Livestock and the Environment
A National Pilot Project

CEEOT-LP Application to Environmental Issues in Poultry Production

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Abstract

With the rapid growth of the poultry industry in the U.S. in recent years, data and information are needed to address the environmental issues associated with poultry production operations. The main environmental concern is the potential for water quality problems when large quantities of poultry litter and manure are generated in small geographic areas.

Although poultry litter is a valuable resource as a fertilizer, excessive application of litter on agricultural land can lead to nutrient enrichment of surface water and groundwater. Nutrients from agricultural land have been identified by several studies as the main cause of eutrophication of inland water bodies as well as a source of nutrient enrichment to estuaries and groundwater. Adverse water quality effects from land application of poultry litter may be prevented by implementation of effective best management practices and planning efforts.

A watershed-level evaluation tool called the Comprehensive Economic and Environmental Optimization Tool-Livestock and Poultry (CEEOT–LP), earlier developed, and successfully applied, to evaluate environmental and economic impacts of alternative management methods in dairy and swine operations, will be developed and adapted for poultry operations to evaluate similar objectives. The development and adaptation of CEEOT-LP for poultry operations, in a region that is experiencing a recent and rapidly growing broiler chicken industry, will provide policy and management tools for water quality protection efforts.
# Unit Conversion

The following table contains unit conversion rules that may be useful in reading this paper.

<table>
<thead>
<tr>
<th>Original Units</th>
<th>Multiply By</th>
<th>To Get</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg/ha, megagram per hectare</td>
<td>893.0</td>
<td>pound per acre</td>
</tr>
<tr>
<td>kg/ha, kilogram per hectare</td>
<td>0.893</td>
<td>pound per acre</td>
</tr>
<tr>
<td>Mg/ha, megagram per hectare</td>
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<td>ton (2000 pound) per acre</td>
</tr>
<tr>
<td>kg, kilogram</td>
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<td>pound</td>
</tr>
<tr>
<td>ha, hectare</td>
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<td>acre</td>
</tr>
<tr>
<td>ppm, parts per million</td>
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<td>milligram per kilogram</td>
</tr>
<tr>
<td>%, percent concentration</td>
<td>10,000</td>
<td>milligram per kilogram</td>
</tr>
</tbody>
</table>
Contents

Unit Conversion ................................................................. 4

CEEOT-LP Application to Environmental Issues in Poultry Production . . . 7
  Introduction .......................................................................... 7
  Poultry Production ............................................................ 8
  Poultry Litter — Benefits and Detriments ............................... 9
  Best Management Practices ................................................ 12
    1. Litter Application .......................................................... 13
    2. Filter Strips .................................................................... 14
    3. Buffer Zones .................................................................. 15
    4. Tillage Practices ............................................................. 15
    5. Chemical Amendments .................................................. 15
    6. Storage .......................................................................... 16
    7. Nutrient Management Planning ........................................ 16
    8. Alternative Uses of Litter ............................................... 16
  Application of CEEOT-LP ..................................................... 17

References ............................................................................. 19
Introduction

The poultry industry is one of the largest and fastest growing livestock production systems in the world, growing at an annual rate of five percent (Sims and Wolf, 1994). Between 1960 and 1998, annual broiler production in the U.S. rose from $2.3 \times 10^9$ kg to $17 \times 10^9$ kg (NASS, 1999). Thus, the economic impact of the poultry industry on the U.S. and global economies is significant and of increasing importance (Sims and Wolf, 1994). Although economically successful, the poultry industry is faced with a number of complex and challenging environmental problems, many of which are related to its size and geographically concentrated nature (Sims and Wolf, 1994). Rapid growth of the poultry industry in several states of the U.S. resulted in huge increases in waste, particularly litter (manure and bedding material), to be managed (Simpson, 1990). Because of the generation of large quantities of waste and nutrients such as nitrogen (N) and phosphorus (P) as by-products, there is a need to manage the waste properly for water quality prevention efforts.

