0.9932</td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^{1}\) Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

\(^{2}\) Footpads scored on a scale of 0-2, with 0 representing a perfectly intact footpad and 2 representing a footpad with a lesion that covered the main pad and extended to the pads of the toes.

\(^{3}\) Footpads were scored individually, resulting in \(n=2\) per bird. The total scores in each pen have been averaged to one score, which has been used as the value for each replicate pen.

\(^{4}\) SEM = pooled standard error of the means.
### Appendix B.13. Breast cleanliness scores\(^2\) by treatment and by wing for weeks 4, 6, and 8

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Week 4</th>
<th>Week 6</th>
<th>Week 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding(^1)</td>
<td>Softwood</td>
<td>8</td>
<td>0.04</td>
<td>0.09</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>8</td>
<td>0.05</td>
<td>0.09</td>
<td>0.33</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>7</td>
<td>0.01</td>
<td>0.14</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>S3</td>
<td>7</td>
<td>0.01</td>
<td>0.10</td>
<td>0.61</td>
</tr>
<tr>
<td>Wing</td>
<td>1- Pens 49-72</td>
<td>16</td>
<td>0.04</td>
<td>0.12</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>2- Pens 73-96</td>
<td>14</td>
<td>0.02</td>
<td>0.10</td>
<td>0.50</td>
</tr>
<tr>
<td>SEM(^4)</td>
<td>---</td>
<td>---</td>
<td>0.01</td>
<td>0.02</td>
<td>0.05</td>
</tr>
<tr>
<td>P - value</td>
<td>Bedding</td>
<td>---</td>
<td>0.3956</td>
<td>0.6598</td>
<td>0.2206</td>
</tr>
<tr>
<td></td>
<td>Wing</td>
<td>---</td>
<td>0.2363</td>
<td>0.5455</td>
<td>0.2358</td>
</tr>
<tr>
<td></td>
<td>Bedding*Wing</td>
<td>---</td>
<td>0.4467</td>
<td>0.3176</td>
<td>0.7072</td>
</tr>
</tbody>
</table>

\(^{a,b}\) Means within a column that do not share common superscripts differ significantly \((P \leq 0.05)\).

\(^1\) Softwood is the control and S1, S2, and S3 refer to switchgrass beddings with average particle sizes of 5.3 mm, 31.4 mm, and 62.8 mm, respectively.

\(^2\) Breasts scored on a scale of 0-2, with 0 representing clean or only slightly dirty/wet feathers and 2 representing more than 50% of the breast feathers being severely soiled with adhering dirt.

\(^3\) Each bird in each pen scored individually. The total scores from each pen have been averaged to one score, which was used as the value for each replicate pen.

\(^4\) SEM = pooled standard error of the means.
Appendix C

Chapter 5 Summary Tables

Appendix C.1. Particle size distribution as a percentage of the total mass.
Appendix C.2. Graphical representation of the water holding capacity expressed in grams of water absorbed per gram of dry matter.
Appendix C.3. Graphical representation of the evaporative water loss of the two bedding treatments tested expressed in grams of water retained per gram of dry matter.
**Appendix C.4.** Nutrient$^1$ and energy$^2$ analyses of bedding samples, “as-is”

<table>
<thead>
<tr>
<th>Treatment</th>
<th>(n)</th>
<th>Moisture (%)$^3$</th>
<th>Total N (g/kg)</th>
<th>Ammonium N (g/kg)</th>
<th>Organic N (g/kg)</th>
<th>P$_2$O$_5$ (g/kg)</th>
<th>K$_2$O (g/kg)</th>
<th>Carbon (g/kg)</th>
<th>C:N Ratio</th>
<th>Carbon (%)</th>
<th>MJ/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>3</td>
<td>13.17</td>
<td>6.72</td>
<td>0.79</td>
<td>5.93</td>
<td>2.34</td>
<td>2.27</td>
<td>409.68</td>
<td>62.72</td>
<td>40.97</td>
<td>13.72</td>
</tr>
<tr>
<td>S2</td>
<td>3</td>
<td>12.27</td>
<td>6.63</td>
<td>0.86</td>
<td>5.77</td>
<td>1.97</td>
<td>1.95</td>
<td>419.82</td>
<td>63.40</td>
<td>41.98</td>
<td>13.47</td>
</tr>
<tr>
<td>SEM$^4$</td>
<td>---</td>
<td>0.33</td>
<td>0.39</td>
<td>0.09</td>
<td>0.33</td>
<td>0.26</td>
<td>0.32</td>
<td>2.89</td>
<td>3.17</td>
<td>0.00</td>
<td>0.48</td>
</tr>
<tr>
<td>$P$-Value</td>
<td>---</td>
<td>0.2062</td>
<td>0.9157</td>
<td>0.7428</td>
<td>0.8299</td>
<td>0.5408</td>
<td>0.6649</td>
<td>0.9280</td>
<td>0.0637</td>
<td>0.0637</td>
<td>0.8328</td>
</tr>
</tbody>
</table>

$^a$ Means within a column that do not share common superscripts differ significantly ($P \leq 0.05$).

