Background

North Carolina’s poultry farmers produced 36 million turkeys and 800 million broiler chickens in 2012 (NASS, 2013). Most turkeys and broilers are raised on bedding such as wood shavings, peanut hulls, or sawdust. Fecal material, spilled feed and water, and feathers accumulate on the bedding, creating a material known as cake. The material beneath the cake, which is mostly bedding with some fecal and feed constituents, is known as litter. In North Carolina, most of the cake is removed after each flock and some producers may also top-dress the litter with some fresh bedding after removing the cake. With the exception of turkey brooder houses, the litter may be removed annually or at even longer intervals. This material, containing both cake from the last flock and litter, is called whole-house litter. In turkey brooder houses where poult-s are raised to five or six weeks of age, the litter is removed after every flock. In North Carolina, the brooder house litter is sent to grow-out houses where the poult-s are raised to market-size, whereas in other states, it may be stored or disposed of as discussed below.

Being a rich source of plant nutrients, most poultry waste (cake or litter) is applied on cropland or pastures after removal from the barns. But when the field, crop, or weather conditions prevent immediate land-application, the waste has to be stored, whether by the producer, a third-party applicator, or by farmers who buy poultry waste for use on their agricultural land. Historically, poultry waste was commonly stockpiled for varying lengths of time either on the poultry farm or in the field—uncovered and on bare soil. Farmers who buy poultry waste usually stockpile it in the field. Due to pollution concerns, however, federal and state regulations and incentives (discussed below) have been established to store poultry waste in a way that reduces pollution and minimizes nutrient losses and odors. Because poultry waste storage regulations vary among states, it is important to check whether a storage method (depending on duration of storage) is acceptable in a particular state.

Improved Poultry Waste Storage Methods

Several authors (such as Fulhage, 1993; Costello et al., 2001; Arogo and Collins, 2009) discuss poultry waste storage methods, including storage sizing considerations, in considerable detail. Therefore, we will briefly summarize these improved storage methods here.
Covered stockpiles

Poultry waste stockpiles can be covered with tarp or plastic to protect them from the elements and reduce the potential for rainfall to move pollutants into the soil through runoff or leaching. The waste, however, remains in direct contact with the soil. Care must be taken to secure the cover (mainly at the edges and where tarps overlap) against wind, and in time the cover will degrade due to exposure to the sun. Spilled waste at the periphery of the stockpile, which is not covered by tarp or plastic, can contribute to pollution. Measures should be taken to prevent run-on from causing runoff pollution.

Selecting a suitable cover material is important for both cost and effectiveness. Plastic sheeting is available in large widths and may also contain ultraviolet (UV) protectors that prolong the life of the cover when it is exposed to sunlight. In addition to higher strength and lower cost, tarps may be preferable to plastic sheets because they come equipped with reinforced edges and grommets (for tying down the tarp). The most widely used tarp is a low-cost polyethylene (PE) tarp (or poly tarp) that consists of a center layer of woven PE strips sandwiched between two sheets of PE (Wikipedia, 2013). The weave count of a PE tarp ranges from 8 × 8 to 12 × 12 weaves/in² with the higher weave count providing greater strength. Thicknesses of PE tarps can range from 5 to 16 mils. Usually PE tarps are color-coded as blue, yellow/orange, green, silver, and brown, with the blue tarp being the lowest in quality and the brown tarp being the best (Wikipedia, 2013). Other types of tarps include canvas tarps (not waterproof) and vinyl tarps. Being waterproof and possessing high abrasion resistance and tear strength, vinyl tarps are suitable for covering stockpiles.

Enveloped stockpiles

This method (Fig. 1) is an improvement over covering with tarp or plastic because the waste is no longer in direct contact with soil, reducing the potential for runoff and leaching losses. Also, securing the edges is easier compared to a covered stockpile. The cover material, however, is likely to be damaged by the loader when the waste is transferred to a spreader.

