Efficacy and Efficiency of Mechanical Mixing Equipment for Poultry Carcass Composting for Avian Influenza Outbreaks

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Abstract.

There are several disposal methods of AI infected poultry carcasses available in the U.S., which include on-site burial, landfill, incineration, rendering, and composting. Of these methods, composting is the most environmentally friendly and poses low risk for biosecurity. The United States Department of Agriculture (USDA) has developed a comprehensive plan for composting AI infected carcasses. The current protocols have the potential for areas of anaerobic pockets within the windrow due to inadequate mixing and the large carcass size of whole birds. This could lead to ineffective virus neutralization or prolonged composting times and higher resource costs. The purpose of this project was to determine if using a horizontal mixer wagon to mix composting ingredients or a vertical mixer wagon to mix and cut up the compositing ingredients is an economical

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and timely means to accelerate the tissue break-down and obtain optimal temperatures for poultry carcass composting during an AI outbreak. A replicated trial with 3 treatments, Horizontal Mixer (HM), Conventional Layering (CL) and Vertical Mixer (VM), and three replications was initiated at the Compost Research and Education Center part of the University of Maine Forest and Agricultural Experimental Station called Highmoor Farm. Daily temperatures and screened core sample weights (screen weights) on day 0, 16, and 30 were recorded for each of the compost piles. The time to build each replication was recorded and used to help calculate the cost of each method. Data on equipment, carbon material and labor costs was collected from private contractors from the 2014-2016 HPAI outbreak and used to compare costs between methods. All treatment methods reached USDA protocol temperatures to neutralize the HPAI virus. Screen weights for both the VM and HM treatments were lower than the CL treatment. Screen weights decreased significantly from day 0 to day 16 for the VM and HM treatments with no significant change from day 16 to day 30. When comparing costs, the mixer wagon methods were more cost effective than the CL method when using high volume equipment. The data from this study supports the use of a mixer wagon to reduce particle size and mix ingredients for more timely and effective composting of poultry carcasses.

Keywords. carcass management, compost, high pathogenic avian influenza, poultry

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Introduction

There are several disposal methods of poultry carcasses available in the U.S. It is important that the disposal of choice be timely, cost-effective, biosecure, environmentally friendly and have a positive public perception. Disposal options include on-site burial, landfill, incineration, rendering, and composting. In the past, on-site burial was the most common method of disposal, but concerns with ground water contamination and public perception caused it to fall out of favor (Swayne and Akey; Blake and Donald). It also raises concerns about prolonged survival of the virus and slow decomposition of the carcasses (Graiver et al.). Landfill burial was the primary method used for the 2002 LPAI outbreak in Shenandoah Valley, Virginia but was associated with high transportation fees as well as biosecurity risks with removal of the carcasses from the site as well as high tipping fees ranging from $45 to $140 per ton (Swayne and Akey). Groundwater contamination is also a concern with landfill disposal (Swayne and Akey). Incineration comes with high fuel costs, concerns for air pollution and smoke complaints, high transportation costs and biosecurity concerns with moving the infected carcasses off-site to the incinerator (Swayne and Akey). Rendering is another option, but due to biosecurity concerns, few rendering facilities will take infected carcasses (Swayne and Akey). Finally, composting is a means of virus neutralization and was used during the 2002 Shenandoah Valley LPAI outbreak when concerns about ground contamination, pollution and biosecurity was rising with other methods (Swayne and Akey). Of all these methods, composting is the most environmentally friendly of the options and poses the lowest risk for biosecurity.

During the 2002 LPAI outbreak in Shenandoah Valley, Virginia, improper construction of windrows raised concern that larger carcasses, such as market weight turkeys, could not be effectively composted. However, in 2004, during an outbreak on the Delmarva Peninsula in Pennsylvania, composting was successfully used with 5 pound broilers to control the spread of the virus (Tablante and Malone). This led to research in 2004 in Virginia with 40 pound market weight turkeys that confirmed composting is successful if done properly (Bendfeldt, Peer and Flory; Flory and Peer). The Virginia research also showed that crushing, shredding, or tilling of the carcasses can speed the degradation and optimal temperatures by opening the carcasses and releasing and distributing moisture, increasing surface area to volume ratio, and exposing the bones to decomposition. Temperatures reached 140^{o} F within 5 days for crushed carcasses and 16 days for whole carcasses. Furthermore, whole birds tended to roll off the piles more, necessitating more labor to replace them in the pile and more carbon material to cover them (Bendfeldt, Peer and Flory).

