Chapter 3

Poultry Manure Management

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The recent demand for low-cholesterol meat products has led to tremendous expansion in the poultry industry. In several states this rapid and concentrated growth of the industry has caused increasing concern about the disposal of poultry wastes with respect to nonpoint source pollution. Although poultry litter is one of the best organic fertilizer sources available, excessive applications of litter (as with any fertilizer source) can cause environmental problems. Nitrate leaching into the groundwater, nonpoint source P runoff into surface water bodies, and release of pathogenic microorganisms are three of the main problems encountered with improper management of this resource. The objective of this chapter is to give an overview of the current state of knowledge on the agricultural use of poultry litter and the options available to integrate litter into economically and environmentally sound management systems.

Manure Production and Composition

Poultry production in the United States is concentrated in the midsouth region. Arkansas, Georgia, North Carolina, and Alabama account for over 40 percent of national cash receipts derived from the sale of poultry products; Arkansas leads all states in both quantity and cash value of poultry products. As midsouth states are crucial to national poultry production, levels of poultry production are similarly important to the economic well-being of these midsouth states. Cash receipts from poultry and eggs constituted 45 percent and 51 percent of total 1989 farm income for the states of Arkansas and Alabama, respectively.

Litter associated with broiler production, manure generated from laying operations (hens and pullets), and dead birds are the three wastes of primary concern in poultry production (Edwards and Daniel 1992). Approximately 13 million Mg of litter and manure were produced on U.S. poultry farms in 1990, much of which (45 percent) was generated in Arkansas, North Carolina, Georgia, and Alabama (table 13). Broiler litter accounted for 68 percent of the total fecal wastes generated by the poultry industry in 1990. Although data on amounts of dead birds generated in poultry production are scarce, a 4-percent mortality rate over a production cycle is considered normal for most poultry operations (Edwards and Daniel 1992). Using this rate combined with the data in table 13 and live weights of 0.9 kg $bird^{-1}$ for broilers, 0.9 kg $bird^{-1}$ for layers, 0.7 kg $bird^{-1}$ for pullets, and 5.0 kg $bird^{-1}$ for turkeys (one-half of the live market weights, Sims et al. 1989), we calculated the weight of dead birds requiring disposal on U.S. poultry farms in 1990 to be approximately 270,000 Mg. Commonly used, approved methods of dead-bird disposal include burying in pits, incinerating, and rendering. However, co-composting dead birds with poultry litter (Cummins et al. 1992), an acceptable and desirable disposal method that produces a material amenable to land application, has become popular.

Land application offers the best solution to management of the enormous amounts of manures generated on U.S. poultry farms each year. Depending on the composition of individual poultry manures, these materials can enhance crop production via their capacity to supply nutrients and increase soil quality. Broiler litter is a mixture of manure, bedding material, wasted feed, feathers, and soil (picked up during recovery). Bedding materials are used to absorb liquid fractions of excreta. The type of material used depends on locality, but typically includes wood chips, sawdust, wheat straw, peanut hulls, rice hulls, and recycled paper products. Owing to its relatively low moisture and high macronutrient content (table 14), broiler litter is generally considered to be the most valuable animal manure for fertilizer purposes (Wilkinson 1979). Broiler litter also contains significant amounts of secondary plant nutrients and micronutrients (table 14). Chicken manure without bedding typically has an N content similar to that of broiler litter, but has higher concentrations of water, P, Ca, Mg, and Zn (table 14). It also has a higher proportion of N as ammoniacal-N, which is subject to loss via ammonia volatilization. Turkey litter typically contains similar amounts of N and P compared to the amounts in chicken litter, but has lower concentrations of K (Sims et al. 1989). Dead-bird compost is similar to broiler litter in its nutrient composition, except for its lower N content; N losses are inherent to the composting process (table 14).

Manure Management Systems

Handling systems for poultry manures encompass operations for removing manure from poultry houses,

Table 13. Number of birds and quantity of manure (dry basis) generated from them on U.S. farms in 1990, ranked according to total amounts of manure generated

	Broilers		Layers[*]		Turkeys		Total	
	Number[†] (millions)	Manure[‡] (thousands of Mg)	Number[†] (millions)	Manure[§] (thousands of Mg)	Number[†] (millions)	Manure[‖] (thousands of Mg)	Number (millions)	Manure (thousands of Mg)
Arkansas	951	1,427	15.3	52.8	22.0	239.8	989	1,719
North Carolina	540	810	12.5	53.4	58.0	632.2	611	1,496
Georgia	855	1,282	18.0	55.6	2.0	21.9	875	1,359
Alabama	847	1,270	9.5	34.1	¶	¶	856	1,304
California	231	347	29.0	136.9	32.0	348.8	292	832
Mississippi	413	620	6.1	24.4	¶	¶	419	644
Virginia	297	445	3.4	12.1	17.0	185.3	317	643
Minnesota	41	62	10.2	41.7	46.3	504.7	98	608
Texas	338	507	14.0	50.9	¶	¶	352	558
Maryland	265	398	3.3	8.6	0.1	1.2	269	408
Missouri	88	132	6.6	26.0	18.0	196.2	113	354
Delaware	232	348	0.6	1.5	¶	¶	232	349
Pennsylvania	116	173	18.7	54.3	8.4	91.9	143	320
Oklahoma	142	213	3.7	14.8	¶	¶	146	228
Florida	120	179	11.2	45.1	¶	¶	131	224
South Carolina	84	125	5.7	20.7	5.5	60.0	95	206
Ohio	21	31	17.7	74.1	4.8	51.8	43	157
Tennessee	99	149	1.1	3.6	¶	¶	100	152
Iowa	9	14	8.6	33.3	8.8	95.9	27	143
West Virginia	41	62	0.7	2.0	3.9	42.0	46	105
Oregon	24	36	2.6	11.8	2.3	25.1	29	72
Washington	33	50	5.0	21.5	¶	¶	38	71
Michigan	1	1	5.4	18.5	4.3	46.9	10	67
Nebraska	3	4	5.1	21.8	2.1	22.9	10	49
Wisconsin	14	21	3.4	18.3	¶	¶	17	39
New York	2	4	3.7	12.7	0.5	5.2	7	22
Kentucky	2	2	1.7	6.0	¶	¶	3	8
Hawaii	2	3	0.9	4.9	¶	¶	3	8
Other states	156	233	47.9	182.9	47.1	513.4	251	930
Total	5,966	8,948	272	1,044	283	3,085	6,520	13,078

[*] Includes laying hens and pullets of laying age; pullets of laying age represent 56 percent of the total number produced.

[†] Adapted from U.S. Department of Agriculture (1991).

[‡] Based on 1.5 kg litter bird^{-1} yr^{-1} (Perkins et al. 1964).

[§] Based on 7.00 kg manure bird^{-1} yr^{-1} for laying hens and 1.4 kg manure bird^{-1} yr^{-1} for pullets of laying age (Sims et al. 1989).

[‖] Based on 10.9 kg manure bird^{-1} yr^{-1} (Sims et al. 1989).

[¶] Included in totals for “other states.”

Table 14. Chemical properties of broiler litter, chicken manure, and dead-bird compost

Component	Broiler litter*		Chicken manure*		Dead-bird compost†	
	Mean	Range	Mean	Range	Mean	Range
	g kg^{-1} material					
Water	245	20–291	657	369–770	362	217–499
Total C	376	277–414	289	224–328	232	167–270
Total N	41	17–68	46	18–72	18	13–36
NH_4–N	2.6	0.1–20	14	0.2–30	0.5	0.1–1.2
NO_3–N	0.2	0–0.7	0.4	0.03–1.5	0.1	0–0.6
P	14	8–26	21	14–34	12	7–17
K	21	13–46	21	12–32	13	8–20
Cl	12.7	‡	24.5	6–60	‡	‡
Ca	14	0.8–17	39	36–60	20	11–34
Mg	3.1	1.4–4.2	5	1.8–6.6	4	3–7
Na	3.3	0.7–5.3	4.2	2–7.4	‡	‡
	mg kg^{-1} material					
Mn	268	175–321	304	259–378	355	205–600
Fe	842	526–1,000	320	80–560	3,002	807–9,530
Cu	56	25–127	53	38–68	392	48–746
Zn	188	105–272	354	298–388	318	163–539
As	22	11–38	29	‡	‡	‡

* Adapted from Edwards and Daniel (1992).
† Adapted from Cummins et al. (1992).
‡ No data.

pretreating it, and transporting it to the field. The means by which poultry manures are handled are controlled, in large part, by the moisture content of the material.