Bunkers

Arogo and Collins (2009) mentioned that storing poultry waste in concrete bunkers for long-term storage was a good option because of increased storage per unit area. Arogo and Collins (2009) also reported that producers used litter storage structures made with concrete lane dividers. Although litter in such structures would need to be covered, the bunkers’ costs and benefits need to be evaluated. Costello et al. (2001) evaluated quality and nutrient losses from litter stored in a bunker built with large round hay bales on two sides, but the researchers preferred a free-standing stockpile for its simplicity when compared to the hay bunker.

Litter sheds

Litter sheds are becoming increasingly popular for poultry waste storage and composting because they can be used to store large quantities of waste and can reduce water pollution. Litter sheds have wooden sides, a metal roof, and usually a concrete floor, although a packed earthen floor is less expensive. A gravel floor is undesirable because gravel can mix with the litter, and when the litter is land-applied, it can damage the equipment or neighboring property or cause injury.

Costello et al. (2001) reported that, without incentives, storing litter in a shed (with a concrete floor) cost 23 times as much as covering with a tarp. The USDA’s Natural Resources Conservation Service (NRCS), through its annual Environmental Quality Incentives Program (EQIP) state funding allocations and competitive application rankings, may provide cost-sharing of 50 to 75% of the total cost for certain conservation practices, including poultry litter sheds (Fig. 2). Details on the North Carolina EQIP program are online: [http://www.nc.usda.gov/programs/EQIP/index.html](http://www.nc.usda.gov/programs/EQIP/index.html). The NRCS provides cost-share funding to build waste storage sheds throughout the country. North Carolina also offers a cost-share program for litter sheds through the NCDA Division of Soil & Water Conservation—NC Agricultural Cost Share Program: [http://www.ncagr.gov/SWC/costshareprograms/ACSP/](http://www.ncagr.gov/SWC/costshareprograms/ACSP/)

![Figure 1. A 20-ton turkey litter stockpile enveloped in a low-cost, blue tarp.](image1)

![Figure 2. Covered litter shed in North Carolina.](image2)
Laws and Regulations

Numerous environmental laws have been enacted at the federal, state, and county levels to regulate air emissions and waste discharge from animal feeding operations (AFOs), and covering those laws in detail is beyond the scope of this publication. The US EPA provides a link to various federal and state laws, regulations, policies, and guidance (US EPA, 2013). Here the focus is on important federal and North Carolina environmental laws that apply to AFOs.

Water quality

Litter-based poultry operations are considered solid waste systems, while swine operations using storage pits and/or other treatment or storage structures are considered liquid waste systems. Neither system is required to obtain a National Pollution Discharge Elimination System permit to comply with the Clean Water Act if it does not discharge pollutants (US EPA, 2012). If solid poultry waste is stockpiled uncovered in the open for more than 15 days, the poultry operation will be considered a liquid waste system (US EPA, 2012), but the EPA will get involved only if there is discharge to surface waters. North Carolina, however, requires litter-based poultry operations with more than 30,000 birds and manure haulers land-applying more than 100 tons of animal waste per calendar year to obtain a general permit if they leave stockpiles uncovered for more than 15 days in the open (NCAC, 2006). Animal waste stockpiles cannot be located within 100 ft of a perennial stream or water body and should be protected from 100-year flooding as determined by the Federal Emergency Management Agency in North Carolina (NCAC, 2006).