An evaluation tool, that assesses the environmental benefits and economic consequences of policy scenarios at the watershed level, has been developed under the Environmental Protection Agency (EPA) Livestock and the Environment: A National Pilot Project (NPP). This tool, called the Comprehensive Economic and Environmental Optimization Tool–Livestock and Poultry (CEEOT–LP), was developed by NPP research partners — Texas Agricultural Experiment Station Blackland Research Center (BRC), Center for Agricultural and Rural Development (CARD) at Iowa State University, and Texas Institute for Applied Environmental Research (TIAER) at Tarleton State University. CEEOT is comprised of separate environmental water quality models and an enterprise-level economic model (Osei et al., 1995). CEEOT has been successfully applied to the dairy industry in watersheds of central Texas (Pratt et al., 1996) and eastern Texas (McNitt et al., 1999) and a watershed in northeastern Iowa with a predominance of swine operations (Norvell et al., 2000). In each application, the modeling system was successfully used to evaluate environmental and economic changes to a baseline condition that resulted from alternative management methods for animal wastes.

The purpose of this report is twofold. First, the environmental issues with land application of broiler chicken litter and best management practices for poultry wastes will be summarized. Second, the application of CEEOT–LP will be developed to assess environmental benefits and economic consequences of broiler chicken litter manage-
ment in an east Texas watershed. Actual application of CEEOT–LP to poultry would occur through subsequent EPA funding.

Poultry Production

Poultry production operations include broiler chickens, turkeys, layer chickens, breeders, pullets, and miscellaneous poultry such as ducks, geese, and pigeons. Broilers account for 80 percent of poultry meat produced in the U.S. Increased domestic consumption of broiler products and growing demand in export markets has triggered a significant increase in broiler production (Jenner, 1998). In 1988, the broiler industry produced over 5.2 billion birds. In 1998, the number increased to almost 8 billion birds. The broiler industry has been able to increase production by producing healthier birds, thereby reducing mortality rates, with improved production efficiencies. Thirty years ago, it took 14 to 16 weeks to raise commercial broilers to a marketable weight of three to four pounds. In recent years, selective genetics have helped to grow birds to marketable weight in about six to eight weeks (http://gallus.tamu.edu/fsis/fsman2.html) and to reflect closely qualities that consumers desire.

Independent growers produced and marketed the vast majority of broilers 30 years ago. As profit margins became smaller, growers were required to maintain progressively larger flocks. Broiler processors became financially involved in grower activities to ensure more predictable broiler supplies. To minimize financial risk, processors negotiated production contracts with growers that allowed processors to coordinate many aspects of broiler production. Independent growers continued to produce the vast majority of birds, but the broiler sector became a vertically integrated industry. Following initial integration, larger processors acquired facilities and assets held by smaller processors. Mergers significantly consolidated processing operations. As a result, more than 80 percent of all broilers that growers produce are being grown for the ten largest broiler integrators (http://gallus.tamu.edu/fsis/fsman2.html).

Integrators generally negotiate production contracts with growers located in the vicinity of broiler processing facilities. In turn, growers tend to locate broiler operations near processing facilities to take advantage of contract opportunities. Because of geographic concentration in the industry, approximately 90 percent of broilers are produced in 14 states (http://www.usda.gov/nass/aggraphs). Broiler operations are particularly concentrated in northwestern Arkansas; northern Georgia and Alabama; central Mississippi; the Delaware, Maryland, and Virginia (DelMarVa) peninsula; the Shenandoah Valley region of Virginia; and North Carolina (http://www.usda.gov/nass/aggraphs).

Contract growers build and maintain their own facilities. However, integrators typically require that contract growers provide housing and equipment that meet the integrator’s requirements and specifications (http://www.msstate.edu/dept/poultry/bropod.htm). Because housing and equipment can represent a significant
expense, growers attempt to design housing, ventilation, and heating systems to minimize cost and enhance the efficiency and profitability of their operations.

