DEL-SG-01-00

An Analysis of Nutrient Utilization Efficiency by Agriculture in Delaware's Inland Bays Drainage Basin

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Sea Grant
University of Delaware

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PREFACE

The University of Delaware Sea Grant College Program has been committed to improving water quality and restoring habitat in Delaware's Inland Bays for more than a decade. Many of the issues the program has addressed have focused on land-use activities around the bays, including residential development, recreation and tourism development, and agriculture.

Sussex County, Delaware, is a major producer of broiler chickens, and this industry is vital to the local economy. Nearly one-half of the jobs in the county have direct or indirect ties to the broiler industry. Delaware broiler processing plants gross over $500 million in sales with indirect benefits of more than $1 billion to local residents.

A major portion of the industry is located in the watershed that drains into the fragile Inland Bays, which suffer from nutrient enrichment and habitat loss. Animal feeding operations generally are regarded to be potentially significant contributors of nitrogen and phosphorus to adjacent water bodies through surface runoff and groundwater discharge.

This current effort represented a collaboration between research and outreach staff of the University of Delaware's Land Grant and Sea Grant Programs to respond in a timely manner to emerging science-based questions at the land-water interface through multidisciplinary research.

CHAPTER 1

INTRODUCTION

BACKGROUND

Delaware's Inland Bays are a series of three coastal bays; Rehoboth, Indian River, and Little Assawoman; located in the southeastern Sussex County on the outer Atlantic Coastal Plain. Both Rehoboth Bay, which is north of Indian River Bay, and Little Assawoman Bay, which is south of Indian River Bay, are estuaries formed on sand bars. Indian River Bay is a drowned river valley. Natural channels connect Rehoboth and Indian River Bays and the Assawoman Canal connects Little Assawoman and Indian River Bays. Rehoboth Bay's principal tributaries are Love and Herring Creeks while the Indian River and Pepper Creek are the principal tributaries flowing into Indian River Bay. Little Assawoman Bay's principal tributaries are Dirickson and Miller Creeks. The three bays and their tributaries have a surface area of approximately 32 square miles and drain an area of approximately 300 square miles. Given the geology of the Inland Bays watershed, ground water discharge is responsible for a substantial fraction of the fresh water entering these embayments.

Direct connection between the Inland Bays and the Atlantic Ocean is limited to the Indian River Inlet, which was created in 1940 following closure of a natural channel through the barrier bar. Little Assawoman Bay is connected indirectly to the Atlantic Ocean through Big Assawoman Bay, which has an inlet at Ocean City, Maryland. Due to the presence of the Little Assawoman Canal which connects Little Assawoman and Indian River Bays, Little Assawoman Bay also is indirectly connected to the Atlantic Ocean through the Indian River inlet. The Lewes and Rehoboth Canal also connects Rehoboth Bay to lower Delaware Bay. Because of the limited connections with the Atlantic Ocean, tidal flushing varies significantly. While eastern

Indian River Bay and southern Rehoboth Bay are relatively well flushed, tidal flushing in other areas occurs at a much slower rate.

Recognition of water quality degradation in the Inland Bays dates back to 1969 when Delaware Governor Russell W. Peterson commissioned what appears to be the first formal study of these embayments (Delaware State Planning Office, 1969). The most recent and probably most intensive study of the Inland Bays followed the inclusion of this estuary system in the U.S. Environmental Protection Agency's National Estuary Program in 1989. The Inland Bays Estuary Program ultimately resulted in a Comprehensive Conservation and Management Plan (CCMP) which was completed in 1995. In the CCMP, two major priority problems were identified. They are eutrophication and habitat loss related in part to eutrophication (A Comprehensive Conservation and Management Plan for Delaware's Inland Bays, 1995). Other areas identified as priorities included circulation and flushing, pathogens, and sea-level rise.

It is generally agreed that both nitrogen and phosphorus are responsible for the highly eutrophic conditions in the Inland Bays. Total nitrogen concentrations generally are in excess of one mg/L and total phosphorus concentrations generally are in the range of 0.1 to 0.2 mg/L (Price, 1997). This combination of nitrogen and phosphorus concentrations is equivalent to that of the most enriched sub-estuarine systems of the Chesapeake Bay. The combined nitrogen and phosphorus concentrations in the middle and upper segments of the Indian River estuary are more enriched than any segment of the Chesapeake Bay.

The level of nutrient inputs to the Inland Bays results in high levels of primary productivity with the resulting phytoplankton densities contributing to high levels of turbidity during the summer months. Also, it is believed that the physical effect of boating activities also is a factor contributing to these high levels of turbidity, which appear to be responsible for the disappearance of submerged aquatic vegetation in these embayments. Consequently, habitat for a variety of shell fish and finfish has been lost as has a food source for certain waterfowl.

While it is generally agreed that the Inland Bays are highly eutrophic, there has been some debate about the relative significance of point versus nonpoint sources of nitrogen and phosphorus. In addition, the relative significance of agricultural versus non-agricultural nonpoint loading of these two nutrients has been debated extensively even though work by Ritter (1986) and Cerco *et al.* (1994) generally agreed that inputs from agricultural nonpoint sources were highly significant.

Ritter reported estimates of annual nitrogen and phosphorus inputs to each of the three Inland Bays from both point and nonpoint sources. Nonpoint source input estimates were based on land use distribution and unit area loading functions derived from the work of Loehr (1974), Reckhow *et al.* (1980), and others. Ritter concluded that land used for agricultural activities was the largest single source of nitrogen input to all three bays and was the largest single source of phosphorus entering Indian River and Little Assawoman Bays. For Rehoboth Bay, agriculture was the second largest source of phosphorus following point sources. The relative importance of the various sources of nitrogen and phosphorus are summarized in Table 1-1.