Air quality

There are some federal regulations but no state regulations that can impact CAFO emissions. The US Environmental Protection Agency (EPA) requires large concentrated animal feeding operations (CAFOs) (more than 125,000 chickens or 55,000 turkeys) to report air emissions of ammonia and hydrogen sulfide in excess of 100 lb over a 24-hour period to state and local emergency officials under the Emergency Planning and Community Right to Know Act (EPCRA) (US EPA, 2009). Additional details can be found in the National Pork Producers Council (NPPC) website: [NPPC-EPCRA-Fact-Sheet-and-Detailed-Guidance.pdf](http://water.unl.edu/c/document_library/get_file?folderId=67759&name=DLFE-4647.pdf). The EPCRA reporting requirement is for the whole farm, which includes barns, stockpiles, and other treatment units (such as compost piles). A producer can voluntarily provide a “good faith estimate” of ammonia emissions under EPCRA using a University of Nebraska worksheet: [http://water.unl.edu/c/document_library/get_file?folderId=67759&name=DLFE-4647.pdf](http://water.unl.edu/c/document_library/get_file?folderId=67759&name=DLFE-4647.pdf). Based on published studies of broiler barns (including Shah et al., 2013; Lin et al., 2012), while some poultry farms may need to report ammonia emissions under EPCRA, it is highly unlikely that the farms will have to report hydrogen sulfide emissions.

The EPA also has the authority to regulate CAFO under the Clean Air Act, but it does not currently use that authority. That may be changing. As part of the 2005 voluntary compliance agreement between the EPA and the livestock industry, a two-year nationwide National Air Emissions Monitoring Study (NAEMS) of 25 dairy, swine, layer, and broiler farms was conducted (US EPA, 2010). Using the data collected through the NAEMS and other studies, the EPA is developing tables of emission rates that producers can use to calculate total emissions for their farms. If the EPA decides to regulate emissions, it will need to establish thresholds (lb/day) for specific pollutants from the farm that will include the barns, storage, and waste treatment units but not the land-application sites. Once emission thresholds are established, the EPA may require use of suitable control strategies or techniques. These control strategies could be similar to those for industries, such as the best available control technology (BACT) or lowest achievable emission limitations (LAER), but the EPA (2010) indicated that they would work with the USDA to search for the least-cost alternatives. Ammonia emissions can be reduced with relatively low-cost options, such as use of waste acidifiers (Shah et al., 2013).

The EPA does not regulate odor emissions or entertain odor complaints from livestock barns. In North Carolina, odor regulations are complaint-driven and apply only to liquid waste systems. Because there have been numerous poultry-farm-related odor complaints in North Carolina, particularly due to land application, counties could enact regulations to control livestock farm odors.

Impacts of Poultry Waste Storage Methods on Air, Soil, and Water Pollution

Summarized below are results from studies on the environmental impacts of poultry waste storage methods. Runoff water quality was evaluated in several studies, but evidence of the runoff reaching receiving waters was not detected. Therefore, it could be reasonably assumed that the runoff would percolate into the surrounding soil and affect the soil—and possibly the groundwater—in the vicinity of the stockpile.

Based on a three-month study in Northern Ireland, Doody et al. (2012) detected no difference in runoff water quality—nitrogen (N), phosphorus (P), pH, conductivity, suspended solids—and leaching (N and P species only) between plastic-covered and plastic-enveloped litter stockpiles formed on forage corn or wheat fields. Because of regulations, Doody et al. (2012) did not have an uncovered stockpile. The effect of litter stockpiling (using either
Penn et al. (2011) reported that 4-ton poultry litter stockpiles aerated using perforated plastic pipes reduced litter mass by up to 27% compared with unaerated stockpiles. Greater loss of mass from the aerated stockpile was attributed to greater microbial activity, resulting in increased consumption of carbon (C) and N. Although aeration reduced stockpile mass and concentrated the nonvolatile nutrients (such as P), it increased ammonia emissions (Penn et al., 2011).Penn et al. (2011) also reported that the acidifier aluminum sulfate (alum) (applied at 10% w/w of the dry litter mass) reduced N loss and stockpile mass. Penn et al. (2011) attributed greater stockpile mass loss due to alum use to a greater fungal population compared to the microbial population. Because fungi are more effective than microbes in degrading the lignin in the litter’s rice hulls and wood shavings, a greater reduction in the litter’s mass occurred when litter was mixed with alum prior to stockpiling. We need to evaluate the economics of aerating poultry waste stockpiles and using alum and the effect on the litter’s N content. Because mixing the alum into the litter is expensive, producers need to evaluate the benefits of a surface-broadcast acidifier.