When an integrator contracts with a nearby grower, an integrator-owned hatchery delivers chicks to the grower’s broiler facility. A grower attempts to maximize the number of birds raised in a broiler house by minimizing the amount of floor space allowed for each bird. A typical contract broiler operation consists of four houses, each house containing up to 25,000 birds. A flock of broilers is usually housed for six to eight weeks (http://www.msstate.edu/dept/poultry/bropod.htm). The integrator supplies feed rations to the grower during the confinement period, and also offers the services of a technician who provides management expertise and veterinary care when needed, however, the grower is responsible for feeding, watering and providing for the general well-being of the flock. The grower is also responsible for managing the bird wastes (http://gallus.tamu.edu/fsis/fsman2.html).

When a flock of broilers reaches a designated market weight, the flock is harvested. Integrators pay growers for the total live weight of the flock. Approximately two weeks after harvest, a hatchery owned by an integrator delivers another batch of chicks to the grower and the production process is repeated. The number of flocks a contract grower produces each year fluctuates, however, a grower can expect to rear between four to six batches of broilers per year. Many growers reserve up to 60 percent of gross receipts to retire loans used to buy land and to construct and equip broiler operations. Growers use receipts to pay for the utility, labor, and maintenance costs associated with their broiler operations. The remaining profit is the compensation growers receive for their production (http://gallus.tamu.edu/fsis/fsman2.html).

The production facilities for broilers are normally single story houses with an earth or concrete floor covered with 5 to 15 cm of litter material such as sawdust, wood chips, rice hulls or a combination of these materials (Sims and Wolf, 1994). Confined production of broilers requires periodic removal of litter from production houses followed by use or disposal. A partial cleaning of litter is normally performed after each flock is removed, but a complete cleaning is done only after about five growth cycles, or about once a year (Moore et al., 1995). Most of the litter is loaded directly from poultry houses onto spreader trucks for nearby fields (Chapman, 1996), generally without incorporation (Edwards and Daniel, 1992). Typically, one truck load of litter is spread per acre, which translates to an application rate of 6.7 to 11.2 Mg/ha (3 to 5 tons/acre), depending on truck size (TNRCC, 1999). If litter is not applied immediately, it is stored in roofed structures, tarpaulin-covered stacks, or in the case of liquid manures, in lagoons or storage tanks made of concrete or steel (Sims and Wolf, 1994).

**Poultry Litter — Benefits and Detriments**

About 1500 kg of litter are produced per 1000 birds in a ten-week growing cycle (Edwards and Daniel, 1992). The disposal of litter and dead birds is the primary concern confronting the poultry industry (Moore et al., 1995). In 1990, poultry farms in
the U.S. generated approximately $13 \times 10^9$ kg of poultry manure, of which 73 percent was produced in ten states (Moore et al., 1995). Many of the poultry-producing states do not have industries that can make an effective use of the wastes (Sims and Wolf, 1994). Poultry production operations in 1992 generated approximately 385 and 200 million kg of manure nitrogen (N) and phosphorus (P), respectively, more than double the amounts (180 and 90 million kg of N and P, respectively) generated in 1949 (Kellogg and Lander, 1999). Because of the generation of large quantities of nutrients as by-products in small geographic areas, there is a strong potential for poultry production operations to impact water quality severely (Moore et al., 1995). The role of poultry wastes in the contamination of groundwater by nitrate-N (NO3-N), eutrophication of surface waters by N and P, and the fate of trace elements and pesticides in litter-treated soils are the main environmental issues associated with poultry production operations (Sims and Wolf, 1994).

Land application of poultry litter as a fertilizer is the best solution to managing the large amounts of litter generated in the U.S (Moore et al., 1995). Total N and P in broiler manure and litter are higher than other animal wastes (Mikkelsen and Gilliam, 1995). Because of its low moisture content (~25 percent) and high nutrient content, together with the large amounts produced daily (Table 1), broiler litter makes the most valuable manure alternative to mineral fertilizer (Moore et al., 1995). Thus, applications of poultry litter at recommended rates considerably increases grass and crop yields (Carreker et al., 1973; Sims et al., 1989; Wood et al., 1993; Sims and Wolf, 1994; Earhart et al., 1995; Heathman et al., 1995; Aldrich et al., 1997; TNRCC, 1999).