Table 1-1. Percentages of nitrogen and phosphorus loads from different sources for the Inland Bays (Ritter, 1986).

	Rehoboth Bay		Indian River Bay		Little Assawoman Bay	
Source	N	P	N	P	N	P
Point sources	27.3	56.9	12.5	15.0	0	0
Urban	11.7	5.9	9.8	8.6	11.2	10.8
Agriculture	33.6	17.0	44.6	39.4	54.7	52.6
Forest	7.4	9.4	11.0	19.2	6.7	19.5
Rainfall	8.8	6.9	6.2	8.6	12.8	11.5
Wetlands	0	0	0	0	0	0
Boating	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Septic tanks	11.2	3.8	16.0	9.3	14.6	5.6

The results of a subsequent study of nutrient inputs to Rehoboth and Indian River Bays by the U.S. Army Corps of Engineers were in general agreement with Ritter's estimates (Cerco *et al.*, 1994). The only significant differences were in the relative magnitudes of nitrogen discharges from point and atmospheric sources. In the Corps' study, point source nitrogen discharges were estimated to be lower and atmospheric inputs deemed to be higher.

The conclusions of both of these studies appear to be consistent with land use patterns in each of the three major watersheds; Rehoboth Bay, Indian River Bay, and Little Assawoman Bay, which comprise the Inland Bays drainage basin.

OBJECTIVES

This study had two objectives. The first was to determine broiler manure production and assimilation potential, based on field crop production and other nutrient inputs, in each of the three major watersheds in the Inland Bays drainage basin. The second objective was to evaluate potential redistribution strategies for broiler manure based on attempted similar efforts in other areas of concentrated animal production.

CHAPTER 2

AGRICULTURAL LAND USE ESTIMATES

The significance of agricultural activities as a source of nitrogen and phosphorus inputs via nonpoint source mechanisms to the Inland Bays is, in part, a function of the land area devoted to these activities. Of specific interest was the area of cropland in the Inland Bays drainage basin which determines the assimilative capacity for these nutrients and the efficiency of utilization, which will be examined later.

The first task in the process to determine the fraction of the Inland Bays drainage basin devoted to agricultural activities and especially crop production was to accurately delineate the boundaries of the drainage basin and its three constituent watersheds; Rehoboth Bay, Indian River Bay, and Little Assawoman Bay. The following methodology was used to accomplish this task. U.S. Geological Survey hypsography data (1992-93) with contour lines at five foot intervals were used to create 30-meter resolution digital elevation models (DEMs) for all 78.5-minute quadrangles in Sussex County. The DEMs covering the Inland Bays drainage basin then were patched together. Next, the GRASS *r. watershed* module was used to analyze the composite DEM in order to determine inferred drainage patterns and re-delineate the drainage basin and the three constituent watersheds. This produced delineation at a higher resolution than current hydrologic unit area maps.

The result of this analysis is shown in Figure 2-1. The Rehoboth, Indian River, and Little Assawoman watersheds are shown respectively in green, blue, and yellow. The brown watershed shown at the top of this figure drains directly into the Atlantic Ocean and Delaware Bay, and the aqua watershed at the bottom of this figure drains into Big Assawoman Bay which is located in Delaware. It should be noted that this watershed has been included in the