Solid poultry manure

Most broiler operations result in the production of solid poultry manure, which is referred to as poultry litter or broiler litter. Solid poultry manures contain more than 150 g dry matter kg^{-1}, which makes them amenable to solid waste handling systems (Miner and Hazen 1977). In most states, poultry litter is removed after five or six flocks of broilers, which takes about 1 yr. However, between each flock of broilers, the hard layer of manure that forms at the surface (referred to as “cake”) is removed using a “decaker.” This implement, which is pulled behind a tractor, lifts the litter off the floor, sifts it through a large mesh screen, and removes large (diameter of greater than 2.5 cm) particles. This material is then applied to land or is used in dead-bird composters as the manure source.

A total cleanout of poultry litter from production houses is typically accomplished with tractor-mounted box scrapers or blades and machinery capable of scooping the material, such as front-end loaders. Upon removal from poultry houses, this material may be directly applied to land or temporarily stored. Manure storage prior to land application, which may occur under roofed structures (dry-stack barns) or well-secured impermeable tarpaulins, allows flexibility in timing of land application (Brodie and Carr 1988). Flexibility in timing of spreading is important for synchronization of plant nutrient needs with nutrient release from poultry manure, which lessens the risk for environmental contamination when these materials are applied to land. Moreover, dry storage reduces the risk of environmental contamination as compared to the risk associated with leaving manure piles exposed.

When solid poultry manures are stored, particularly under roofed structures, they can be subjected to treatments aimed at enhancing their spreading characteristics, maintaining their nutrient composition, or altering their chemical and biological properties via composting. Solid poultry manures that are wetter than normal can be dried via static aeration or by mixing with drier materials, and this drying may be desirable from a weight-reduction or spreading perspective. Drying is particularly desirable if solid poultry manures are to be transported long distances. However, mechanical drying (using fans and/or dryers) of these materials is rarely practiced. During handling of solid poultry manure, considerable N loss from ammonia volatilization can occur. Additions of water-soluble phosphate fertilizers (excluding ammonium phosphates), which react with ammonia in manures to form ammonium phosphates, have been put forward as a means to conserve N (Mitchell et al. 1990). Additions of water-soluble phosphates to solid poultry manures increases the P concentration of the manure, which may be undesirable from an environmental perspective. Additions of aluminum sulfate to litter is probably the best method of avoiding ammonia volatilization (Moore et al. 1995a, 1996). This practice would not only decrease ammonia volatilization, it would decrease P runoff as well.

Runoff of dissolved P from fields receiving poultry litter can occur, even when best management practices (BMP’s) are used. The reason for this is that poultry litter contains high concentrations of water-soluble P (often in excess of 2,000 mg P kg^{-1}). This P fraction is readily transported in runoff water during intense rainfall events.

Recent work has shown that the level of water-soluble P in litter can be reduced by several orders of magnitude with the addition of flocculating materials commonly used in wastewater treatment and lake restoration. Moore and Miller (1994) showed that water-soluble P levels decreased from around 2,000 mg P kg^{-1} to less than 1 mg P kg^{-1} litter with the addition of aluminum, calcium, or iron compounds, such as alum, slaked lime, and ferrous chloride. These compounds not only reduce water-soluble P concentrations but also decrease suspended solids, biological oxygen demand, heavy metals, bacterial counts, virus viability, and parasites. Field studies on the effects of chemical amendments to litter have shown that treatment of poultry litter with aluminum sulfate reduces P runoff by as much as 87 percent, compared to normal litter (Shreve et al. 1995). Tall fescue yields were also found to be significantly higher when litter was treated with aluminum sulfate (Shreve et al. 1995).

Composting, which occurs naturally when nonsterile organic substrates are combined with water and oxygen, may be a desirable treatment for poultry manures or carcasses. In the composting process, aerobic microbial decomposition generates sufficient heat energy to raise the temperature of compost mixtures to the thermophylic zone (40 to 75 ^{o}C), destroying pathogenic organisms and weed seed as temperatures surpass 60 °C. Composting reduces the volume and weight of original organic substrates, and the end result of successful composting is a material that is biologically stable, odor free, and useful as a potting medium and soil amendment.

Liquid poultry manures

Liquid poultry manures (those containing less than 150 g dry matter kg^{-1}) are generated when manure is scraped or flushed into storage reservoirs, such as tanks, detention basins, aerobic or anaerobic lagoons, and oxidation ditches. Most of the liquid poultry manure is generated in laying-hen operations. Although these materials are generally amenable to hydraulic pumping, those containing between 40 and 150 g dry matter kg^{-1}, referred to as slurries, can present problems to pumping equipment because of their viscosity and potential to plug orifices (Miner and Hazen 1977). Solid-liquid separation via sedimentation or filtration may be necessary when liquid poultry manures with higher amounts of solids are to be pumped.

Although storage in reservoirs often serves to enhance hydraulic properties of liquid poultry manures with regard to ease of pumping, this can result in considerable loss of plant nutrients, particularly N. Ammonia volatilization losses from storage reservoirs range from 25 to 80 percent of original N contained in liquids or slurries (Tisdale et al. 1985). Nitrogen losses are minimized when the liquids or slurries are added to the bottom of storage reservoirs instead of to the surface (Loehr 1984).

Land Application of Manure

Except for small amounts used in animal feed, the major portion (greater than 90 percent) of poultry litter is applied to agricultural land (Carpenter 1992). This application usually occurs no more than a few miles from where the manure was produced. Thus, in states with a large or growing poultry production industry, increasing demands are being imposed on agricultural acreage to efficiently use the nutrients (primarily N and P) contained in manure. In the major poultry producing states, the amounts of nutrients produced in manure exceed crop requirements. Data compiled by National Agricultural Statistics Service (1989), indicate that the amount of P produced annually in poultry manure exceeds that required by the three major crops in several poultry producing states (fig. 12).

Poultry production is often concentrated in regions with small farms, which have very limited acreages for land application. While poultry production provides a fairly good income for these small farmers, problems created by manure use may have major environmental consequences.

Transportation

Generally, transportation of poultry litter is restricted to less than 10 to 20 km. Obviously, being able to transport the manure greater distances from the source of production increases the acreage for application. Assuming poultry litter contains respective N and P contents of 3.4 and 1.7 percent (dry-weight basis), a farmer would have to add 5 times as much poultry litter as 17–17–17 fertilizer to achieve the same N and P application rate.

Transport of solid poultry manure to the field, depending on the distance, is typically done with spreader trucks. Liquid poultry manures (slurries) may be pumped from storage reservoirs into tank-bearing vehicles for transport to the field, which requires agitation (Miner and Hazen 1977). Liquid poultry manures having less than 40 g dry matter kg^{-1} may be handled in the same manner as slurries or may be pumped directly from storage reservoirs though pipeline systems to irrigation equipment at the site of application.

The cost of moving poultry litter is a major obstacle facing the more efficient use of this resource. The recent trend of several neighboring farmers to form cooperatives to compost and compact manure more cost effectively should be encouraged by cost-sharing programs. By composting and compacting, the bulk density of the litter is increased, which reduces the cost of transportation. However, for this to be cost effective, the nutrient content of the litter should be high. Since composting can result in N loss, growers may have to add compounds, such as aluminum sulfate, to the litter to reduce ammonia volatilization during this process.