For instance, Coastal Bermuda grass plots in Oklahoma that received poultry litter at 11 Mg/ha/yr produced a yield of 8515 kg/ha/yr., whereas a control plot with no litter application produced a yield of 3501 kg/ha/yr. (Heathman et al., 1995). In east Texas, litter application of 24.8 Mg/ha over two years produced a sweet corn yield of 22,264 kg/ha, whereas untreated plots yielded only 13,689 kg/ha of sweet corn (Earhart et al., 1995).

| Table 1: Typical daily manure production and chemical characteristics |
|--------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                          | Beef            | Broiler         | Dairy           | Layer           | Swine           | Turkey          |
| Total Manure (kg/day)a   | 58              | 85              | 86              | 64              | 84              | 47              |
| Total N (kg/day)a        | 0.34            | 1.1             | 0.45            | 0.84            | 0.52            | 0.62            |
| Total P (kg/day)a        | 0.18            | 2.8             | 0.09            | 0.61            | 0.34            | 0.51            |
| Total N (%)b             | 1.4             | 2.9             | 1.4             | 1.5             | 0.50            | -               |
| Total P (%)b             | 0.53            | 1.1             | 0.24            | 0.88            | 0.20            | -               |

a. Fresh manure, based on 1000 kg live animal mass per day (Mikkelsen and Gilliam, 1995).
b. Concentrations of N and P in manure at the time of land application; broiler litter includes manure plus bedding material (McFarland et al., 1998).

Improper management of poultry litter, however, can result in losses of litter components such as carbon, N, and P that may be detrimental to both crop production and
water quality (Edwards and Daniel, 1992). Litter applications at more than the recommended rates decrease crop yields (Earhart et al., 1995). In a three year study by Earhart et al. (1995), no application of litter produced 2,824 kg/ha of turnip, 14 Mg/ha of litter application over three years produced 4,913 kg/ha, whereas an application of 28 Mg/ha over three years produced a yield of 4,756 kg/ha. Decreased yields associated with overapplication rates may be attributed to toxic concentrations of NH₃, NO₃-N, and soluble salts in the soil (Edwards and Daniel, 1992). Excessive application of litter also raises soil salinity, which reduces crop yield (Liebhardt, 1976). Potassium has been identified as the main cause for increased salinity (Wood et al., 1996) because all the potassium in poultry manure is water soluble (Sims et al., 1989).

Land application of poultry litter can potentially increase the concentrations of carbon, calcium, potassium, magnesium, N, and P in surface and subsurface soils (Sharpley et al., 1993; Kingery et al., 1994; Wood et al., 1996). Long term losses of poultry manure constituents from litter-treated soil may impact downstream water quality by accelerating eutrophication and diminishing suitability for aquatic life (Sharpley et al., 1993; Mozaffari and Sims, 1994; Moore et al., 1995). Runoff concentrations of N and P from litter-treated areas have been shown to increase linearly with application rate and rainfall intensity (Edwards and Daniel, 1993a). Heathman et al. (1995) reported that broadcast applications of poultry litter, with or without incorporation, increased P loss in runoff for up to 16 weeks after application. Comparing runoff concentrations between poultry litter and fields treated with dairy manure, McLeod and Hegg (1984) reported higher losses of ammonium N (NH₄-N), total N, total P, and suspended solids from litter-treated fields. Elements (such as arsenic, copper, iron, manganese, selenium, and zinc) added to poultry diet may result in high elemental concentrations in the litter as shown in Table 2, and consequently, elevated elemental levels in runoff from litter-treated fields (Moore et al., 1998). Furthermore, land applications of poultry litter promote NO₃-N leaching in the subsurface (Liebhardt et al., 1979; Adams et al., 1994; Wood et al., 1996) and may result in elevated levels of NO₃-N to depths to or near bedrock (Kingery et al., 1994). This is mainly because poultry manure contains significant amounts of NH₄-N and uric acid and therefore, a large percentage of N may be converted to NO₃-N, often within a period of a few weeks (Sims and Wolf, 1994).

Table 2: Reported mean concentrations of elements in poultry litter.