At an Iowa layer operation infected with HPAI in 2015, particle reduction size and mixing of carcasses and carbon material was successfully utilized to compost more than 4 million birds. Initially, a horizontal tub grinder was used to grind up carcasses and carbon material. Then, a Tebbe manure spreader, with the horizontal spinners off and at a very low discharge speed, created the compost windrows (Elbert). The tub grinder was used inside of a manure shed and loaded with birds, corn stover and wood chips and the mixture was loaded into the manure spreaders and taken to the outdoor composting site. During the height of the operation, when the crew was running most efficiently, a crew of 3-4 five-cubic yard loaders, 1 tub grinder, 1 tractor with a 42-cubic yard Tebbe manure spreader and 1 tractor with a 32-cubic yard Tebbe manure spreader could process approximately 350,000 birds in 12-13 hours (Elbert).

The USDA has developed a comprehensive plan for composting AI infected carcasses titled “Mortality Composting Protocol for Avian Influenza Infected Flocks” (Miller et al.). This plan requires that all carcasses, feed and litter be composted in windrows for 28 days prior to release of the material from the site. The windrows must reach an average of 131^{o} F for 3 consecutive days during the first 2 weeks, at which point, the windrows are turned and then must reach 131^{o} F for 3 consecutive days during a second 2-week period. Alternatively, if 131^{o}

F is not reached, 110º F for 10 consecutive days during both 2-week periods is acceptable. The provided protocols do not currently support the use of mechanical equipment that aggressively mixes or grinds due to concern with virus aerosolization. The current protocols have the potential for areas of anaerobic pockets within the windrow due to inadequate mixing and large carcass size of whole birds. This could lead to ineffective virus neutralization or prolonged composting times and higher resource costs.

If an economical and safe means for carcass size reduction and mixing can be accomplished, then, in theory, the decomposition and pile temperatures will be more uniform and, therefore, virus inactivation and carcass degradation will occur faster.   If it is established that carcass reduction and mixing is more effective at composting carcasses, then the question must also be addressed if there is an economical and time effective means to accomplish this in a large outbreak situation. The purpose of this project was to determine if using a horizontal mixer wagon to mix composting ingredients or a vertical mixer wagon to mix and cut up the compositing ingredients is an economical and timely means to improve and accelerate tissue break-down and obtain optimal temperatures for poultry carcass composting during an AI outbreak.

Materials and Methods

Layer Hens Carcass Composting Trials

On August 8th, 2016, a replicated trial with two treatments, horizontal mixer (HM) and conventional layering (CL), and three replications was initiated at the Compost Research and Education Center part of the University of Maine Forest and Agricultural Experimental Station called Highmoor Farm. The six piles were oriented in a south to north direction on a paved surface. All feedstocks were handled by a tractor loader with an approximately ¾ cubic yard bucket. An 18-inch base layer of used horse bedding, moistened slightly with water, approximately 6 feet wide and 30 feet long was formed for each treatment. Feedstocks for each replication were; used horse bedding, wood chips, poultry manure and chicken carcasses. The average number of birds per bucket load was 254 birds, which was determined by counting 12 bucket loads of birds on 3 different occasions.

Pile formation was different for each treatment. For the HM treatment one bucket of used horse bedding, one bucket of wood chips, one bucket of poultry manure, one bucket of chicken carcasses and 100 gallons of water were loaded in the HM (Kuhn Knight Model 3042) and allowed to mix. Mixing occurred continuously as feedstocks were added. This mixture was discharged to the top of the 18-inch base layer of used horse bedding. For the CL treatment feedstocks were layered directly on to the base layer in the following order; a ½ bucket of chicken carcasses, 1 bucket of used horse bedding, 1 bucket of poultry manure, 1 bucket of wood chips, another ½ bucket of chicken carcasses, and another bucket of used horse bedding. Each layer was moistened with water as needed. Finally, both treatments were covered with an approximately 10 to 12-inch layer of dry wood shavings for vector control. All six piles were approximately 5 feet in height and 8-10 cubic yards including the cap and base material.