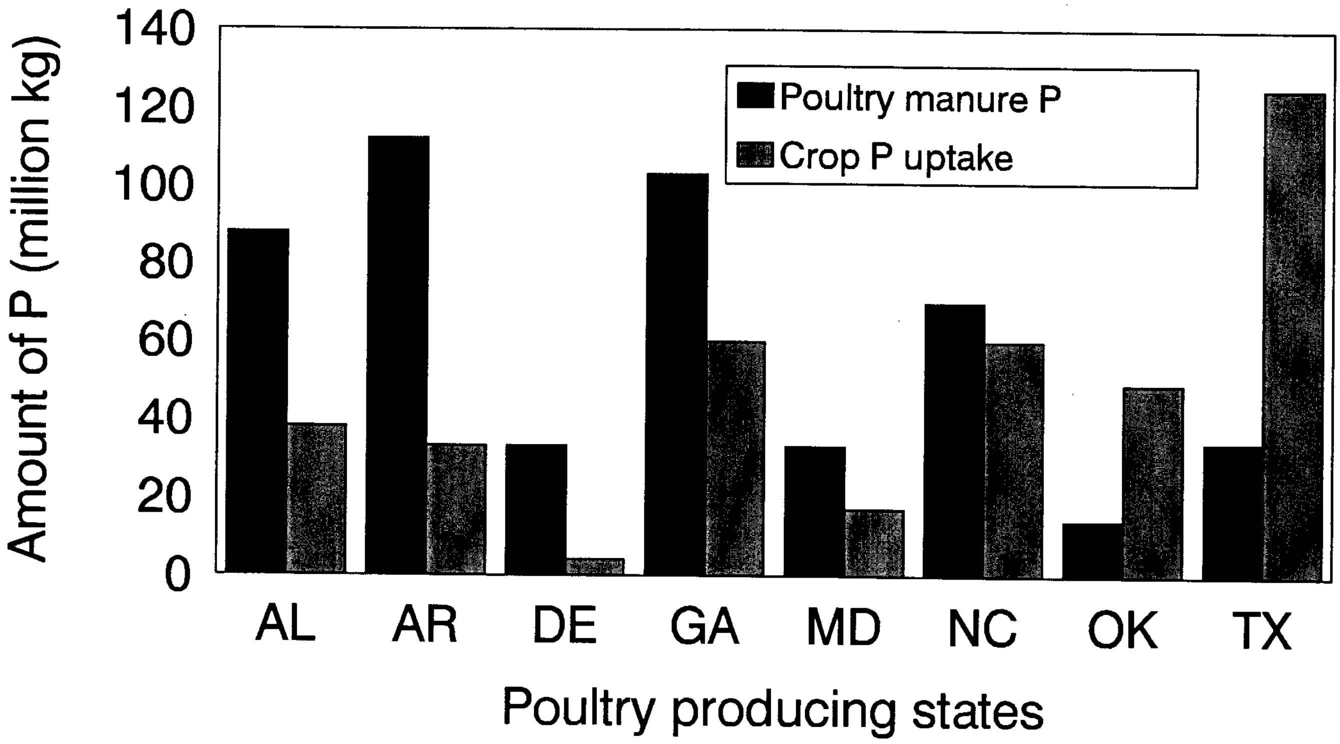

Figure. 12. Amount of P produced in poultry manure and taken up by the three major crops in several poultry producing states in 1988 (adapted from National Agricultural Statistics Service 1989)

Spreading equipment

The type of spreading equipment used depends on the method of storing and handling poultry manure. Traditionally, poultry litter is broadcast directly from the house, using a variety of spreaders. Manure stored in deep pits is removed by scraping and is applied with a spreader. In a few cases, manure stored in shallow pits is removed by flushing and, after large solids have been removed by sedimentation and/or filtration, is applied with an irrigation system. Spreading equipment can vary among contractors. In many locations where the poultry industry has recently expanded, existing farm equipment is used to apply the manure. There has been less progress in improving spreading equipment for solid manure than for liquid manure. Equipment development should involve better control of the application rate and provide even distribution of manure.

Available land base

In states where the poultry industry and/or confined animal operations are concentrated, the land base available for manure application is often limited. This limitation mainly arises from the cost of manure transportation. Consequently, poultry manure is usually applied in the immediate vicinity of the production site, with little regard to the geology, soils, or topography. This inflexibility may result in the application of litter to areas with elevated soil N and P contents from previous applications or with high runoff or leaching potentials. Consequently, in the future, recommended manure application rates should be flexible and account for differing geology, soil, and topography of potential application sites.

Proliferation of the poultry industry has been economically driven. Numerous farmers with limited resources have turned to poultry production as a ready source of income with limited cash outlay. In many areas of the southern United States, intensive poultry production has developed on agricultural land unable to maintain high crop yields due to such factors as erratic weather, sloping topography, or soils that are rocky, shallow, coarse textured, or highly permeable. Local need for N and P in such regions would be lower than in areas of intensive crop production.

The current land base for manure application is dwindling. High transportation costs for manures have led to repeated applications on fields immediately surrounding poultry farms, resulting in a buildup of N and P in soils, particularly P. Manure applications to these soils may be based on soil test P requirements rather than on crop N requirements. Currently, most manure application rates are based primarily on the management of N to minimize nitrate losses by leaching. In most cases this has led to an increase in soil P levels after successive poultry manure applications because most crops require a higher N:P ratio than that supplied in poultry manure. For example, poultry litter has an average N:P ratio of 3 (table 14), while the N:P requirement of major grain and hay crops is 8 (White and Collins 1982). Soils receiving repeated applications of poultry litter for several years accumulate more P then N and have more P than the crop can use (Sharpley et al. 1991a, Sims 1992, Wood 1992).

Basing litter application rates on soil P levels rather than on crop N requirements may mitigate the excessive buildup of soil P and at the same time lower the risk for nitrate leaching to groundwater. However, such a strategy for determining proper litter rate would eliminate much of the land area with a history of continual litter applications, since many years are required to lower soil P levels once they reach excessive levels (Kamprath 1967, Wood 1992). In addition, farmers relying on poultry litter to supply most of their crop N requirements will have to purchase commercial fertilizer N instead of using their own manure N. Although basing rates on soil test P may resolve potential environmental issues, it places unacceptable economic burdens on farmers, that is, the cost associated with transporting the manure and buying additional fertilizer N are too high.

Hydrology of the available land base will also be important in determining whether manure application rates should be based on N or P. If the potential for leaching of soluble chemicals from an application site exists, one could argue that N should be a priority management consideration. Conversely, if runoff and erosion potential far exceed leaching potential, then P would be the main element governing application rates.

As the poultry industry continues to grow in areas where poultry production is already high and where the land base suitable for agronomically and environmentally sustainable manure applications continues to decline, manure will, by necessity, be moved outside of these intense poultry producing areas. Research in Alabama, Arkansas, and Oklahoma is evaluating appropriate application rates and cultural practices for poultry litter as a nutrient source for field crops (corn, cotton, rice, sorghum, and wheat) and bermudagrass (coastal and midland). The major obstacle to using this manure on these crops in non-poultry-producing areas continues to be the cost of transport.

Tillage effects

Application of poultry manure before or during tillage will reduce surface soil accumulation of added N and P and increase distribution of these nutrients in the root zone. If a ground cover can be maintained during times of the year when runoff-producing rainfall is common, environmental risks will be reduced while crop use of N and P will be increased. Preliminary research in Arkansas and Oklahoma using simulated rainfall on soil receiving poultry manure indicated that soil incorporation of manure with tillage reduced N and P loss in surface and subsurface runoff compared to broadcast applications. This effect was attributed to a dilution of manure N and P in the depth of tilled soil.

However, there are two main disadvantages to tilling manure into the soil. First, the time frame for manure application will be restricted to the time frame needed for tillage operations. Second, labor requirements in the short time available for seedbed preparation are increased and can sometimes delay sowing and increase weed problems.