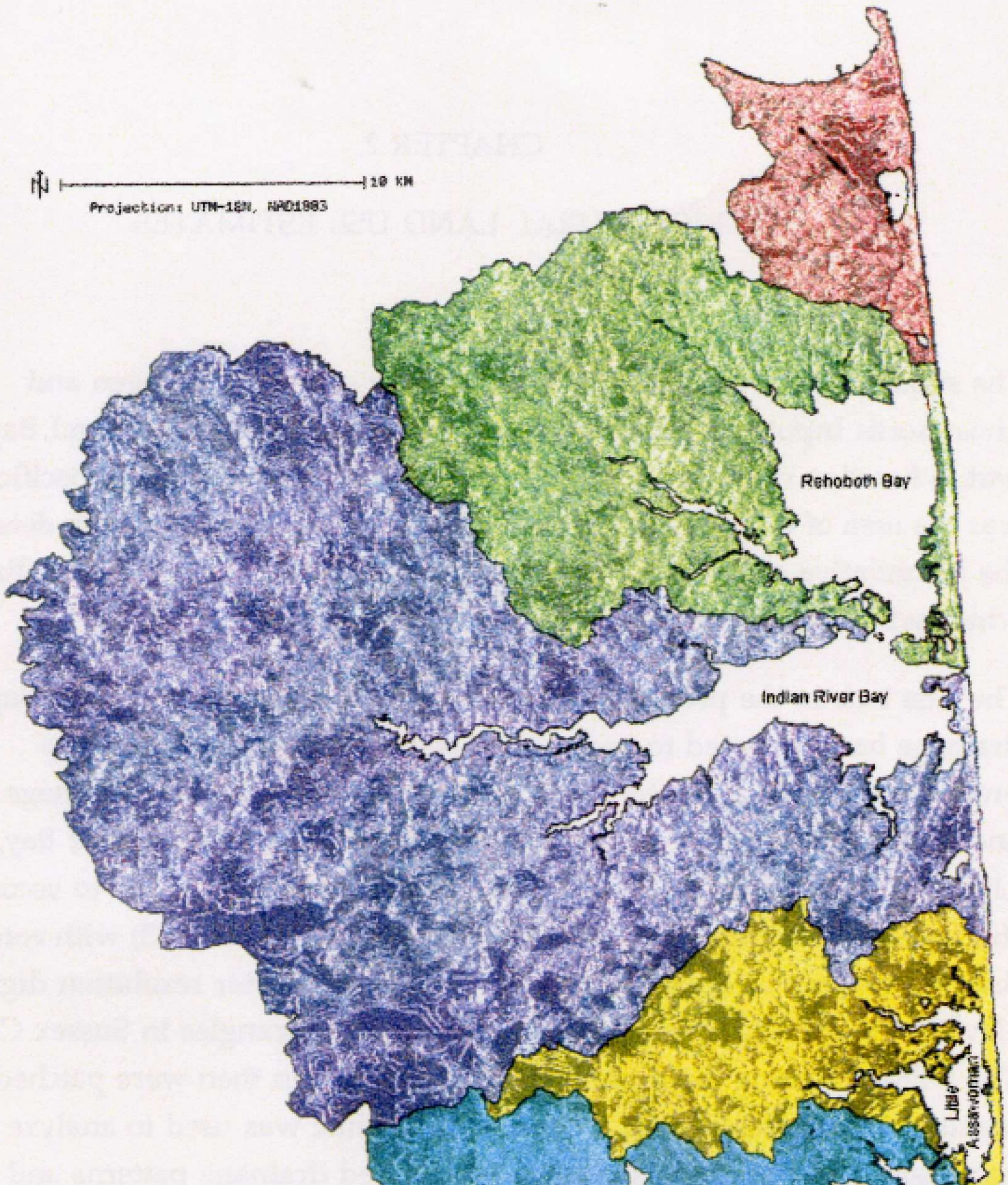

Figure 2-1. Delaware's Inland Bays drainage basin delineation.

Inland Bays drainage basin in past delineations. It also should be noted that transfers between watersheds due to ditching have been ignored.

Under contract with the Delaware Department of Natural Resources and Environmental Control, a 1992 mapping of land-use/land cover for Delaware was developed by Photo Science, Inc. from its 1992 digital ortho-photo series. This land-use/land cover mapping was based on digitized polygons with a four acre minimum mapping unit. Digital vector data for each county were re-projected in ARC/INFO to Universal Transverse Mercator (North American Datum, 1983), exported to GRASS, and rasterized at a 30 meter by 30 meter resolution.

In Tables 2-1 and 2-2, the results of this generalized land-use/land cover analysis for the Inland Bays drainage basin (Figure 2-2) are summarized by watershed on percentage and area bases. As shown in these tables, agriculture is the largest land use category in all three watersheds followed by upland forest in the Rehoboth Bay and Indian River watersheds and wetlands which includes forested wetlands in the Little Assawoman watershed. Thus, all three watersheds can be characterized as agricultural and primarily rural.

Ritter (1986) also analyzed land use by watershed by updating a detailed land use study conducted as part of the Federal Water Pollution Control Act Amendments of 1972 Section 208 nonpoint planning program for coastal Sussex County (Ritter and Scheffler, 1977). In the 1986 analysis of land use, watershed boundaries and individual categories were defined somewhat differently than in the more recent analysis discussed above. For example, residential and other developed areas were combined but sub-divided into sewered and unsewered. Also, areas of confinement feeding were combined with pasture (rangeland), wetlands were defined less stringently, barren land was included in the estimate of forest land, and water included the surface area of each bay. However, there appears to be some merit in comparing the results of Ritter's 1986 analysis (Tables 2-3 and 2-4) with the more recent results.

When Tables 2-1 and 2-2 are compared with Tables 2-3 and 2-4, it is apparent that use of land for housing and commercial and industrial activities is

Table 2-1. Delaware Inland Bays 1992 land-use/land cover, percent of total area.

Land-Use/ Land Cover	Percent		
	Rehoboth Bay	Indian River Bay	Little Assawoman Bay
Residential	13.00	7.92	8.81
Other developed	3.29	4.28	2.40
Agriculture	36.37	40.72	48.04
Rangeland	1.47	0.54	0.77
Forest, upland	29.51	25.57	11.97
Wetlands, incl. forested	11.92	17.65	23.50
Misc. water	1.87	1.33	2.16
Beach/Barren	2.57	1.99	2.35
Total	100.00	100.00	100.00

Table 2-2. Delaware Inland Bays 1992 land use/land cover.

Land-Use/ Land Cover	Acres			
	Rehoboth Bay	Indian River Bay	Little Assawoman Bay	Total
Residential	5,117	8,576	1,740	15,433
Other developed	1,295	4,634	474	6,403
Agriculture	14,316	44,092	9,489	67,897
Rangeland	579	585	152	1,316
Forest, upland	11,615	27,687	2,364	41,666
Wetlands, incl. forested	4,692	19,111	4,642	28,445
Misc. water	736	1,440	427	2,603
Beach/Barren	1,016	2,155	464	3,635
Total*	39,361	108,280	19,753	167,394