All piles were created with one person operating both the tractor and HM and the time to create all piles, except pile 1, was timed for comparison. In accordance with USDA protocol, two back connect bimetal thermometers (Reotemp®) were placed 18 inches deep and 36 inches deep in each pile. (Miller et al.). The thermometers were placed on the east side of piles 1,3,4,6 and the west side of piles 2 and 5.

Temperatures were recorded manually once a day (Monday-Friday, excluding holidays) for a 30-day period. USDA protocol allows turning of HPAI piles after 14 days if temperature requirements are met, so on Day 16 all treatments were turned with the tractor loader by first rolling the pile over to the east and then rolling back to the west to their original location. A 2-gallon bucket sample of the core was taken from both the east and west side of the piles on day

0, after turning on day 16, and on day 30. All pavement was marked with orange spray paint for the start and stop of each pile and sample locations were 5 feet from the edge of the pile markers to avoid sample bias. Samples were screened through a ½ inch mesh screen. The remaining material that did not pass through the screen was weighed and recorded. These measurements were referred to as screen weights.

On August 31, 2016, a third treatment, vertical mixer (VM), was created including the same feedstock materials as in the HM and CL treatments. However, the VM treatment did not have water added to the mixer or the base layer when first created. These piles were created west of the HM treatment on the paved surface. A base layer was created in the same manner as the previous treatments. One bucket of chicken carcasses, 1 bucket of used horse bedding, 1 bucket of wood chips, and 1 bucket of poultry manure was placed inside a VM (Kuhn Knight Vertical Maxx VT144) and allowed to mix. The VM was used to apply the mix to the top of the horse bedding. Due to the low discharge door on the VM, the first load was applied to the entire length of the base layer rather than as an individual pile. The next 2 loads were mixed similarly and applied across the length of the base layer again. Finally, the piles were covered with a cap in the same manner as the previous treatments. The VM piles were not as tall as the HM and CL piles, but were wider, due to the low discharge door of the VM, and were approximately 3-4 feet tall and a total of 8-10 cubic yards including base and cap.

Thermometers were placed in the VM treatment and temperatures were recorded once daily for a 28-day period as in the HM and CL treatments. The piles were turned in the same manner on day 14 and day 28. On day 14, the VM replications were split open with the tractor loader and approximately 100 gallons of water was added to the center of the piles due to low moisture content. On day 0 and after turning on day 14 and 28 core compost samples were collected, screened, and weighed as described for the previous treatments.

Screen weight data for each treatment from day 0 and after turning (day 14 or 16 and day 28 or 30) were compared using independent t-tests with Microsoft Excel software. Variances for each data set were calculated and either an equal or unequal variance independent t-tests were used depending on the variance ratio between treatments.

Economic Calculations

For each of the treatment methods, the time to create the replications was recorded. The average number of birds per bucket was used to calculate the time it would take to process 200,000 birds with each method. Due to the small scale of our operation, calculations were then extrapolated for larger sized equipment that could handle more birds at the same time. It was assumed it would take the same amount of time to process the higher amount of birds with larger equipment, more equipment, and an operator for each piece of equipment.

Equipment and cost information was collected from the 2015 HPAI outbreak in Iowa. Information included hourly rates for equipment (including operator, equipment, and fuel), equipment type, number of each piece of equipment and average number of birds processed in a day (Elbert).

Cost calculations were made for composting of birds for layer barns and turkey barns based on estimated times for each treatment, equipment numbers and cost information from the Iowa layer farm outbreak (Elbert) and the Iowa State University 2016 Iowa Farm Custom Rate Survey (Plastina, Johanns and Erwin), carbon amounts from the treatments, and carbon amounts and costs from recent HPAI outbreak (Payne). Based on recommendations from a USDA agricultural economist, a low and high range is provided for changes in supply and demand depending on the availability of equipment, labor, and carbon material in different regions of the country and on the scale of the outbreak (Johnson). Since data was provided from actual HPAI outbreaks, the high range is 1.25 times the low range, rather than the suggested 1.5 times the normal cost.