The use of manure on grassland without tillage can be reasonably efficient, especially in areas with a humid climate. This is probably because grass species can use N and P from the manure throughout the whole growing season.

Soil and manure testing

There are many variables associated with poultry management systems that can affect manure quality at the time of application. These include the type and amount of bedding material used, accumulation time, feed, amount and quality of water used to flush the house, location in a storage pit from which the manure is removed, and length of storage before land application. All of these factors can have a big effect on the nutrient composition of the manure applied (Edwards and Daniel 1992). As a result, farm advisors and extension agents in several states are recommending that the N and P composition of both manure and soil be determined by soil test laboratories before manure is applied to land. These tests should be helpful to farmers because there is a tendency to underestimate the nutritive value of manure. Thus, manure analyses are a constructive educational tool for farmers, showing them that manure represents a valuable source of N and P.

In those states where manure analyses are conducted, total N, NH_4–N, and moisture content are generally determined in the analyses. With the use of more sophisticated analytical equipment allowing multi-element analysis in soil test laboratories, total P, K, and other nutrients can also be determined and reported to the farmer upon request. Since most of the N and P in poultry manure is in organic forms (Edwards and Daniel 1992, Wood and Hall 1991), much of the N and P is not immediately available to plants. Thus, for maximum crop production, N and P application rates based on total nutrient content may need to be greater for manure than inorganic sources.

Manure application based on total nutrient content should be adjusted to account for nutrient availability in the soil. Nitrogen availability is related to mineralization of organic N (usually 50 to 60 percent of the organic N fraction) and recovery of added NH_4–N. This availability may be adjusted further to account for the effect of storage time on N mineralization and volatilization and of soil type on NH_4–N fixation. It is generally assumed that 75 to 80 percent of added total P and all of the added K is plant available. A cautionary note to basing application rates on manure analyses must be sounded because of the wide variability in nutrient contents that can be obtained. For example, variabilities associated with sampling the manure alone can be 10 to 15 g N kg^{-1} manure. This could amount to a 25 percent overestimation or underestimation of N content. Thus manure analysis should be used as a guideline only.

Current soil test methods represent, for the most part, plant available inorganic N and P levels in soil. Because of the high organic N and P content of manure, soil test recommendations for manure application rates must account for the mineralization of organic nutrients during the growing season. In addition, poultry manure can provide plant-available N and P for several years after application. Thus, soil tests must also account for the residual effects of poultry manure, possibly resulting in a reduction in application rates in years following initial applications. In many instances it is difficult to account for differences that are due to variable soil, climate, and cropping conditions encountered.

Cost-effective best management practices (BMP's) Poultry manure is a valuable natural resource if managed properly. In many areas of intensive poultry production, manure applied on hilly land has increased vegetative cover, thereby reducing runoff and erosion potential. These unproductive soils would not normally receive mineral fertilizer; thus, the careful use of poultry manure can reduce environmental degradation.

Before poultry manure is used, the producer should consider which BMP's are needed, based on the crop being grown, timing of application, land base available, and previous applications. Crop type and yield will affect the amount of N and P removed from the production system when the crop is harvested (fig. 13). Obviously, the accumulation of manure N and P within an agricultural system will be reduced if the nutrients are removed from the farm in the harvested crop.

Alternative Uses of Poultry Litter

Poultry litter, when mixed with feed grains, has been used as a successful feed for cattle. Approximately 4.2 percent of the poultry litter produced in the United States is fed to cattle (Carpenter 1992). In some states, high-quality poultry litter (20 percent crude protein and less than 10 percent ash) can be worth as much as \$99 Mg^{-1} as feed whereas the same litter may only be worth \$33 Mg^{-1} as fertilizer (Payne and Donald 1992).

Although disease problems have not been reported from feeding manures to animals under acceptable conditions, copper toxicity has been reported to be a problem in sheep (Fontenot et al. 1971). The poultry litter contained 195 mg Cu kg^{-1} because the chickens had been fed a diet containing high levels of copper sulfate. Currently, most poultry producers feed their broilers an excess of copper sulfate. Although this excess results in faster weight gains, the gains are not due to a change in diet per se, but rather to a change in litter composition (Johnson et al. 1985). There are two possible explanations for this phenomenon: (1) the high copper levels in the litter reduced populations of pathogenic microorganisms or (2) nonbiologically mediated reactions, such as ammonia volatilization, are affected. It should be noted that not all broilers respond positively to this excess of copper in the diet.

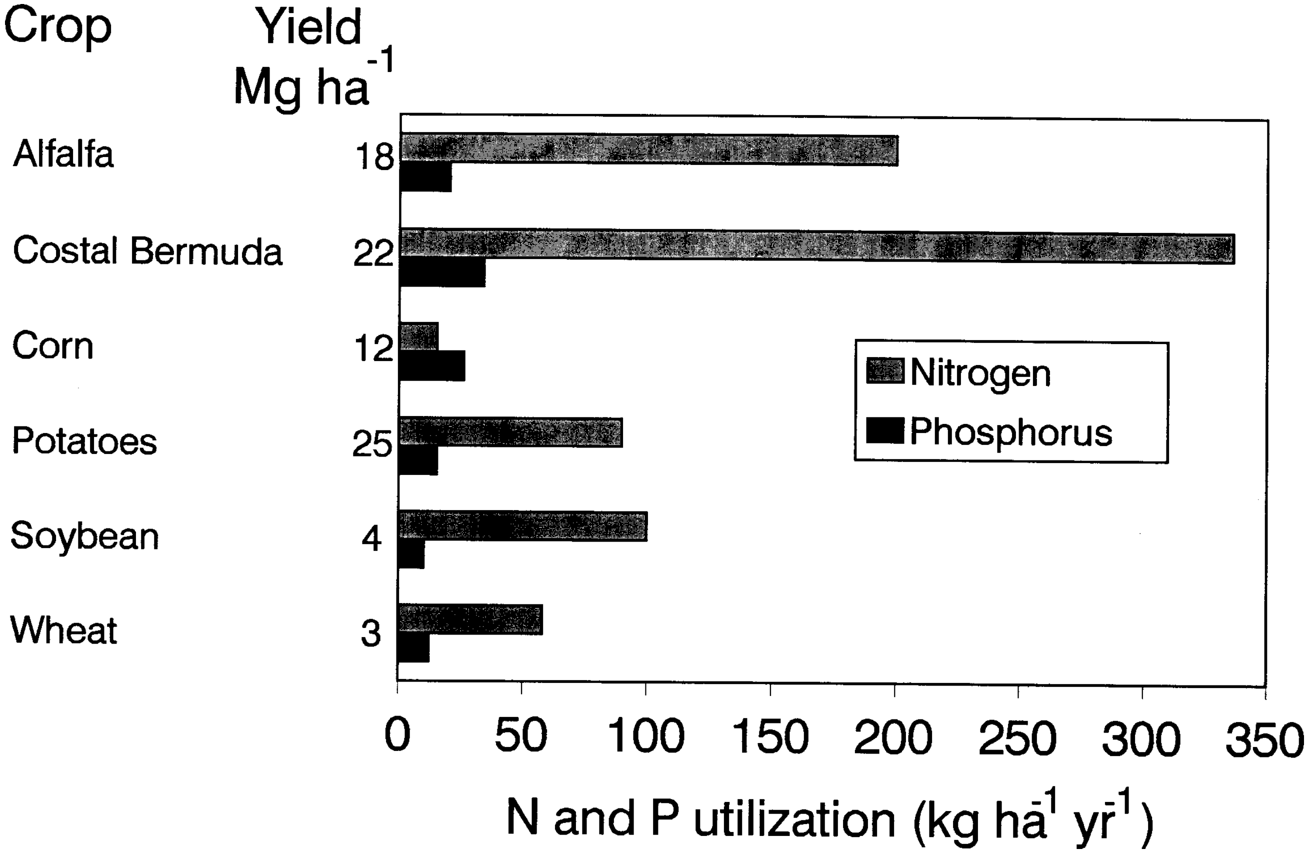

Figure 13. Approximate annual N and P use by several crops (adapted from White and Collins 1982)

Wideman et al. (1995) showed that high copper levels in broiler diets can lead to proventriculitis, a malady characterized by necrosis and enlargement of the proventriculus (glandular stomach). When these birds are processed, the proventriculus ruptures easily during evisceration, contaminating the carcass with stomach contents.