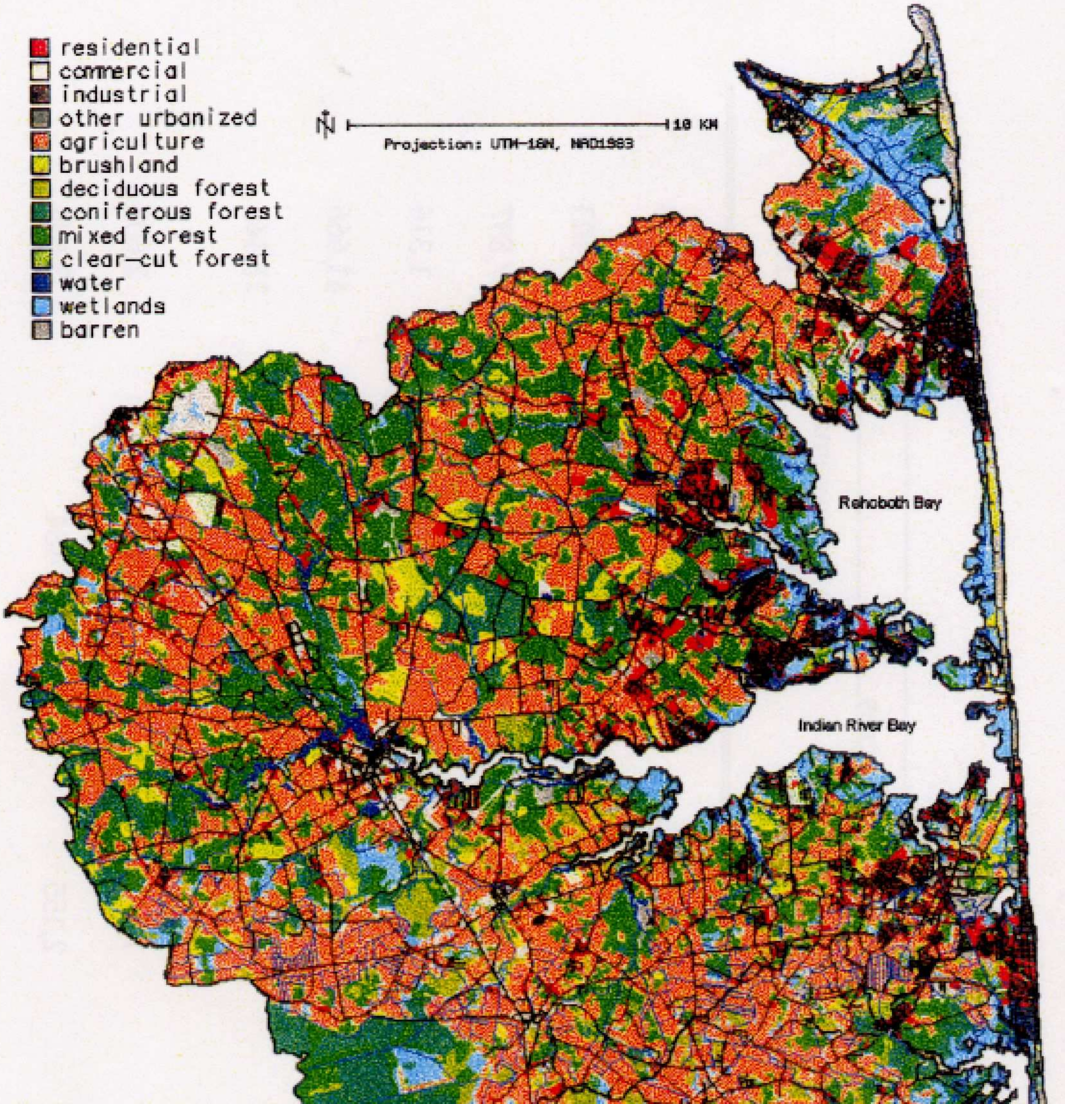

Figure 2-2. Delaware's Inland Bays 1992 land use/land cover analysis.

Table 2-3. Delaware Inland Bays 1986 land-use/land cover, percent of total area (Ritter, 1986).

Land-Use/ Land Cover	Percent		
	Rehoboth Bay	Indian River Bay	Little Assawoman Bay
Urban	8.4	6.8	10.0
Agriculture	35.0	39.3	47.8
Confined feeding/ pasture	1.6	1.4	1.1
Forest	32.2	39.9	24.1
Wetlands	5.3	3.0	5.5
Water	17.5	9.6	11.4
Total	100	100	100

Table 2-4. Delaware Inland Bays 1986 land use/land cover (Ritter, 1986).

Land-Use/ Land Cover	Acres			
	Rehoboth Bay	Indian River Bay	Little Assawoman Bay	Total
Urban	3,536	6,981	2,343	12,860
Agriculture	14,700	40,660	11,179	66,539
Confined feeding/ Pasture	662	1,465	250	2,377
Forest	13,526	41,276	5,631	60,433
Wetlands	2,226	3,150	1,285	6,661
Water	7,344	9,876	2,674	19,894
Total	42,034	103,339	23,362	168,735

increasing fairly rapidly. Comparison of the combination of the residential and the other category in Table 2-1 with the urban category in Table 2-3 suggests that the developed land area in both Rehoboth Bay and Indian River Bay watersheds doubled between 1986 and 1992. However, there was little increase in the Little Assawoman watershed. This rate of development is not surprising if the proximity of the region to the major population centers of Philadelphia, Pennsylvania; Wilmington, Delaware; Baltimore, Maryland, Norfolk, Virginia; and Washington, DC is considered.

Although it would have been reasonable also to find a comparable decrease in agricultural land during this same time period, the percentages listed in Tables 2-1 and 2-3 do not suggest this has occurred. Rather, it appears that development has occurred primarily on forest land. Typically, this development has occurred on the fringes of wooded areas along roads. Although there also has been some development on cropland, it appears that much of the area developed has been replaced by the clearing of forest parcels. This pattern is consistent with changes in land in farms and cropland acreage in Sussex County between 1982 and 1992 (Table 2-5).