Results

Temperatures

Both the HM and CL treatment temperatures (Figure 1 and 2, respectively) performed as expected for appropriately formed compost piles. The HM treatment temperatures reached above 131° F for both the 18” and 36” depth by day 4, which was 1 day sooner than the CL treatment at day 5. The HM treatment 36” temperatures were approximately 10 ° F warmer than the CL treatment 36” temperatures during the first 14-day cycle. The temperatures for the VM treatment (Figure 3) only reached 131° F at both the 18” and 36” depth for one day after the piles were watered and turned. The VM treatment was significantly dry compared to the other treatments. Additionally, the VM piles did not have a sufficient parabolic shape, as is ideal for composting, due to the low discharge door on the wagon used in our trial. The temperatures for the VM treatment did stay above 110° F for most of the treatment trial. The thermometers for the VM treatment were reset on day 12 of the first cycle due to the thermometers sinking too low into the pile and reading close to ground level at 36” level. The reset resulted in a 10° F increase in temperature for the 36” reading and a 3 degree increase at the 18” reading (Figure 3).

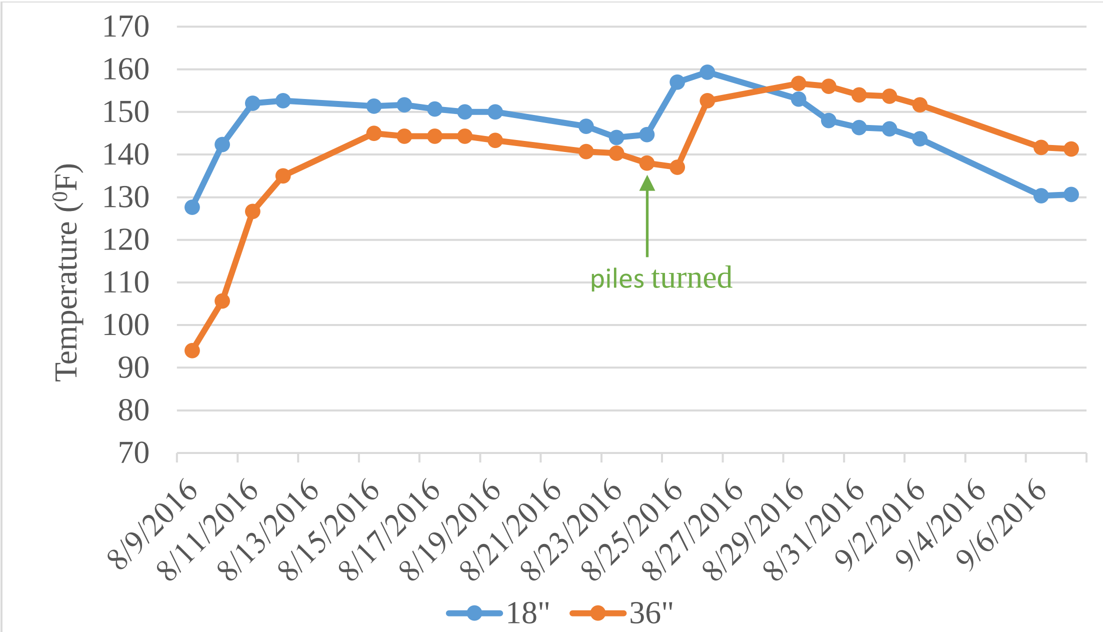

Figure 1. Average Temperatures for Horizontal Mixer Treatment

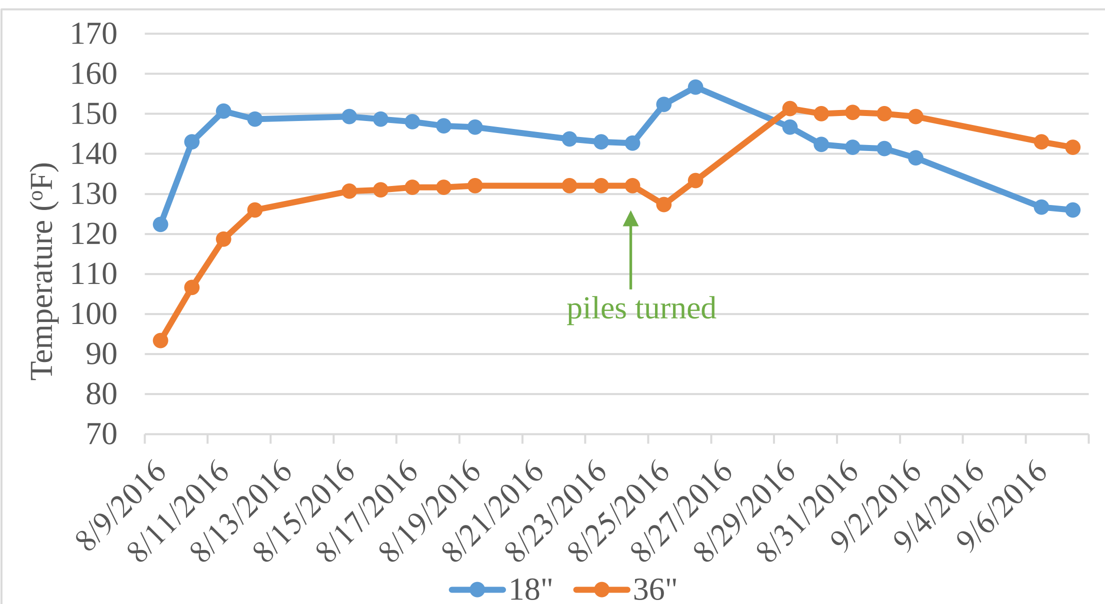

Figure 2. Average Temperatures for Conventional Layering Treatment