It is important to remove any foreign materials such as wire, plastic, or glass from the litter before it is used for feed. It is also important to maintain a low ash content. When large quantities of soil are removed with the litter, the ash content increases dramatically. Litter with ash contents exceeding 28 percent should not be fed to cattle.

Poultry litter can also be sold to nurseries and garden stores as an organic soil amendment for homeowners. However, at present the amounts sold in this manner represent much less than 1 percent of the total litter produced. Poultry litter may also be used to produce electricity. A power station using poultry litter became operational in Suffolk, England, in 1992. The power plant cost approximately $35 million and uses 10,000 Mg of litter per year from the area's poultry farms.

Agronomic and Environmental Effects of Poultry Manure Application

Effects on soil properties

In addition to providing nutrients for crop production, poultry litter applications build soil organic reserves. The organic matter benefits crop production via increases in soil water-holding capacity, water infiltration rates, cation exchange capacity, structural stability, and soil tilth. Weil and Kroontje (1979) found that high rates of poultry manure, when incorporated into the soil, resulted in decreases in bulk density and increases in water-holding capacity and water-stable aggregates. Kingery et al. (1993) showed that litter applications resulted in increased organic C and total N to depths of 15 and 30 cm, respectively.

Metals, such as As, Cu, and Zn, are often fed to poultry. This results in average concentrations in the litter of 22, 56, and 188 mg of the three metals kg^{-1}, respectively (table 14). Kingery et al. (1993) found elevated levels of K, Ca, Mg, Cu, and Zn in soils heavily fertilized with poultry litter. Elevated levels of heavy metals in the soil will result in increased uptake by plants, which will be consumed by animals or man. However, normally concentrations do not reach toxic levels. High levels of heavy metals, particularly copper, in the water-soluble fraction of litter can also lead to high concentrations of these metals in runoff water from pastures fertilized with poultry litter. Moore et al. (1995b) found that treating poultry litter with aluminum sulfate significantly decreased heavy metal concentrations in runoff water from tall fescue plots fertilized with poultry litter.

Effects on soil fertility

Poultry litter is generally considered the most valuable of animal manures for use as a fertilizer, due mainly to its low water content. As mentioned earlier, poultry litter contains large amounts of N, P, and K as well as secondary and trace elements. Under certain conditions, however, various salts can build up from excessive poultry litter applications. Soil salinity attributed to poultry litter applications has occasionally been shown to reduce germination and growth of corn (Shortall and Liebhardt 1975, Weil et al. 1979). However, it should be pointed out that poultry litter has long been recognized as an ameliorant to salt-affected soils. Research by Hileman (1973) showed that poultry litter promotes growth on brine-contaminated soils in south Arkansas.

Stephenson et al. (1990) found that the average fertilizer equivalent of poultry litter was 3–3–2 (3 percent N, 3 percent P_2O_5, and 2 percent K_2O) when determined on an "as spread" basis. Poultry litter also contains substantial quantities of B, Ca, Cu, Fe, Mg, Mn, S, and Zn.

Nutrient imbalances in forages due to excessive poultry litter applications have been observed. Grass tetany in ruminants, which is related to the ratio of K to Ca plus Mg in forages, appears to be more likely on soils that receive excessive rates of poultry litter (Wilkinson et al. 1971), possibly due to high K levels in the litter. Therefore, application rates for poultry litter should be limited to 9 Mg ha^{-1} or less for use on tall fescue.

Poultry litter can also be a valuable amendment for rice soils that have been leveled by grading. Miller et al. (1991) showed that rice yields increased as much as 286 percent with poultry litter additions. Although they saw some yield responses when inorganic N, P, K, S, and Zn fertilizers were added at the same rate, these responses did not match those resulting from poultry litter.

Effects on water quality

The customary method of land application for poultry litter is broadcasting without incorporation. However, the same nutrients that make poultry manure a good fertilizer can, under some circumstances, be detrimental to the quality of groundwater and downstream surface water. The potential for water quality degradation from nutrients responsible for eutrophication (N and P), oxygen consumption (organic carbon), and metal toxicities is of particular interest in areas such as northwest Arkansas, where shallow, cherty soils and karstic geology greatly increase the interaction between surface water and groundwater.

One of the primary health concerns with excessive poultry litter applications is nitrate leaching into the groundwater. The U.S. Environmental Protection Agency limits nitrate concentrations in drinking water to 10 mg NO_3–N L^{-1}. Liebhardt et al. (1979) found that excessive applications of litter to corn resulted in nitrate leaching through the profile and elevated nitrate levels in groundwater. Ritter and Chirnside (1982) indicated that 32 percent of the water wells in Sussex County, Delaware, had high nitrate levels (>10 mg N L^{-1}) due to improper poultry litter applications.

Kingery et al. (1993) found that long-term applications of poultry litter at relatively high rates resulted in a buildup of nitrate in the soil to a 3-m depth or to bedrock (fig. 14).

From a surface water viewpoint, P is the element of primary concern, since it is generally considered to be the limiting nutrient for eutrophication. Excessive applications of poultry litter to soils result in a buildup of P near the soil surface. Kingery et al. (1993) observed soil test P levels as high as 225 mg P kg^{-1} soil in soils that had long-term applications of poultry litter at relatively high rates (fig. 14).

In a similar study of continual long-term poultry litter application to 12 Oklahoma soils, Sharpley et al. (1993) found that P accumulated in the surface meter of treated soil to a greater extent than N. This reflects the differential mobility, sorption, and plant uptake of N and P in soil.

The movement of soluble and sediment-bound (particulate) P can be predicted using kinetic and enrichment-ratio approaches. Sharpley and Smith (1993) used these approaches to estimate the P concentration