To estimate current cropland acreage in each of the three Inland Bays sub-basins, satellite imagery obtained from the Spot Image Corporation, Reston, VA was analyzed. Imagery for 30 August 1994, 30 November 1995, and 5 July 1996 were co-registered to Universal Transverse Mercator (North American Datum, 1983) coordinates and classified simultaneously to identify all cropland areas and index overall vegetative biomass densities within the watershed. These represent periods of varying vegetation density. Simple histogram equalization was then applied to each band file's color table prior to compositing. Three Normalized Difference Vegetation Index (NDVI) maps were calculated from the three sets of multi-spectral band files using the following formula :

$$NDVI = \max(0, 255 * (IR - red)/(IR + red))$$

NDVI values should typically exhibit higher seasonal variation for cropland pixels than for most other land-use/land cover categories. Figures 2-3 and 2-4 are examples of the NDVI maps generated.

Table 2-5. Changes in land in farms and cropland acreage in Sussex County, Delaware—1982-1992*.

	1982	1992	Change
Land in farms, acres	343,333	304,680	-38,653
Cropland, acres	262,196	255,543	-6,653
Cropland, % of Sussex County	41.9	40.9	-1.0

*U.S. Department of Commerce, 1993.

A cluster analysis was performed on the resulting 15 files (nine original SPOT multi-spectral band files, three NDVI maps, and three texture vegetation maps) defining signatures for 50 statistical clusters. Next a maximum likelihood procedure was used to perform an unsupervised classification of the entire map area. Then 26 categories from the unsupervised classification were identified as agricultural from an analysis of statistical coincidence of these categories with a 1984 cropland mapping. Finally, this cropland mapping was validated against five meter resolution color infrared digital ortho-photos from March 1992.

The results of these cropland estimates are summarized in Table 2-6. The estimate from this analysis of total cropland area, 69,084 acres, is remarkably close to the estimate of agricultural plus rangeland of 69,213 acres from the Delaware Inland Bays 1992 land-use/land cover estimate (Table 2-2). While the Inland Bays drainage basin contains 26.8 percent of the land area in Sussex county, it contains a somewhat higher percentage of the county's cropland, 32.2 percent.

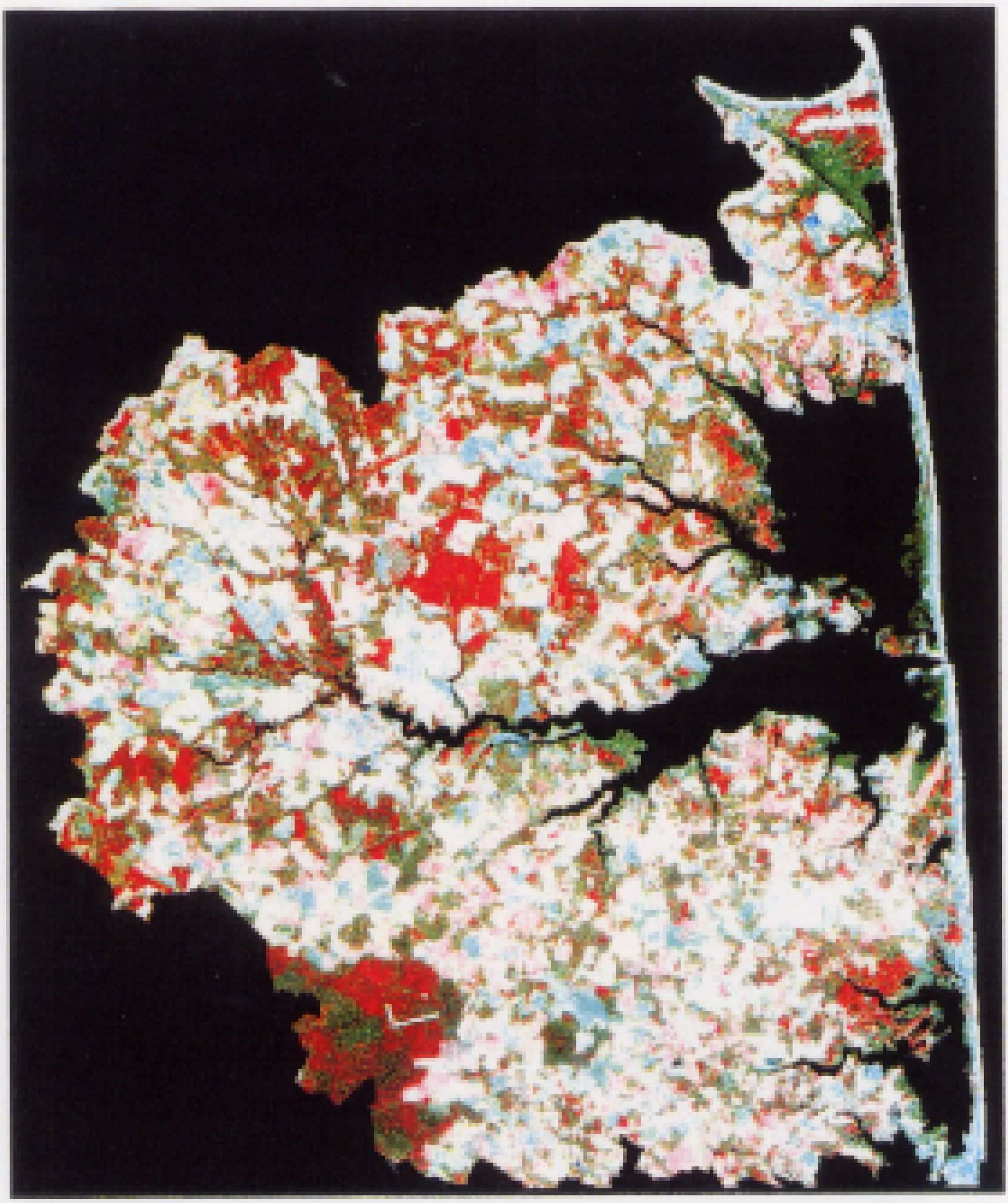

Figure 2-3. SPOT satellite imagery for 30 November 1996 used to map vegetative biomass indices and vegetative texture.