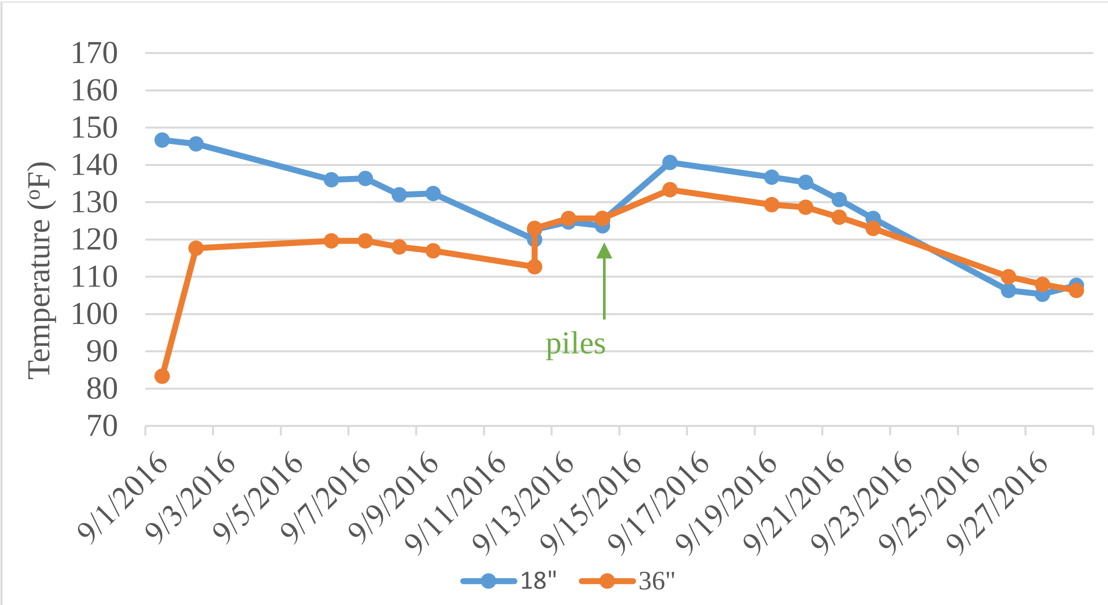

Figure 3. Average Temperatures for Vertical Mixer Wagon Treatment

Screen Weights

Screen weights for both the HM and VM treatments significantly decreased (p=0.09 and 0.00001 respectively) in the first 2-week cycle, whereas there was no significant difference in the CL treatment (Figure 4). This was due to the presence of whole birds on day 0 in the CL treatment, and the inability to get a true screen weight value with a small 2-gallon sample size. The 2-gallon sample either had a whole bird or no birds at all depending on where the pile was sampled. The screen weights were significantly higher for the VM treatment on day 0 than for the CL treatment (p=0.008). This is also explained by the presence of whole birds and dry carbon material in the CL treatment and an evenly distributed mixture of bird parts and carbon material in the VM treatment.

At the end of the first 2-week cycle, there was no significant difference between the screen weights for the HM (1.08 lbs.) and the CL (1.95 lbs.) treatments or between the VM (0.73 lbs.) and HM treatments. However, there was a slightly significant difference (p=0.10) between the VM and CL treatment screen weights. Screen weights on day 16 for the CL treatment had a large variance due to the continued presence of whole birds in some samples and only dry carbon in other samples, in comparison to small variances for both the HM and VM treatments.