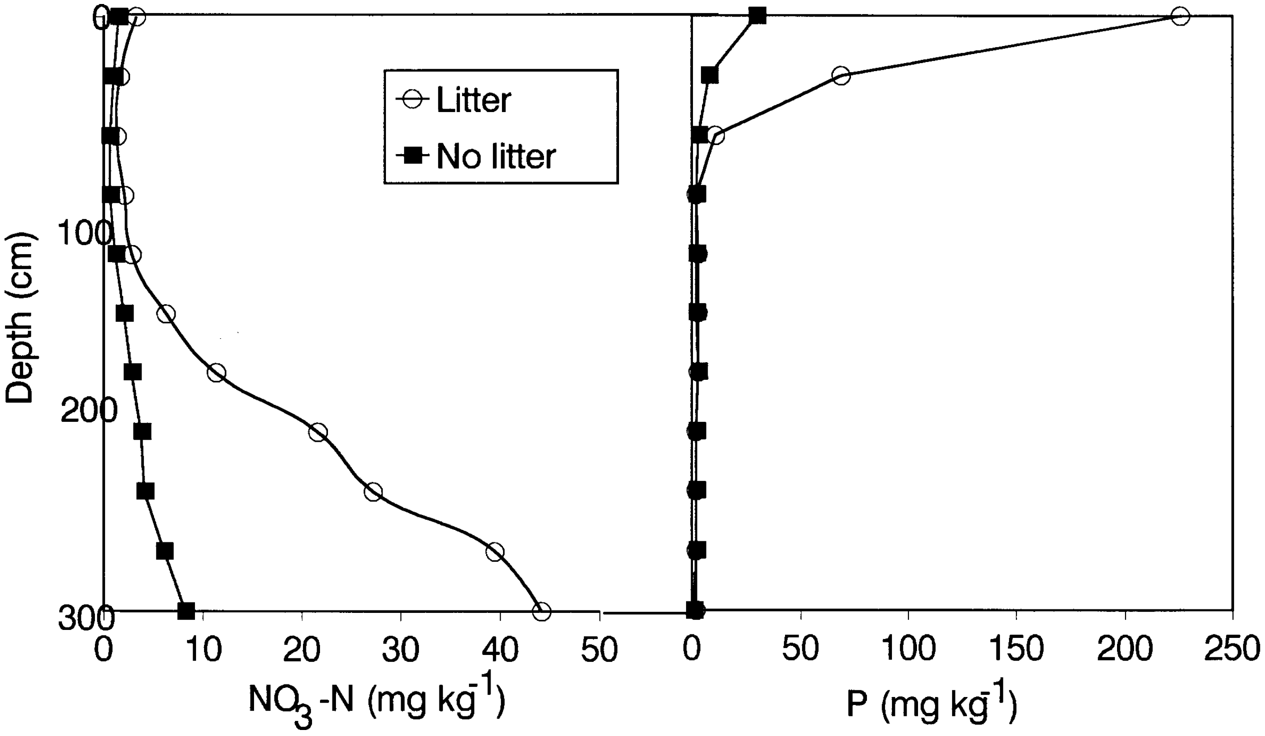

Figure 14. Average soil NO_3–N and extractable P concentrations for 12 pasture pairs in the Sand Mountain Region of Alabama that have received either long-term applications of broiler litter or no litter (Source: Kingery et al. 1993)

in runoff water from a 2.5-cm runoff event (10 kg ha^{-1} yr^{-1} soil loss) for grasslands in Oklahoma. Predicted P concentrations in runoff water from three soils treated with poultry litter were much greater than from untreated soils (fig. 15). On grasslands, erosion is minimal, and thus about 80 percent of the P is transported in a bioavailable form (soluble and NaOH-extractable particulate P available for algal uptake). These concentrations are approximately two orders of magnitude greater than values associated with eutrophication (0.01 and 0.02 mg P L^{-1} soluble and total P, respectively) (Sawyer 1947, Vollenweider and Kerekes 1980). The potential increase in P transport in runoff highlights the need for careful management of surface soil accumulations of P as a result of poultry litter applications on soil susceptible to runoff and erosion.

In Tennessee, Green and Bucham (1992) sampled well water on poultry farms and found that 43 percent of the wells sampled contained fecal coliform bacteria and 8 percent of the wells exceeded 10 mg NO_3–N L^{-1}. They found that well location was an important factor with regard to contamination and indicated that wells should be at least 15.2 m from chicken houses and 30.4 m from stacked broiler litter.

Poultry wastes are known to contain many pathogens, which could potentially contaminate both surface water and groundwater resources. Alexander et al. (1968) tested 44 poultry litter samples for the presence of pathogens. They found 10 different species of *Clostridium*, 3 species of *Salmonella*, 2 species of *Corynebacterium*, 1 species of yeast, and 1 species of *Mycobacterium* (which is occasionally responsible for tuberculosis) in various litter samples. All of the litter samples contained Enterobacteriaceae (other than *Salmonella*), *Bacillus* spp., S*taphylococcus* spp., and *Streptococcus* spp. In Arkansas, the Nation's leading poultry producing state, 90 percent of the surface water bodies (statewide) sampled by the Arkansas Department of Pollution Control and Ecology con-

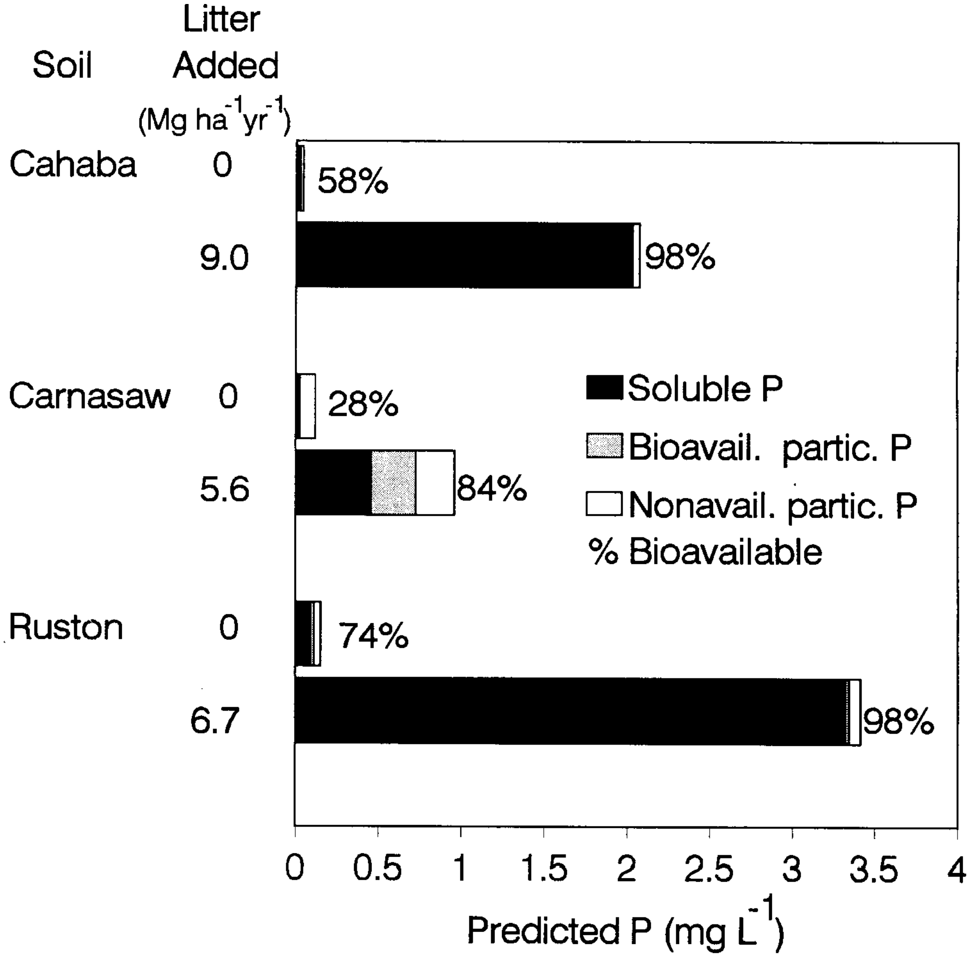

Figure 15. Predicted soluble, bioavailable particulate, and nonavailable particulate P in runoff from grasslands receiving poultry litter. Litter applications were made annually for 12 years to the Cahaba and Ruston soils and for 20 years to the Carnasaw soil.

tained fecal coliform counts in excess of the primary contact standards. However, fecal coliform counts prior to the rise in poultry in this state are not available. Therefore, it is unknown whether these levels are indigenous or, in fact, due to runoff from animal manures.

Viruses have also been reported in poultry litter and may represent a greater threat to water resources than bacteria. These include viruses responsible for newcastle disease and Chlamydia (Biester and Schwarte 1959). At present, very little information on virus runoff from fields receiving poultry litter is available.

Effects on air quality

The number one complaint against animal growers received by state and Federal environmental regulatory agencies involves odor problems (Williams 1992). Much of the odor is due to high levels of ammonia. Volatilization of ammonia results in decreased poultry productivity due to an increase in the incidence of ascites and other respiratory related maladies, such as newcastle disease. Ammonia volatilization also results in tremendous losses of N that could otherwise be used for fertilization of pasture or cropland. Wolf et al. (1988) found that 37 percent of the total N applied on the surface of a pasture was lost via volatilization after only 11 days. With the inclusion of in-house losses, this figure would increase to well over 50 percent of the total N. Another reason ammonia volatilization is detrimental is the negative impact it has on the environment with respect to acid rain (van Breemen et al. 1982, Ap Simon et al. 1987). Another air pollution problem aggravated by ammonia loss from poultry manure is the formation of airborne particles of NH_4NO_3, which contribute to PM_{10}s (particulate matter less than 10 μm in diameter).