Figure 2-4. SPOT satellite imagery for 5 July 1996 used to map vegetative biomass indices and vegetative texture.

Table 2-6. Total and cropland acreage in the Inland Bays drainage basin.

Sub-basin	Cropland	Total	Cropland/ total, %
Rehoboth Bay	15,878	39,361	40.3
Indian River Bay	44,730	108,280	41.3
Little Assawoman Bay	8,476	19,753	42.9
Total	69,084	167,394	41.2

CHAPTER 3

BROILER PRODUCTION CAPACITY ESTIMATES

In order to estimate the quantities of manurial nitrogen and phosphorus and also potassium produced annually and available for use in crop production in the Inland Bays drainage basin, it was first necessary to estimate animal production. This area is similar to the rest of Sussex County with broiler production being the overwhelmingly predominate form of animal agriculture. Although there are a few dairy, beef, and swine operations in this area, the associated animal numbers are insignificant when compared to the numbers of broiler chickens produced. Thus, it appeared reasonable to assume that the quantities of nitrogen, phosphorus, and potassium in manures resulting from livestock production in this drainage basin also were insignificant. Consequently, estimates of these plant nutrients contained in manure produced in the Inland Bays drainage basin were based solely on broiler production.

Estimating broiler production in the Inland Bays drainage basin required the identification of each active production facility since production data only are routinely compiled on a county or state basis. Initially, it was attempted to utilize the Delmarva Poultry Industry, Inc. (DPI) list of broiler producers and associated production capacity to obtain production estimates. However, this list is organized on a DPI grid basis with a number of grids containing production facilities located both within and also outside of the Inland Bays drainage basin. Others contained production facilities located in more than one sub-basin. Since only mailing addresses, rural route and box number, were listed, it was impossible to determine which facilities were located within as opposed to outside the drainage basin. It also was impossible to determine the number of production facilities within each sub-basin, which was desired.

It subsequently was determined that a search of Sussex County tax records for those districts located completely and also partially in the Inland Bays drainage basin could provide the information necessary to estimate broiler production capacity. This process consisted of the following steps. First, all parcels in each district zoned for agricultural activities were identified. Next, those parcels in each district with improvements noted were examined to identify those parcels with poultry houses listed. A list of those parcels with owner's name, location, number of houses, and floor area of each house was then assembled. This was followed by the development of a summary of broiler production facilities in each of the three major Inland Bays' sub-basins from each district list based on indicated location. Finally, the accuracy of each sub-basin list was checked by the random physical inspection of more than 50 percent of the production facilities identified.

The estimated broiler production capacity for each of the three Inland Bays' sub-basins as determined by the process outlined above is presented in Table 3-1. Production capacity was based on an assumed placement density of 0.75 square foot per bird. As indicated in this table, the majority of the broiler production capacity in the Inland Bays drainage basin is concentrated in the Indian River Bay and the Little Assawoman Bay sub-basins. Not shown in this table but shown in Figure 3-1 is the concentration of production capacity in the southern half of the Indian River Bay sub-basin.

In Table 3-2, annual broiler production potential per acre of estimated cropland in each of the three major Inland Bays' sub-basins are compared and also compared with all of Sussex County. This estimated production capacity was based on the assumed value of 5.5 flocks per year, which historically has been typical. As shown in this table, there are significant differences among the three sub-basins in the intensity of broiler production when expressed on a per acre of cropland basis. Most significant is the difference in intensity between the Rehoboth Bay and Little Assawoman Bay sub-basins and the intensity in the latter which is more than three time the value for Sussex County. There is little difference, however, between the average for the entire basin and the county. The Inland Bays drainage basin contains approximately 27 percent of the cropland in Sussex County and is the source of approximately 31 percent of annual broiler production.

Table 3-1. Estimated broiler production capacity in the Inland Bays drainage basin, 1995.

Sub-basin	No. of Farms	No. of Houses	Range per Farm, birds/flock	Total Capacity*
Rehoboth Bay	10	34	43,000—130,000	716,339
Indian River Bay	168	539	4,320—241,920	7,763,055
Little Assawoman Bay	87	327	9,557—184,000	4,474,648
Total	265	900	—	12,954,042

*Based on an average housing density of 0.75 ft^2 per bird.