<table>
<thead>
<tr>
<th>Study Area</th>
<th>N (%)</th>
<th>P (%)</th>
<th>K (%)</th>
<th>Fe (ppm)</th>
<th>Mn (ppm)</th>
<th>As (ppm)</th>
<th>Cu (ppm)</th>
<th>Zn (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carreker et al. (1973) n=2</td>
<td>GA</td>
<td>4.3</td>
<td>1.7</td>
<td>2.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Bitzer and Sims (1988) n=20</td>
<td>DE</td>
<td>5.3</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Edwards and Daniel (1992)a</td>
<td></td>
<td>4.1</td>
<td>1.4</td>
<td>2.1</td>
<td>842</td>
<td>268</td>
<td>22</td>
<td>56</td>
</tr>
<tr>
<td>Evers et al. (1994) n=61</td>
<td>TX</td>
<td>3.4</td>
<td>1.8</td>
<td>2.6</td>
<td>1742</td>
<td>545</td>
<td>40</td>
<td>547</td>
</tr>
</tbody>
</table>
Dissolved N and P constitute the bulk (>75 percent) of total concentrations in runoff from land treated with poultry litter (Edwards and Daniel, 1993a; Nichols et al., 1994; Chaubey et al., 1995; Shreve et al., 1995; Edwards et al., 1996a; Srivatsava et al., 1996). Because poultry litter contains high concentrations of water soluble P, the majority of P in runoff from fields fertilized with litter is dissolved P (Edwards and Daniel, 1993a; Moore et al., 1995; Edwards et al., 1996a). In soil treated with poultry litter, P is present mainly as inorganic P as opposed to organic P that dominates the P-fractional pool in untreated soils (Sharpley et al., 1993). Accumulation of P in primarily inorganic forms in soils treated with poultry litter is important to both soil productivity and water quality, in terms of the potential availability of P in the soil and that transported in runoff (Sharpley et al., 1993). In general, fresh and composted animal manures have a lower proportion of inorganic N (1 to 15 percent of total N) compared to organic N. The N in poultry manure, however, may be as high as 50 percent inorganic N, which possibly suggests the presence of a form of organic N in poultry manure more susceptible to mineralization than that in cattle and swine manures (Cabrera and Gordillo, 1995). Thus, there is a strong potential for N and P to be released from poultry wastes and impact water quality in poultry producing regions.

### Best Management Practices

Best management practices (BMPs) for poultry wastes must reflect both the potential value of the waste as a resource and a realistic appraisal of the negative effects waste constituents may have on the environment (Sims and Wolf, 1994). Subsequent discussion of BMPs will consider poultry litter (manure and bedding material) but not consider dead bird disposal, a related but separate environmental issue. The main resource value of poultry wastes is as a source of plant nutrients for crop production (Simpson, 1990). Major environmental impacts include groundwater contamination by nitrates, eutrophication of surface waters by N and P in runoff, long term effects of trace elements and pesticides on soils, waters, and the food chain, and pollution of drinking waters by pathogens such as *E. coli* (Sims and Wolf, 1994). Avoiding degradation of surface and groundwater by nutrients, pesticides, trace elements, and pathogens is the most pressing environmental issue associated with poultry production operations. Major processes that may be involved in the movement of N and P from poultry wastes to surface water and groundwater include land application, litter
storage, and leaching from unprotected poultry house pads (Chapman, 1996). General discussion topics for poultry litter BMPs include:

1. Litter Application
2. Filter Strips
3. Buffer Zones
4. Tillage Practices
5. Chemical Amendments
6. Storage
7. Nutrient Management Planning
8. Alternative Uses of Litter

1. Litter Application

Most agricultural BMPs, with regard to manure applications, are based on providing sufficient N to meet crop-N requirements and restricting NO3-N contamination of groundwater (Sims, 1995). The plant-available N in poultry wastes is described by decay coefficients that take into account losses of N, such as volatilization and denitrification, as a function of time (Edwards and Daniel, 1992). Sims et al. (1989) suggested the following equation to predict plant-available N (PAN) from poultry litter:

\[ \text{PAN} = (E_f \cdot \text{inorganicN}) + (k_m \cdot \text{organicN}) \]

where \( E_f \) is a factor that accounts for inorganic N losses and varies with soil type, cropping system and method of application, and \( k_m \) is the percentage of organic N that is mineralized (40 to 60 percent).