The human nose can detect atmospheric ammonia concentrations as low as 5 $\mu L\ L^{-1}$, and some people are susceptible to eye irritation at levels as low as 6 $\mu L\ L^{-1}$. Currently OSHA has not set exposure levels for U.S. poultry workers; however, in Europe the COSHH (Control of Substances Hazardous to Health) has determined exposure limits to humans at 25 $\mu L\ L^{-1}$ for an 8-hr exposure and 35 $\mu L\ L^{-1}$ for a 10-min exposure (Williams 1992). As mentioned earlier, aluminum sulfate has been shown to be extremely effective in reducing ammonia volatilization from poultry litter (Moore et al. 1995a, Moore et al. 1996).

Effects on crop production

Poultry litter and manure have increased yields in many different crops, such as bermudagrass, corn, fescue, orchardgrass, rice, and wheat (Miller et al. 1991, Edwards and Daniel 1992, Wood 1992). Most of the yield increases have been reported to be due to the N content of the litter; however, the response in rice on graded soils that occurs in Arkansas cannot be duplicated with inorganic N, P, K, S, and/or Zn (Miller et al. 1991).

Improving Management of Poultry Manure

Education and technology transfer

Technology transfer in production agriculture has become a fairly familiar process. For example, if a new herbicide is developed, it will undergo field testing by industry and universities, and if proven successful, information on the herbicide will be made available through a variety of mechanisms, including field days, extension brochures, industry field personnel, published journals, and other outlets. A tried-and-proven infrastructure exists for getting the proper information to the potential user in an efficient and timely manner. Equally important, most everyone is aware of the target audience—in this case the growers.

The infrastructure for transfer of technology relating to nonpoint source pollution, especially with regard to poultry waste management, is not as highly developed as that for production agriculture. Researchers in this area can and should become involved in the technology transfer process. For proper planning and conduct of research, the researcher should have input and an ongoing dialogue with every player, including industry personnel, state and Federal agencies, and ultimately the grower. As information is generated, these same players must be informed of developments. The initial target audience for this information is the professionals working in the water quality area, especially those agency professionals deciding which practices will be identified as a BMP. The first step for researchers is to establish scientific credibility of their work by publishing it in journals and presenting it at scientific meetings. Concomitant with the first step, this same information needs to be repackaged and transferred to state and Federal agency personnel working in the water quality area. Information transfer to this group may take several avenues, including workshops, brochures, and seminars. A parallel process needs to occur with representatives of the poultry industry and selected growers. This is a necessary, time-consuming, and dynamic process of identifying a series of BMP's.

Ultimately, the information must be disseminated to the end user or grower. The USDA's NRCS and Cooperative State Research Education and Extension Service provide the critical link between farmers and public agencies. The Extension Service has the primary responsibility of information dissemination to farmers. The USDA–NRCS is the technical arm at the county level that incorporates the BMP's into the farm plan.

Best management practices (BMP's)

The concept of BMP's was introduced in Public Law 92–500, which outlined several rigorous requirements for a practice to qualify as a BMP. The BMP must relate directly to water quality and must be cost effective. This requirement makes it necessary to place a dollar value on water quality. For example, the benefits of a practice that controls animal manure runoff near a trout stream are easier to evaluate than the benefits of implementing the same practice near a less sensitive water resource. Until alternative methods are developed, the process for assessing benefits and cost effectiveness will continue to be decided on a case-by-case basis. Other requirements of BMP's are that they must be acceptable to the grower and must provide economic returns to the grower (otherwise volunteer adoption will be low).

Adverse impacts resulting from land application of poultry manure may be prevented by implementing of effective BMP's. Examples of recommended BMP's include using buffer zones between treated areas and waterways, adding aluminum sulfate to litter between successive flocks of birds to precipitate soluble phosphate, applying litter when there is a low likelihood of rainfall in the near future, and incorporating litter when conditions permit.

Most specialists will agree that implementation of a combination of practices adopted as "best" will, in fact, have a positive effect on quality of runoff from areas treated with poultry litter. However, it is often difficult to determine the effectiveness of individual practices because supporting data can be limited. A lack of data on BMP effectiveness makes it difficult to quantify the water quality effects of BMP implementation and may therefore cast doubt on the appropriateness of policies and the recommendations developed by decision-making organizations. BMP's are available now that will protect and maintain water quality; others are in the process of being developed and field tested. Some of the recommended practices were initially used for erosion control and have been around for some time, while others are new and were designed specifically for protecting water quality.

These practices focus on controlling the problem at the source, rather than after entry into the aquatic system. Example practices include limiting manure application rates, applying manure only on certain slopes, and applying manure only at a certain time of year. Runoff losses of soluble P are affected by land application of commercial fertilizer and animal manure, and the amount lost in the runoff is directly related to how the materials are managed (Baker and Laflen 1982, Logan 1991). These losses are often linearly related to application rate, with the greatest losses of P occurring when the fertilizer or manure is broadcast and not incorporated (Baker and Laflen 1982, Westerman et al. 1983, Mueller et al. 1984). Rainfall intensity and soil type were also shown to significantly affect the amount of total solids transported. McLeod and Hegg (1984) investigated impacts of different fertilizers (organic and commercial) on runoff quality and reported minimal nutrient losses (less than 4 percent of the total Kjeldahl N and less than 2.5 percent of the total P). The highest nutrient losses occurred on plots treated with commercial ammonium nitrate. Giddens and Barnett (1980) showed that high application rates of poultry litter drastically reduced the volume of runoff water and soil erosion but increased the coliform bacteria in the runoff.

Timing manure applications to coincide with maximum crop uptake and minimum runoff potential will enhance crop use of manure. In Arkansas, computer simulations have shown that windows for optimal timing of application of manure exist (Edwards et al. 1992). However, demands on farmer's daily schedules and use of independent contractors often limit the practicality of precise timing of manure applications. As a result, application timing is possibly the greatest obstacle to better manure management, with many BMP's needing to be done at the busiest times of the year for farmers.

Moving poultry litter to areas where soil N and P levels are low would not only improve crop production but would decrease the likelihood of environmental problems associated with excess litter. In Arkansas, the poultry industry is concentrated in the northwest section of the state in the Ozark Highlands. However, most of the row crop agriculture is located in the eastern portion of the state in the Mississippi Delta. Transporting the litter from the Ozarks to the Delta appears to be one solution to the current problem. However, the cost of transportation is prohibitive unless the government or the industry provides subsidies for such a program.

Various investigators have shown that the level of soil test P also influences the concentration and eventual loss of soluble P in runoff. In fact, a highly significant linear relationship has been demonstrated between the level of soil test P in the surface soil and soluble P concentration of surface runoff (Hanway and Laflen 1974; Romkens and Nelson 1974; Sharpley et al. 1978, 1981; Oloya and Logan 1980). One BMP that several states have implemented is an upper cutoff level for soil test P, above which the grower would not apply P from any sources, including animal manures.

Buffer strips, also referred to as vegetative filter strips and buffer zones, have a proven record of effectiveness in reducing nutrient runoff from fields fertilized with manure. For example, buffer strips installed below cattle feedlots have proven effective in reducing transport of both N and P. Doyle et al. (1977) found that a 4-m fescue buffer zone reduced concentrations of dissolved P by 62 percent and nitrate by 68 percent. Young et al. (1980) observed total N and P reductions of 88 percent and 87 percent, respectively, for a 30-m orchardgrass buffer zone. A sorghum-sudangrass mixture buffer zone performed similarly, with 81 percent and 84 percent reductions in total N and P, respectively. Chaubey et al. (1995) found that 21.4-m vegetative filter strips reduced the mass transport of TKN, ammonium, TP, and PO_4-P by 81, 98, 91, and 90 percent, respectively, from plots fertilized with poultry litter.