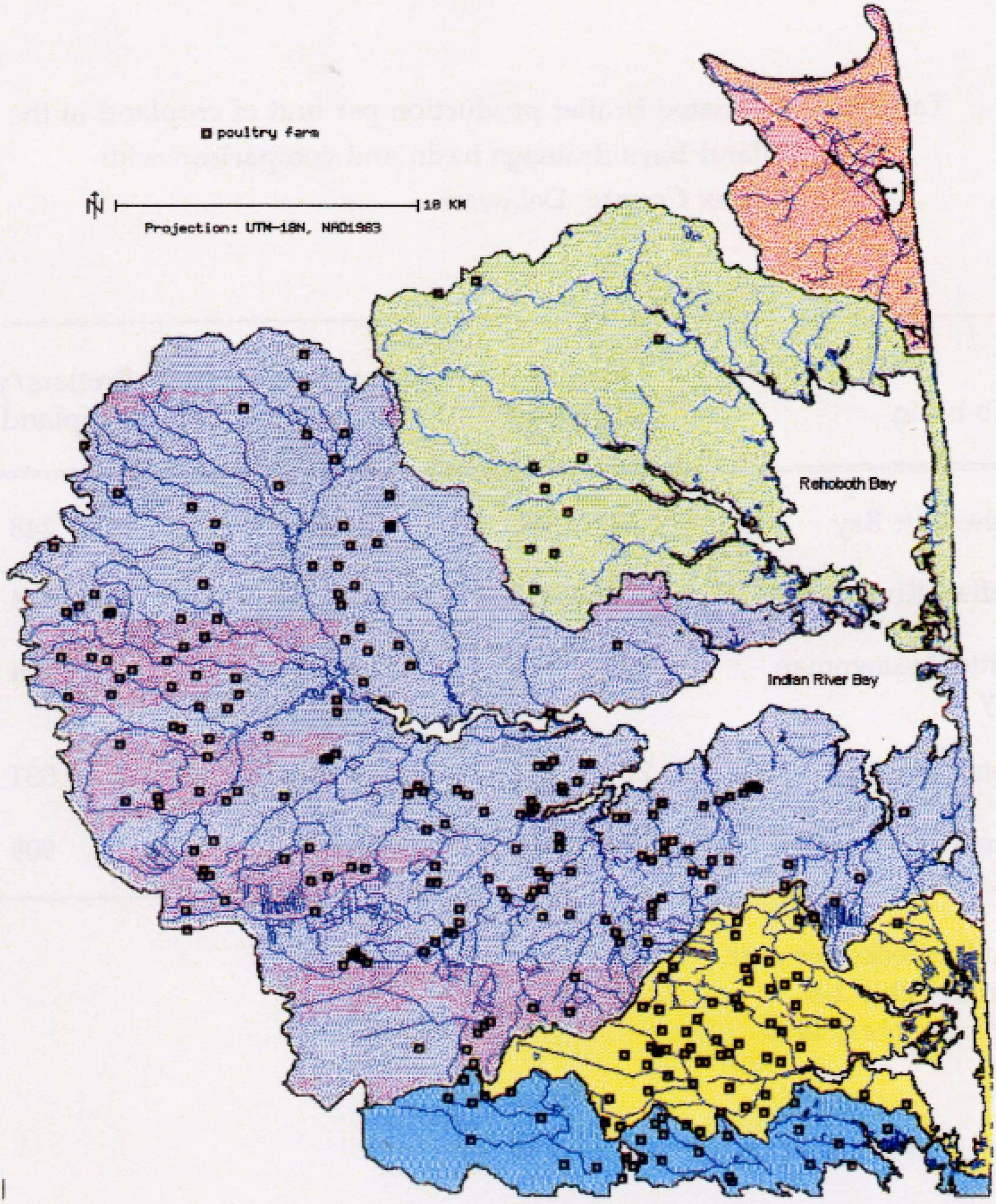

Figure 3-1. Spatial distribution of broiler production units in Delaware's Inland Bays drainage basin.

Table 3-2. Estimated broiler production per unit of cropland in the Inland Bays drainage basin and comparison with Sussex County, Delaware.

Sub-basin	Broiler Production*	Cropland, acres†	Broilers/year/cropland acre
Rehoboth Bay	3,939,864	15,878	248
Indian River Bay	42,696,803	44,730	954
Little Assawoman Bay	24,610,564	8,476	2,904
Total/average	71,247,231	69,084	1,031
Sussex County#	232,387,146	255,543	909

*At 5.5 flocks per year.
†From Table 2-6.
#Martin *et al.*, 1998

Since this appears to be the first rigorous estimate of broiler production in the Inland Bays drainage basin, there is no basis to ascertain changes with time. In addition, recent estimates for Sussex County are available only from the Census of Agriculture (U.S. Department of Commerce, 1993) for 1982 and 1992. However, production estimates for the state of Delaware are published annually by the Delaware Department of Agriculture and provide a general indication (Figure 3-2) of changes with time in the Inland Bays drainage basin. As shown in this figure, there was a dramatic increase in Delaware broiler production beginning in 1975. For the period 1975 through 1995, the average rate of increase has been over six million birds per year. While it is not possible to ascertain the rate of increase during this period in the Inland Bays drainage basin, it appears reasonable to assume that the rate of increase has been significant.