By the end of the composting trials, the final screen weights for the VM (0.67 lbs.) treatment were significantly lower than the screen weights for both the HM (1.21 lbs.) and CL (1.61 lbs.) treatments (p=0.05 and 0.01, respectively). There was no significant difference between the HM and the CL treatment screen weights. In the second 2-week cycle, there was no significant change in screen weights for the HM, CL, or VM treatments.

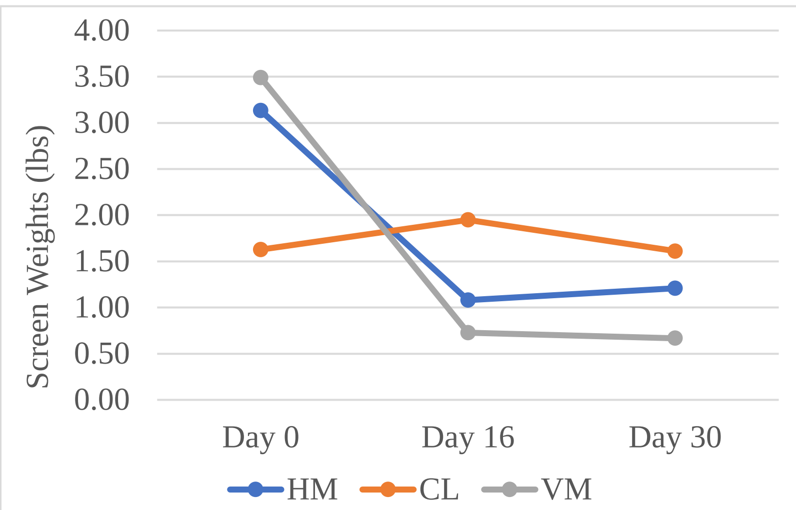

Figure 4. Average Screen Weights for CL, HM and VM Treatments Day 0, 16*, and 30*

*Actually Day 14 and 28 for VM treatment

Economic Calculations

Table 1 lists minimal times for the CL, HM, and VM treatments per 254 birds (the average number of birds per bucket load/pile). These times were used to calculate the number of hours it would take to process 200,000 birds based on the small-scale set up in our trials. When calculating the costs for the HM or VM treatment versus the CL treatment in Table 2, the size of equipment and quantity of equipment and operators was scaled up to process more birds in the same amount of time. It was approximated that if two 5 cubic yard loaders with 2 operators (instead of a ¾ cubic yard loader) and at least a 24-cubic yard mixer wagon (instead of a 15-16 cubic yard mixer) were used, 1700 laying hens with manure or 3400 laying hens without manure could be processed in the average 15 minutes.

While the Iowa HPAI outbreak farm interviewed for this study used a Tub grinder (rented at $500/hr including fuel and operator) and Tebbe manure spreaders (rented at $180/hr per spreader including fuel and operator), it was assumed that the mixer wagon rental rates would be similar to the Tebbe manure spreader and would take the place of both the tub grinder and manure spreader. This rate assumption seemed reasonable when a local Iowa equipment dealer gave a rental rate of approximately $80-100/hr for their vertical mixers without fuel and operator costs. The CL method for both layer and turkey farms required at least one additional laborer on the ground due to the tendency for whole birds to roll off the pile and necessitates more labor to replace them and more carbon material to cover them up (Table 2 and 3).

For a layer operation outbreak, when using at least a 24-cubic yard mixer and 2 five cubic yard loaders, 200,000 layer birds can be processed in 20 hours without manure and 30 hours with manure and costs between $15,000 and $37,256, depending on supply and demand and the amount of manure that needs to be composted. In comparison, the CL method takes approximately 35 hours to complete and costs between $20,500 and $48,300 depending on the supply and demand and the amount of manure per 200,000 birds (Table 2).