$^1$ Analyzed by the Agriculture Analytical Laboratory (University Park, PA)

$^2$ Analyzed by Barrow Agee Labs (Memphis, TN)

$^3$ Percentage data evaluated with an arcsine transformation

$^4$ SEM = pooled standard error of the means.
## Appendix C.5. Litter moisture (%)\(^1\) by treatment and by house

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Day 12</th>
<th>Day 35</th>
<th>Day 46</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>S1</td>
<td>6</td>
<td>16.66</td>
<td>32.88</td>
<td>30.55</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>6</td>
<td>17.23</td>
<td>33.60</td>
<td>33.30</td>
</tr>
<tr>
<td>House</td>
<td>House 9</td>
<td>6</td>
<td>16.78</td>
<td>33.34</td>
<td>32.75</td>
</tr>
<tr>
<td></td>
<td>House 10</td>
<td>6</td>
<td>17.12</td>
<td>33.14</td>
<td>31.09</td>
</tr>
<tr>
<td>SEM(^2)</td>
<td>--</td>
<td>---</td>
<td>0.47</td>
<td>0.91</td>
<td>1.20</td>
</tr>
</tbody>
</table>

\(^{1}\) Percentage data evaluated with an arcsine transformation.

\(^{2}\) SEM = pooled standard error of the means.

\(^{a}\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).
**Appendix C.6.** Litter temperature (°C), by treatment and by house

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Day 12</th>
<th>Day 35</th>
<th>Day 45</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>S1</td>
<td>6</td>
<td>27.81</td>
<td>27.01</td>
<td>25.46</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>6</td>
<td>27.87</td>
<td>25.28</td>
<td>25.97</td>
</tr>
<tr>
<td>House</td>
<td>House 9</td>
<td>6</td>
<td>28.23</td>
<td>27.77&lt;sup&gt;a&lt;/sup&gt;</td>
<td>26.32</td>
</tr>
<tr>
<td></td>
<td>House 10</td>
<td>6</td>
<td>27.45</td>
<td>24.52&lt;sup&gt;b&lt;/sup&gt;</td>
<td>25.11</td>
</tr>
<tr>
<td>SEM&lt;sup&gt;1&lt;/sup&gt;</td>
<td>--</td>
<td>---</td>
<td>0.33</td>
<td>0.66</td>
<td>0.53</td>
</tr>
<tr>
<td>P-value</td>
<td>Bedding</td>
<td>---</td>
<td>0.9321</td>
<td>0.0773</td>
<td>0.6670</td>
</tr>
<tr>
<td></td>
<td>House</td>
<td>---</td>
<td>0.2923</td>
<td>0.0053</td>
<td>0.3209</td>
</tr>
<tr>
<td></td>
<td>Bedding*House</td>
<td>---</td>
<td>0.4256</td>
<td>0.8210</td>
<td>0.9027</td>
</tr>
</tbody>
</table>

<sup>a,b</sup> Means within a column that do not share common superscripts differ significantly ($P \leq 0.05$).

<sup>1</sup> SEM = pooled standard error of the means.
Appendix C.7. Litter pH by treatment and by house

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Day 12</th>
<th>Day 35</th>
<th>Day 46</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>S1</td>
<td>6</td>
<td>6.93</td>
<td>9.03</td>
<td>9.04</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>6</td>
<td>7.12</td>
<td>9.11</td>
<td>9.07</td>
</tr>
<tr>
<td>House</td>
<td>House 9</td>
<td>6</td>
<td>6.89(^b)</td>
<td>9.07</td>
<td>9.03</td>
</tr>
<tr>
<td></td>
<td>House 10</td>
<td>6</td>
<td>7.15(^a)</td>
<td>9.07</td>
<td>9.08</td>
</tr>
<tr>
<td>SEM(^1)</td>
<td>--</td>
<td>---</td>
<td>0.07</td>
<td>0.03</td>
<td>0.02</td>
</tr>
<tr>
<td>P-value</td>
<td>Bedding</td>
<td>---</td>
<td>0.0840</td>
<td>0.2580</td>
<td>0.3297</td>
</tr>
<tr>
<td></td>
<td>House</td>
<td>---</td>
<td>0.0272</td>
<td>0.9424</td>
<td>0.1354</td>
</tr>
<tr>
<td></td>
<td>Bedding*House</td>
<td>---</td>
<td>0.2065</td>
<td>0.8536</td>
<td>0.3297</td>
</tr>
</tbody>
</table>

\(^a\) Means within a column that do not share common superscripts differ significantly (\(P \leq 0.05\)).

\(^1\) SEM = pooled standard error of the means.
### Appendix C.8. Ammonia flux (mg/m$^2$/min) for House 10 taken at day 46

<table>
<thead>
<tr>
<th>Factor</th>
<th>Level</th>
<th>(n)</th>
<th>Flux</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bedding</td>
<td>S1</td>
<td>3</td>
<td>19.35</td>
</tr>
<tr>
<td></td>
<td>S2</td>
<td>3</td>
<td>14.80</td>
</tr>
<tr>
<td>SEM$^1$</td>
<td>--</td>
<td>---</td>
<td>1.70</td>
</tr>
<tr>
<td>$P$-value</td>
<td>Bedding</td>
<td>---</td>
<td>0.5969</td>
</tr>
</tbody>
</table>

$^{a,b}$ Means within a column that do not share common superscripts differ significantly ($P \leq 0.05$).

$^1$ SEM = pooled standard error of the means.