Because data on inorganic N losses are sparse for poultry manure and litter, these aspects, although significant, are generally neglected in estimating application rates, and therefore result in over or underapplication of N relative to crop needs (Edwards and Daniel, 1992).

While N and salinity related problems may be transient due to losses of N and leaching of soluble salts, long term applications of litter may result in the buildup of P in soil (Edwards and Daniel, 1992). The N to P ratio of poultry manure generally results in the addition of P to soil due to overapplication of manure P relative to crop needs, except in extremely P deficient soils (Earhart, 1995; Sims and Wolf, 1994; Sharpley et al., 1996). For example, 300 pounds of N per acre are required to produce a six ton yield of Coastal Bermuda grass. Applying five tons of poultry litter almost meets this demand but supplies about three times the required amount of P (TAEX, 1994). Also, P is retained to a greater extent, 72 percent, compared to N, 44 percent, in soils treated with poultry litter because of greater sorption coefficient of P and greater plant uptake of N than P (Sharpley et al., 1993). Therefore, in areas susceptible to eutrophication due to P, management strategies may need to be based on P rather than N, particularly for soils susceptible to surface runoff losses (Moore et al., 1995; Sharpley et al., 1996). It is, thus, essential that litter application guidelines reflect and prioritize
the risk associated with N and P based strategies to maximize resource value and minimize environmental impacts.

Litter application rates need to account for the nutrient content of the litter, the needs of the receiving crop, and processes such as N mineralization and volatilization (Edwards and Daniel, 1992). In Texas, at high soil test P levels (>200 ppm), manure application based on the P requirement of the crop is recommended (TNRCC, 1999).

Surface and subsurface applications of poultry waste are not recommended within 8m of rock outcrops, 30m of streams, ponds, lakes, sinkholes, wells, water supplies, or dwellings (Chapman, 1996). TAEX (1994) recommends limiting application to beyond 45m of any water well and 150m from sensitive areas (schools, highways, and neighboring properties).

Poultry wastes should not be applied on land with greater than 15 percent slope (TAEX, 1994; Chapman, 1996), because nutrient losses in surface runoff is directly related to slope (Aldrich et al., 1997). Nitrogen losses in surface runoff at an experimental plot with a 5 percent slope were three to five times higher than a plot with a slope of 0.5 percent (Aldrich et al., 1997).

Fall and winter applications of poultry manure should be avoided (Sims et al., 1989), because maximum leaching of nitrates occurs during late fall and winter months (Adams et al., 1994). Fall and winter applications may also result in considerable N loss via leaching early in the following year due to the combined effect of spring rainfall and minimal crop uptake of N (Sims et al., 1989). Land application should not be undertaken when soil is saturated or frozen (TAEX, 1994).

The time interval, or drying time, between application and first runoff event, may be increased in order to minimize nutrient losses in runoff (Edwards and Daniel, 1993a). Likewise, litter application should be avoided when storms are eminent (Edwards and Daniel, 1993a).

Time of application also affects forage production. Applying litter in autumn substantially increases the amount of cool season forage production, which is economical and of higher quality than warm season grass production (Evers et al., 1996).

Based on simulation modeling of three hypothetical fields, Edwards et al. (1992) identified “windows of time,” during which litter application minimized mean annual nutrient losses and maximized crop yields, however, these windows varied with location and parameter changes.

2. Filter Strips

Vegetative filter strips have a high potential for reducing nonpoint source pollution by attenuating the mass transport of nutrients from litter treated fields (Chaubey et al., 1995; Srivastava et al., 1996; 1998; Whiteside, 1996). Therefore, edge-of-field grass strips should be used to separate water courses from litter application areas (TNRCC, 1999).
3. **Buffer Zones**

In litter treated areas, riparian buffer zones can potentially attenuate NO₃-N levels in groundwater (Gburek and Pionke, 1995) and surface water (Hubbard et al., 1995) through vegetative uptake and denitrification.