Discussion

Avian influenza outbreaks in the U.S. have become increasingly more common in the past couple of decades. Due to its severe impacts on food security, international trade, and human health, AI is an important disease that requires thorough surveillance as well as efficient and timely response to eradication. During the most recent outbreak of HPAI in the U.S. from 2014-2016, composting and burial were the most common methods of carcass disposal

(Johnson, Seeger and Marsh). Due to the size of the outbreak, disposal efforts were challenged by availability of equipment, labor, and carbon material (Johnson, Seeger and Marsh). Bottleneck effects drove up the cost of labor and supplies and, subsequently, the speed of clean-up efforts. As an epizootic disease, it is imperative that efforts are made to improve response and disposal in the future. It is also important that the disposal methods do not pose a risk to biosecurity and environmental pollution and are as economically efficient as possible. While burial may be a less technical and easier solution to carcass disposal than composting, it brings risk of environmental pollution and, if taken offsite, to biosecurity. Concerns about virus survival with burial of infected carcasses have also been raised (Graiver et al.). In contrast, on-site composting carries little risk to biosecurity, is efficient at viral inactivation, poses minimal risk to the environment, and creates a useful end-product that can be marketed and utilized. For these reasons, further efforts should be made to improve and reduce the cost of composting methods to encourage its use as the preferred method of carcass disposal during FAD outbreaks.

During the composting trials at the Compost Research and Education Center, the VM treatment had superior tissue breakdown than the CL or the HM treatment and accelerated tissue decomposition. However, the HM treatment had superior peak temperatures during the first 2-week cycle compared to both the VM and CL treatments. Both the VM and HM treatments had significant decreases in particle size from the start of the trial to the end of the first 2-week cycle. While the VM treatment did not perform as well for temperature, this can be explained by inadequate moisture content and poor windrow formation. Additionally, pile thermometers sunk too low in the pile and were reset on day 12 causing a significant increase in temperature at the 36” level. Higher peak temperatures for the first cycle could have been missed due to improper thermometer placement. One challenge with the VM was the discharge door was too low to create a sufficiently high enough pile. This can be remedied with the addition of a belt driven chute that can discharge material up to 6 feet tall. Alternatively, a loader could be used to push the piles higher. Despite these challenges, tissue break down was superior. While temperatures for this method did not meet the 131^{o} F for 3 consecutive days' standard set by the USDA Composting Protocol, it did meet 110^{o} F for 10 consecutive days for both cycles and temperatures were more than adequate to kill the virus. Other factors besides heat during composting have been shown to be important in virus inactivation as well (Glanville et al.; Guan et al.). The temperatures in all treatments in this study were consistently adequate for efficient virus inactivation within compost piles according to published research (Lu et al.; Chumpolbanchorn et al.; Senne, Panigrahy and Morgan).

The VM and HM treatments also support shortening of the current requirement of a 4-week composting cycle. The data from the HM and especially the VM treatment showed a significant difference in particle size in the first 2 weeks, but no difference in the second 2-week cycle. Since virus inactivation has been demonstrated to occur within 24 hours at temperatures as low as 25^{o} C (77^{o} F) in manure (Chumpolbanchorn et al.) and as low as 42^{o} C (107^{o} F) in compost (Senne, Panigrahy and Morgan), a 2 week cycle with turning of the piles after 7 days to ensure homogeneous temperatures and mixing, should be ample time to achieve neuralization of the virus. While shortening of the composting cycle may not have direct effects on the cost of carcass disposal, it could have an immense impact on reducing the opportunity costs to producers if their barns or fields were only occupied for half the time. This could accelerate the cleaning and disinfecting of the barns, allowing producers to restock their flocks sooner and encourage producers to choose composting over burial. While the compost product would not be ready for field application as a soil amendment, it could be safely moved to an approved storage site without biosecurity risk.

Even without the reduction in opportunity cost with a shorter composting cycle, the economic calculations in this project support the use of a mixer wagon for carcass composting.

The reduced amount of carbon material and manual labor required, as well as the increased speed with larger equipment, make it an economical choice. A similar method of particle reduction size and windrow construction was achieved during an outbreak in Iowa and not only proved to be effective but also economical (Elbert). Other forms of equipment, such as the tub grinder and Tebbe manure spreaders used in Iowa, could be considered, depending on availability and cost. In large agricultural regions, such as Iowa, equipment such as feed mixers may be more available than in other regions of the country.

During the 2014-2016 AI outbreak, reports of prolonged times between depopulation and carcass disposal have been reported due to shortages in labor, equipment, and carbon sources during the height of the outbreak (Johnson; Elbert). Several lessons can be learned from this, including the importance of securing equipment, labor, carbon sources, and other supplies for each state prior to an outbreak. These preparations not only help insure adequate resources are available and efficiently acquired but can also help reduce hikes in cost if contracts are already in place. Reduced costs could make composting even more economically feasible and reduce the amount of facilities that choose burial as their method of disposal. Poultry producers should be encouraged to develop emergency plans of their own as well.