Ammonia emissions from broiler cake stockpiled in a litter shed in summer (7 days) and winter (15 days) caused daily losses of about 0.2% of the initial cake N content (Yao et al., 2011). Ammonia emissions increased with total N content and pH of the cake as well as air temperature and wind speed. Prior to the summer trial, the cake had been covered with a tarp in the shed. As the tarp was removed to form the stockpile, a large amount of ammonia was released that could not be measured. Ammonia loss on the first day of summer monitoring (after the accidental release) accounted for 1% of the initial cake N content (Yao et al., 2011). Based on the findings of two companion studies, Yao et al. (2011) and Shah et al. (2013), daily ammonia emissions from barns per bird marketed (averaged over a 63-day flock) were more than five times higher than from stockpiles. While tars may reduce air and water pollution, removing the tarp to transport the litter or cake for land application may cause substantial and unavoidable ammonia loss.

In a study in eastern North Carolina, soluble chemicals (N, P, C species) leached into the soil to a depth of at least 24 in. from uncovered turkey litter and cake stockpiled for 12 months (Shah et al., 2009). At the end of the study, ammonium (NH₄) concentrations were 62 times higher in the 12- to 24-inch soil layer beneath the stockpile than in the same layer in the adjacent soil outside the stockpile footprint (Shah et al., 2009). Soil cores 12 to 24 in. beneath the stockpiles were dark because of dissolved organic C (DOC) leaching from the stockpiles and had a strong smell of ammonia. Leaching of DOC and soluble P from the stockpiles likely solubilized arsenic (As) in the soil, resulting in elevated soluble As levels beneath the stockpiles (down to 24 in.) compared to levels outside the stockpile footprint. The stockpiles did not shed rainfall but absorbed it like a sponge. While the shape and size of the stockpile and its initial moisture content will affect runoff, movement of pollutants through the stockpile into the soil below may be a bigger concern than runoff losses into the surrounding soil.

During a 592-day study in Nova Scotia, Canada, Sullivan et al. (2009) reported that poultry litter stockpiles covered with tarp had about 20% lower runoff mass losses of total P, total Kjeldahl N (TKN), and total ammoniacal N (TAN) than uncovered stockpiles. Runoff loss of nitrate was slightly higher in the covered stockpiles. Leaching losses of the N species were 20 to 30% lower in the covered stockpiles. Due to the degraded tarp, the covered stockpile had higher subsurface total P losses (Sullivan et al., 2009). In both, covered and uncovered stockpiles, except for total P, mass losses of TKN, TAN, and nitrate-N were higher due to leaching than in runoff. Covering the stockpile reduced ammonia by 92%, nitrous oxide by 73%, and methane emissions by 71% (Sullivan et al., 2009).

In a six-month study in the UK, Sagoo et al. (2007) monitored ammonia volatilization and leachate losses from five types of litter stockpiles, all created on concrete pads. The highest ammonia loss (19% of initial N) was from a triangular pile in a shed (roofed) and the lowest (1.3% of initial N) was from a plastic-covered triangular pile. Other treatments (flat pile in open air, pile turned twice in open air, triangular pile in open air) had ammonia losses in between the plastic-covered and roofed piles (Sagoo et al., 2007). Lack of stockpile surface sealing in the roofed treatment resulted in greater ammonia loss than the other treatments (that were not plastic-covered) where the litter surfaces were found to be sealed. Although odor was not measured by Sagoo et al. (2007), odor emissions from a plastic-covered pile could be lower than from a roofed pile or an uncovered stockpile. There were no leachate losses from the roofed treatment, while the highest losses (2.9% of initial N) occurred from the plastic-covered treatment; losses from the other treatments were about 1% of initial N (Sagoo et al., 2007). When considering both ammonia and leachate losses, the highest N loss of about 20% occurred from the roofed treatment (all through ammonia volatilization), whereas the plastic-covered treatment lost less than 5%. The other treatments had losses of 12 to 16% (Sagoo et al., 2007). It is unclear how there could have been leaching from the plastic-covered treatment unless rain entered the plastic through tears or the litter was saturated (moisture content not mentioned). Ammonia loss from the litter that had been stored under plastic was higher following land application than from litter that had been stored outside in a flat pile, indicating that most of the ammonia conserved during storage was lost during land application (Sagoo et al., 2007).