4. **Tillage Practices**

Cultivated crops, as opposed to permanent grassed pastures, provide an opportunity for incorporation of litter into the soil. Minimum-till with slight incorporation immediately after application is recommended where practical (Sims, 1986). Surface application of litter without incorporation may result in losses ranging from 37 to 60 percent of the surface applied N due to volatilization of ammonia (Cabrera and Gordillo, 1995). Manure incorporation can, however, increase the soil pH to a point where manganese and zinc availability could be reduced (Sims, 1986). Additionally, at reasonably warm temperatures concurrent with nitrification in poultry manure, the pH will decrease (cause acidity) where toxicity of elements such as aluminum and manganese may be of concern (Sims, 1986).

No-till farming reduces particulate P loss but increases soluble P loss (Sharpley et al., 1996). Nonetheless, application of poultry manure before and during tillage potentially reduces surface soil accumulation of added N and P and increases distribution of nutrients in the root zone (Moore et al., 1995).

5. **Chemical Amendments**

Addition of alum and ferrous sulfate, which consists of flocculating elements such as aluminum, calcium, and iron, can substantially reduce, up to 87 percent, P concentrations in surface runoff from litter treated fields and help increase forage yields (Moore and Miller, 1994; Shreve et al., 1995). Amending poultry litter with alum can also reduce trace element concentrations in surface runoff from litter treated fields (Moore et al., 1998). Additionally, chemical amendments inhibit or minimize NH₃ volatilization by lowering the pH of litter and thus, reduce NH₃ levels in poultry houses (Moore et al., 1996).

Addition of phytase to poultry feed increases the availability of organic P in the feed by converting unavailable organic P to a form that poultry can use, and thus, reduces by 20 to 25 percent P content in the manure (http://www.agnr.umd.edu/pfiestria/agpro2.htm).

6. **Storage**

Storage methods influence the fate of N contained in livestock and poultry manure (Cabrera and Chiang, 1994; Collins et al., 1995). Significant losses of N through volatilization may occur if manure is allowed to remain on open lots for long periods of time (Collins et al., 1995). Therefore, litter storage should be roofed to prevent leaching or
surface runoff (Chapman, 1996). Additionally, poultry litter should be stored under dry conditions because losses of N through denitrification and volatilization of NH3 increases with increasing water content of the litter due to rain (Cabrera and Chiang, 1994).

7. Nutrient Management Planning

The following nutrient management guidance was compiled by Klausner (1995):

- Analyze feed and balance rations profitably.
- Manage animal-to-land ratios appropriately to prevent excessive application of nutrients.
- Determine the quantity of manure produced and collected to estimate the quantity of manure and nutrients that must be managed in land application programs.
- Analyze manure to determine nutrient content and estimate nutrient availability in manure.
- Use crop rotation and cultural practices that maximize economic feed production.
- Evaluate the hydrologic sensitivity of fields and their risk level.
- Maintain a soil-testing program to monitor the nutrient status of fields.

8. Alternative Uses of Litter

Livestock Feed

Broiler litter is more desirable as a feedstuff compared to other animal wastes for the following reasons (McCaskey, 1995):

- Higher nutrient content
- Relatively dry
- Easily stored and preserved
- Amenable to handling with conventional feed equipment
- Readily available at low cost in poultry producing areas

Litter acceptable for feeding should have <25 percent moisture, <30 percent ash, and >19 percent crude protein (McCaskey, 1995; Evers et al., 1996).

Compost

Composting of poultry litter results in a product of lower density and volume and more free of noxious odors and toxins than other manures. The composted litter may be used in nurseries, greenhouses, home gardens, landscaping, and for large land applications (Hauck, 1995). Composted litter has a lower rate of N mineralization and
thus, lowers the losses of NH$_3$ through volatilization (Brinson et al., 1994). Therefore, land application of composted litter poses a lower risk of polluting groundwater than fresh poultry litter.

**Fuel**

Litter may be used as a fuel either by direct burning or methane generation by anaerobic fermentation (Hauck, 1995).