Another BMP that has been shown to reduce nutrient runoff from fields fertilized with poultry litter is the addition of aluminum sulfate (alum) to the litter. Alum additions to manure reduce soluble P levels in the litter (Moore and Miller 1994), which results in significantly lower P concentrations in the runoff water (Shreve et al. 1995). Alum also reduces ammonia volatilization from poultry litter, resulting in higher N concentrations in the litter and therefore contributing to significantly higher crop yields (Moore et al. 1995a, 1996; Shreve et al. 1995).

Soluble P in soils that test high in P can also be reduced using chemical amendments. Peters et al. (1995) found that soluble P levels in soils that had received excessive manure applications could be reduced with the addition of alum sludge (a waste product from drinking water treatment plants), bauxite red mud (a waste product from aluminum mining), and cement kiln dust.

Program implementation, agency interactions, costs, and benefits

Ensuring compatibility between poultry manure use and water quality requires a continued and long-term commitment from industry, citizens, and public agencies. To assure a favorable cost-benefit ratio, priority watersheds should be selected to focus sparse implementation funds and expertise. Such watersheds can be selected on a regional, state, or local basis. The criteria for selection should be based on severity of the problem and the benefit to water quality. The complexity of the issue means that management programs will not be easy to establish or maintain. It is also clear that the concept of zero discharge is not workable. In many cases, we may only be able to maintain lakes and streams in their present state and not improve their water quality; we can simply keep them from deteriorating further. The inherent fertility of other aquatic systems may have progressed to such an extent that no improvement is guaranteed regardless of funds expended.

Although BMP’s are being developed for dealing with poultry manure, institutional mechanisms for implementing this technology need improvement. In the past, cost-sharing programs generally focused on support of production practices, but recently many programs also support practices that protect water quality. Changing the tax laws is another approach that might accelerate implementation of environmental technology. Voluntary adoption and dissemination of new technologies that protect water quality will only be possible if agricultural producers can be convinced that the adoption of these practices is in their best interest. Dissemination of information on the relative profitability of management options and the importance of agriculture’s role in water quality protection will be essential. The successful design of environmentally sound management practices must be coordinated with the institutional mechanism developed to promote adoption. Successful programs will emphasize management, control of the problem at the source by implementation of BMP’s, and, perhaps most of all, informal planning sessions between the USDA–NRCS field technician and the grower to produce a field-by-field farm plan that protects water quality.

Sociological benefits

As the human population continues to grow, ever increasing strains are placed on natural resources. Recently, there has been an increased awareness of the pressures being placed on the environment from human activities. Sustainable agriculture appears to be one important means by which we can minimize the impact of food production on the environment. The use of animal manures for fertilization of crops will decrease the amount of inorganic fertilizers needed. This will conserve fossil fuels that are needed to produce these products and should also improve the fertility status of soils by providing a well-balanced fertilizer and by increasing soil organic matter. Also, if more nutrients in manure are recycled through agricultural crops, less of these nutrients will escape to the environment and result in environmental degradation.

Research Needs for Poultry Manure Management

Historically, strategies for land application of animal manures have been based on meeting the N needs of the crop being produced. Although this approach can be justified on the basis of groundwater protection, there is little basis for this approach for surface water protection, since eutrophication of freshwater systems is normally limited by P. Therefore, the question as to whether poultry litter applications should be based on P loading, rather than N loading, has arisen. Research is needed to determine when litter application should be based on N and when it should be based on P.

Soil test P levels clearly influence soluble P concentrations in runoff water from agricultural fields. Thus, fundamental and applied research is needed regarding the critical level above which additional P should only be applied with limitations. Information is needed as to how this critical level will vary with soil types, slope, crops, and management.

Use of critical soil test P levels should be applied at a watershed level rather than at the farm level because P losses are rarely uniformly distributed within a watershed (that is, critical P-contributing areas exist due to land use and natural processes). In addition, the watershed is the logical unit for correlating land use with the impacted water body. To aid in developing a cause-and-effect relationship, runoff models need to be refined to better account for P losses from various land-use scenarios.

The traditional methods of analysis for P in the soil should be reviewed in light of the move to sustainable agriculture and conservation tillage. Under these systems and where land application of manure is practiced, the pool of soil P appears to be changing (Pierzynski et al. 1990, Sharpley et al. 1991a), and this may not be reflected by the traditional soil test. In some cases, soil test results may unnecessarily suggest the addition of P without a possibility of P response due to crop needs being met by mineralization of organic P.

From a water quality standpoint, methods for analyzing runoff are needed that determine the amount of algal-available P in soluble and adsorbed form. Methods such as those outlined by Sharpley et al. (1991b) that identified bioavailable P (BAP) should undergo wider testing by researchers and appropriate agencies. Additionally, some method of relating soil test P to water quality is required. Investigations that examine the relationship between quick tests for soil, labile, and algal-available P should be encouraged (similar to those investigations by Wolf et al. 1985).

Future research should be directed towards understanding the dynamics of different P fractions (soluble, particulate, and especially bioavailable P) transported in runoff and their dynamics in lakes. This research should focus on the mechanism of exchange between sediment and solution P. With the accumulation of fertilizer and residual P at the soil surface, the relative importance of the present partitioning processes may need to be reevaluated. In particular, more accurate simulations of residual soil P release are needed. With the move to low-input agriculture, these improvements will enable evaluation of P transport in runoff from soils with high residual P levels in the absence of additional P inputs.

Although many models are available, it is often difficult to select the most appropriate model to obtain the level of detail of information required. Once the appropriate model is chosen, a major limitation is often the lack of input data to drive the model. This most frequently limits model use, and output will only be as reliable as data input. Because of these limitations, more research should be directed to development of a soil index to identify soil and management practices that may enrich the bioavailable P content of surface waters.

Land management programs that minimize P losses in runoff are needed. While models can provide some direction, the resource manager needs a practical method for handling P such that loss is minimized. Such a program should involve the amount of P in the soil and manure, soil chemical and physical properties, slope, management, time of year, etc. Efforts similar to those by the Phosphorus Index Core Team (PICT), sponsored by USDA–NRCS, should be encouraged.

More applied work is needed on evaluating water quality impacts of existing poultry manure management practices. Additionally, efforts toward developing innovative new practices should be encouraged. For example, Edwards et al. (1992) examined the best time of year to apply broiler litter from a water quality standpoint. Certain times of the year were clearly better than others. Future research for determining the ideal timing of manure applications should balance the timing of nutrient requirements by the crops with the cleanout schedule of the animal rearing facilities.

More research is needed on P precipitation in manure utilizing Al, Ca, and Fe compounds, such as aluminum sulfate. Research is needed to determine which chemical amendment will transform phosphate in poultry manure to an insoluble mineral that is stable for geological time periods. If P runoff can be controlled in this fashion, then application rates of poultry manure could be based upon N loading. The compounds used for P precipitation should also inhibit ammonia volatilization, hence conserving N and decreasing the threat of acid rain.

Runoff studies focusing on the movement of microorganisms from land-applied poultry litter into adjacent water bodies have not been reported in the literature. High counts of indicator organisms, such as those found in the streams and rivers of Arkansas, indicate the possibility of a potential health hazard that so far has received very little attention. Research needs to be conducted on the types and amounts of organisms reaching water bodies from land application of poultry manures and on developing BMP’s to deter such movement. The use of filter strips, composting, or chemical litter treatments, such as alum or slaked-lime applications, should help reduce the number of viable organisms entering the aquatic system. More research also needs to be conducted on decreasing ammonia volatilization from poultry litter, both within and outside of chicken houses. Nutrient management studies should also be conducted to determine BMP’s that minimize groundwater contamination from nitrate in poultry litter.

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