Felton et al. (2007) evaluated the impact of cover (tarp or none) and soil type (silt loam or sandy loam) on runoff losses (generated using a rainfall simulator) from poultry litter stockpiles in Maryland. As expected, nitrate runoff losses were higher from...
the silt loam site and under wetter antecedent soil conditions. Covering the stockpiles on both soils resulted in higher runoff volumes and nitrate mass losses (Felton et al., 2007). Higher nitrate mass losses from covered stockpiles may have been due to spilled litter during stockpiling (the actual stockpile footprint was less than 40% of the plot area). While the cover or soil type did not affect P runoff losses, Felton et al. (2007) suggested that covering stockpiles in sandy loam could reduce soluble P loss.

In the Czech Republic, Zemek and Mareček (2005) reported that treating a broiler litter (also pig waste) stockpile with the biotechnological agent Amalgerol reduced ammonia emissions by 41% compared to an untreated control stockpile. Amalgerol consists of several vegetable oils, bound together with vegetable extracts, including sea algae, and it also contains paraffin distillates (Zemek and Mareček, 2005). Amalgerol stimulates growth of those microbial strains that degrade ammonia (Zemek and Mareček, 2005). We are unaware of the availability of Amalgerol in the United States. Researchers also need to investigate the impacts of additives on odor emissions.

In Sweden, Rodhe and Karlsson (2002) reported that N losses due to ammonia emissions were 10% from covered (12 in. of straw) and 7% from uncovered poultry litter stockpiles. The covered stockpile stayed much warmer and drier, which contributed to higher ammonia losses than the uncovered stockpile (Rodhe and Karlsson, 2002). Although leaching was not monitored by Rodhe and Karlsson (2002), a covered stockpile with lower moisture content might be less likely to leach pollutants into the soil than a wetter, uncovered stockpile. Air emissions and leaching from a stockpile (covered or uncovered) will also depend on rainfall, wind, and air temperature.

Costello et al. (2001) reported that litter properties changed very little in a tarp-covered stockpile, whereas N and C concentrations decreased in an uncovered stockpile over a 13-month study in Arkansas. The uncovered stockpile had surface runoff concentrations of suspended solids and nutrients comparable to liquid animal waste. Unlike Shah et al. (2009), who reported considerable leaching of pollutants into the soil (loamy sand), Costello et al. (2001) reported very little leaching, which may also be due to differences in soil properties (not reported).

Zebrath et al. (1999) stockpiled solid turkey manure on coarse-textured soil in British Columbia, Canada, over six years from fall through winter. Nutrient concentrations down to 12 ft were much higher beneath the stockpile than outside, with NH₄ concentrations 120 times higher, similar to the findings of Shah et al. (2009). Zebrath et al. (1999) reported that they did not find elevated nitrate levels beneath the stockpile—probably because high free ammonia in the soil solution was toxic to the nitrifying bacteria. They also monitored two other stockpiles, covered and uncovered. Ammonium concentrations were 6.6 times higher beneath the uncovered stockpile (down to 6.9 ft) due to leaching caused by heavy fall and winter rains. Nitrate concentrations, however, were 4.2 times higher under the covered stockpile due to low NH₄ concentrations that did not inhibit nitrification (Zebrath et al., 1999).