**Application of CEEOT-LP**

Application of the Comprehensive Economic and Environmental Optimization Tool-Livestock and Poultry modeling system to poultry litter management is a logical continuation in its application to livestock issues. CEEOT–LP has been successfully applied to dairy waste management (Pratt et al., 1996; McNitt et al., 1999) and swine waste management (Norvell et al., 2000). These applications have provided insight into the benefits in nutrient load reduction obtained from various combinations of BMPs and the economic costs to the industry of these BMPs.

From an environmental perspective on nutrient losses, several modeling efforts have addressed poultry litter (Edwards and Daniel, 1993b; Edwards et al., 1992, 1994, 1996b; Yoon et al., 1994; Minkara et al., 1995; Wang et al., 1996; Srivastava et al., 1998); however, these modeling applications have had mixed success. Using the EPIC field model, Edwards et al. (1994) reported significant correlation between event predictions and observations in two of the four fields that they studied. The model, however, consistently overestimated soluble P and total P and consistently underestimated organic N (Edwards et al., 1994). In a study by Yoon et al. (1994), the GLEAMS simulation of N and P in surface runoff did not agree with field data. In addition, the model simulated higher NH$_4$-N than NO$_3$-N losses in runoff while field data showed the opposite (Yoon et al., 1994). An AGNPS single event watershed model simulation by Young et al. (1996) indicated that soils in East Texas, under current management practices and application rates (6.7-11.2 Mg/ha), may be able to accommodate large quantities of litter with minimal effects on runoff water quality.

A continuous long-term watershed assessment of water quality impacts from poultry litter management was not found in the scientific literature. CEEOT–LP provides the mechanism for conducting such a long-term watershed assessment with the inclusion of water quality implications and economic costs associated with alternative BMPs for poultry litter. Because of previous applications to dairy (Pratt et al., 1996; McNitt et al., 1999) and swine operations (Norvell et al., 2000), adaptation of CEEOT–LP to poultry operations can readily occur and will mostly involve development and refinement of the economic component. Because of a recent EPA grant to the Brazos River Authority (BRA) for the Brazos-Navasota Management Project, the Brazos-Navasota watershed of south-central Texas provides an excellent opportunity for CEEOT–LP application. The Brazos-Navasota watershed is experiencing a recent and rapidly growing broiler chicken industry. Application of CEEOT–LP to this water-
shed not only provides policy research by TIAER and its collaborators, but also gives BRA a management tool.

In order to evaluate the long-term impacts of poultry production operations on water quality, the Duck Creek subwatershed, which has the highest density of poultry houses in the Brazos-Navasota watershed, has been selected. The Duck Creek subwatershed is located mostly within Robertson County and covers an area of approximately 40,000 ha (100,000 acres). It includes a small reservoir, the Twin Oak Reservoir, which is located at the headwaters of Duck Creek. The subwatershed consists mainly of rangeland (45 percent), pasture (37 percent), and wooded areas (14 percent). The landscape is characterized by gently rolling hills, heavily wooded stream banks, and a number of small ponds in low-lying areas. There is one publicly owned wastewater treatment plant (Franklin, 0.165 MGD) in the region according to EPA’s 1996 survey of wastewater treatment facilities across the U.S (http://www.epa.gov/owm/tx1.htm). With the exception of atmospheric release of toxic chemicals, the Toxic Chemical Inventory (1987 to present) of the EPA indicates that there has not been any toxic chemical release to the surface waters in Robertson county (http://tree2.epa.gov/ceis/ceis.nsf). It, thus, appears that agricultural runoff is the main source that might potentially impair the water quality of the Duck Creek subwatershed.

In conclusion, the application of CEEOT–LP to poultry litter management is pertinent because of continued national water quality issues associated with poultry production and its wastes. The Duck Creek subwatershed of the Brazos-Navasota provides an excellent location for CEEOT–LP application as a result of relatively high density of poultry houses in the subwatershed and the high potential for increased poultry production in the subwatershed and surrounding areas. Expansion of the model from Duck Creek to the entire Brazos-Navasota watershed applies CEEOT–LP water quality management to an area with an expanding poultry industry and an expanding human population, especially around Bryan-College Station. Actual application of CEEOT–LP to poultry would occur through subsequent EPA funding.


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