The 2016 USDA APHIS protocol for carcass composting of AI flocks does not currently support the use of mixing or grinding equipment for carcass disposal due to the potential risk of virus aerosolization. This project did not address aerosolization concerns with the VM or HM and should be investigated in future studies. Additionally, due to the small sample size of this study, a larger and blinded trial could provide more information. A larger trial with a vertical mixer wagon with a 6-foot discharge chute and adequate moisture could improve the temperature profile and efficiency and provide more support for its use during an outbreak.

Conclusion

Particle size reduction and mixing improves and accelerates degradation rates of poultry carcasses in compost. This study indicates that a vertical or horizontal mixer wagon is an economical method for processing poultry carcasses. Other equipment that achieves particle size reduction and mixing should be considered depending on equipment availability in different regions of the country. Besides a reduction in the direct costs of carcass composting with efficient handling of carcasses, manure, and carbon material, reduced opportunity costs for producers could be achieved with a shorter composting cycle based on current research on AI virus stability in compost and manure. Direct cost reductions for composting could also be achieved if states and producers planned for equipment, labor, carbon material, and other supplies prior to an outbreak. These reductions in direct and opportunity costs could encourage more producers to select composting as the means for carcass disposal over burial, which can have additional costs associated with groundwater contamination and prolonged virus inactivation as well as reduced value of property.

Table 1. Minimal Processing Times for HM, CL, and VM Treatments with 1 (¾ yd^3) Loader, 1 Tractor Operator, 1 Mixer and 1 Laborer, with Manure

CL	**VM (16.3 yd^3)**	**HM (15.5 yd^3)**
14 min per 254 birds	16.22 min per 254 birds	14.17 min per 254 birds
11,023 min per 200,000 birds	12,600 min per 200,000 birds	11,157 min per 200,000 birds
184 hours per 200,000 birds	210 hours per 200,000 birds	186 hours per 200,000 birds

Table 2. Economic Estimates for Conventional Layering and Mixer Wagon Methods for Layer Hens

	COST PER 200,000 birds			
MIXER WAGON METHOD	**No manure**		**With manure**	
2 days without manure, 3 days with manure (10hrs/day) per 200,000 birds	**Low**	**High***	**Low**	**High***
Equipment (fuel, equipment, operator included)				
5 yd^3 wheel loader making base/ cap ($125/hr)	$2,500	$3,125	$3,750	$4,688
5 yd^3 wheel loader adding birds, carbon, manure to mixer ($125/hr)	$2,500	$3,125	$3,750	$4,688
1 tractor with mixer ($180/hr)	$3,600	$4,500	$5,400	$6,750
Labor				
1 Laborer on the ground ($20/hr)	$400	$500	$600	$750
1 Foreman ($40/hr)	$800	$1,000	$1,200	$1,500
Carbon Material				
600 -1180 cubic yards ($9-16 /yd^3)	$5,400	$9,600	$10,620	$18,880
Total cost	**$15,200**	**$21,850**	**$25,320**	**$37,256**
CONVENTIONAL LAYERING METHOD				
3.5 days (10hrs/day) per 200,000 birds	**Low**	**High***	**Low**	**High***
Equipment (fuel, equipment, operator included)				
1 Track skid loader making base/ cap ($100/hr)	$3,500	$4,375	$3,500	$4,375
1 Track skid loader layering carbon/litter ($100/hr)	$3,500	$4,375	$3,500	$4,375
1 Track skid loader layering birds ($100/hr)	$3,500	$4,375	$3,500	$4,375
1 Track skid loader layering manure ($100/hr)			$3,500	$4,375
Labor				
2 Laborers on the ground ($20/hr)	$800	$1,000	$800	$1,000
1 Foreman ($40/hr)	$800	$1,000	$800	$1,000
Carbon Material				
900 -1800 cu yd ($9-16/ yd^3)	$8,100	$14,400	$16,200	$28,800
Total cost	**$20,200**	**$29,525**	**$31,800**	**$48,300**

Based on recorded times and carbon amounts for each method at Highmoor Farm, costs from HPAI outbreak farm in Iowa in 2015 (7) and carbon amounts and costs from HPAI influenza outbreak farms (10)

*High estimate is 1.25 times the low end to allow for changes in supply and demand

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