Ritter et al. (1994) monitored nitrate concentrations in wells (15 ft deep) upgradient and downgradient of covered (3) and uncovered (3) poultry litter stockpiles in Delaware for three years. As needed, the broiler producer added and removed litter from the stockpiles. Stockpiling resulted in elevated nitrate-N concentrations, generally exceeding 10 mg/L (EPA primary drinking water standard) in both the upgradient and downgradient wells. These high nitrate concentrations in both locations were probably because the wells were within 10 ft of the stockpile edges and the nitrate plume dispersed as it reached the groundwater (Ritter et al., 1994). Wells near both covered and uncovered stockpiles had similar nitrate concentrations. Compared to the adjacent soil, when the stockpiles were removed, NH₄ and nitrate concentrations in the soil were elevated down to 59 in. though most of the NH₄ was in the top 24 in. As the NH₄ moved down into the soil, it converted to nitrate (Ritter et al., 1994). Nitrogen (in the NH₄ and nitrate forms) build-up in the top 59 in. of soil beneath the stockpiles ranged from 960 to 9,170 lb/acre (Ritter et al., 1994).

Ritter et al. also reported that the cover reduced leaching while the stockpile was in place. Once the stockpile was dismantled for land application, rainfall transported the residual litter into the soil (Fig. 3). Therefore, Ritter et al. (1994) recommended that stockpiles in southern Delaware should not be covered but formed on impervious surface to allow for complete cleanout. Ritter et al. (1994) did not report rainfall during the study nor the moisture content of the litter. If litter is stockpiled, uncovered on an impervious surface, under heavy rainfall conditions, there could be considerable runoff losses, which may leach into the surrounding soil.

Figure 3. Footprint of a 4.5-ton turkey cake stockpile on sod in eastern North Carolina.
Mitigation

If the quantity of waste is not too large, stockpiling on a concrete pad and covering with a good-quality tarp would minimize pollution and would be less expensive than building a litter shed. Waste stockpiled on a concrete pad with a low wall (treated lumber or poured concrete) on the upslope edge of the pad would be easier to clean out than waste stockpiled on soil and would be protected from run-on. The concrete pad option, however, may be too expensive for farmers who buy poultry waste and stockpile it in the field for short periods. Keeping the footprint covered can reduce runoff or leaching of residual pollutants (or both) from the stockpile footprints (Fig. 3) between ongoing short-term stockpiling events. To reduce pollution from ongoing or even discontinued poultry waste stockpiling sites on soil, longer-term and more expensive measures might be required which are beyond the scope of this paper. It might be desirable, however, to monitor soil and groundwater pollutant concentrations from stockpiling sites if they are located over shallow aquifers that are used for drinking water (Shah et al., 2009).

It is clear that a storage method that can minimize air pollution may increase water pollution or vice-versa. Based on empirical evidence, litter sheds may improve water quality but not air quality. Some of the findings were conflicting. For example, whereas, Shah et al. (2009) reported leaching from stockpiles, Costello et al. (2001) did not. Obviously, pollutant losses are not only affected by the storage method but also by the waste’s properties and weather conditions.

Summary

1. When allowed by regulations and if the quantity of waste to be stored is not excessive (say, hundreds of tons), enveloping a poultry waste stockpile will be economically and environmentally acceptable. If the waste is not excessively wet, if the site does not pond, and if it is protected from run-on, then covering the stockpile may be adequate.

2. Between short-term stockpiling events at the same site on soil, covering the stockpile footprint will reduce leaching or runoff losses (or both) of remnant stockpile pollutants.

3. A good-quality tarp with UV resistance will be cost-effective for covering or enveloping stockpiles.

4. Litter sheds provide considerable management flexibility. But if cost-share support for building these structures is eliminated or downscaled, if not required by law, many producers may not build new litter sheds. If the quantity of waste is not excessive, covering on a concrete pad may be a more cost-effective option to litter sheds. A low wall on the upslope edge would make it easier to clean out the stockpiled waste and protect the stockpile from run-on.

5. Waste additives may reduce ammonia emissions and the mass of litter, thus reducing transportation cost. Producers need to evaluate the cost-effectiveness of additives, including their impact on odor.

6. Because a method effective in reducing air pollution may not be as effective in reducing soil and water pollution and vice-versa, economics aside, selection of a storage method will depend on whether the objective is to reduce air emissions or soil and water pollution.
References