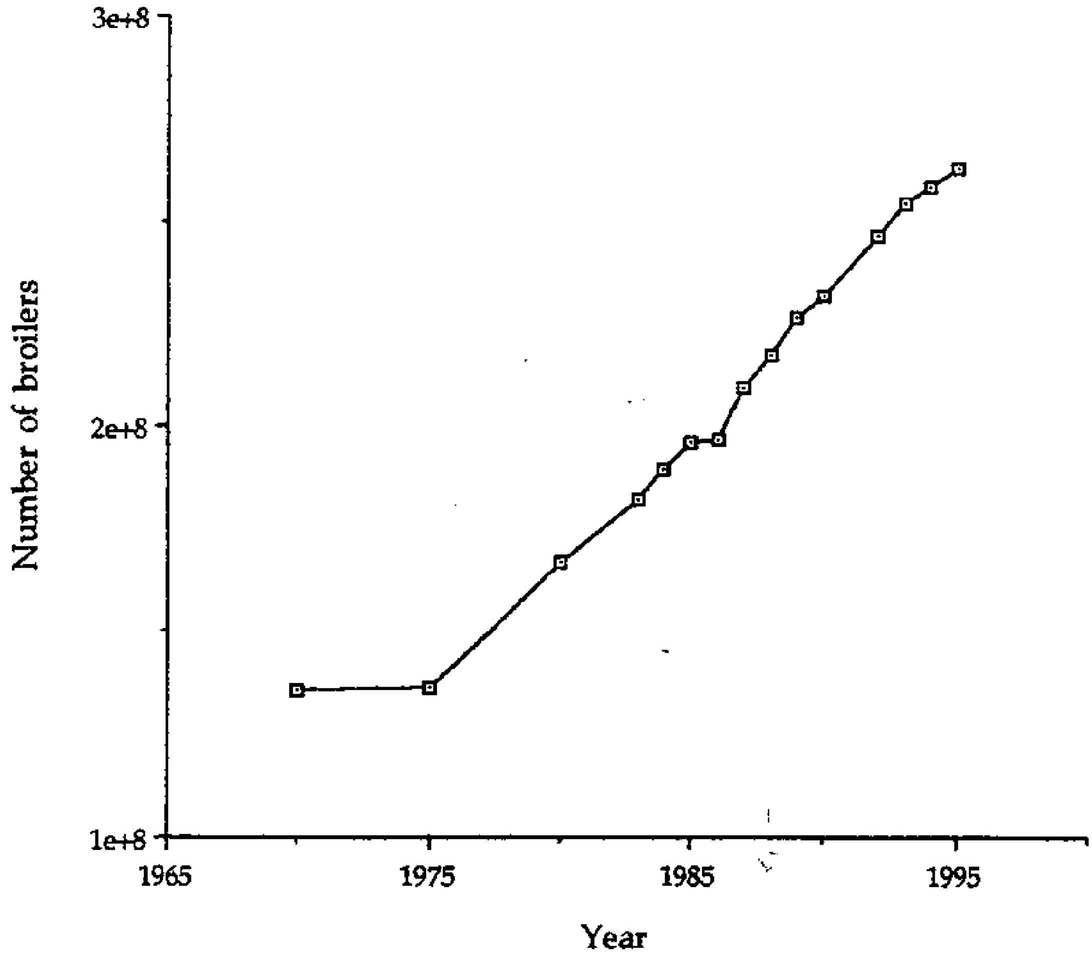

Figure 3-2. Annual Delaware broiler production, 1970—1995 (Delaware Agricultural Statistics Service, 1995).

CHAPTER 4

ESTIMATES OF AVAILABLE NUTRIENTS FOR CROP PRODUCTION

In the Inland Bays drainage basin, both manufactured fertilizer materials (commercial fertilizers) and animal manures are significant sources of nutrients for crop production. Since the Delaware Department of Agriculture requires fertilizer dealers to report sales of fertilizer materials annually and tabulates sales by county, determining annual sales of nitrogen, phosphorus, and potassium in Sussex County was a relatively simple task. It was only possible, however, to estimate the fractions of these nutrients used in the Inland Bays drainage basin and in each of the three major watersheds in this basin. To do so, it was assumed that the average application rates of these three nutrients per cropland acre in Sussex County and in each of the three major watersheds in the Inland Bays drainage basin are comparable. This appeared to be a reasonable assumption since crop production in the Inland Bays drainage basin and the rest of Sussex County; predominately corn, soybeans, wheat, and barley; is similar. Then, total use was determined based on the fraction of Sussex County cropland acres in each watershed. It is recognized that these estimates probably are only rough approximations and may be over or under-estimates to some degree given differences in broiler production per cropland acre between the Inland Bays drainage basin and other areas in Sussex County and also between the three major watersheds in this drainage basin.

Estimating the potentially recoverable quantities of these primary plant nutrients contained in animal manures was more difficult. As is discussed below, a number of variables influence physical and chemical characteristics of these materials and reported values vary significantly.

COMMERCIAL FERTILIZERS

Annual nitrogen, phosphorus, and potassium fertilizer use, based on reported sales, in Sussex County, Delaware from 1987 through 1996 are summarized in Table 4-1. As shown in this table and also in Figures 4-1, 4-2, and 4.3, year-to-year differences in sales can be substantial making evaluations of any trends difficult. A number of factors probably contribute to these year-to-year variations. Included are previous year farm income; shifts in acreages of corn, soybeans, and small grains in response to anticipated prices; and ealry fertilizer purchases in response to anticipated prices increases.

Table 4-1. Annual nitrogen, phosphorus, and potassium fertilizer use in Sussex County, Delaware during the period 1987-1996, tons/yr*.

Crop year	Nitrogen	P_2O_5	K_2O
1987-88	7,266	2,107	6,950
1988-89	8,379	2,771	8,187
1989-90	11,045	3,174	12,631
1990-91	10,454	3,084	15,840
1991-92	10,679	3,121	9,202
1992-93	9,981	2,820	8,331
1993-94	9,860	2,934	7,440
1994-95	10,820	2,853	8,640
1995-96	11,408	2,973	8,326
Mean±SD	9,988±1,271	2,871±300	9,505±2,709

*Delaware Department of Agriculture.

The magnitude of deviations between years and the limited scope of the data bases made simple regression analysis useless as a statistical technique to discern any possible trends. When cumulative sales over time of nitrogen, phosphorus, and potassium are plotted versus time (Figure 4-4), the relationships for nitrogen and phosphorus are highly linear, however. This suggests that there have been no significant changes in sales of two plant

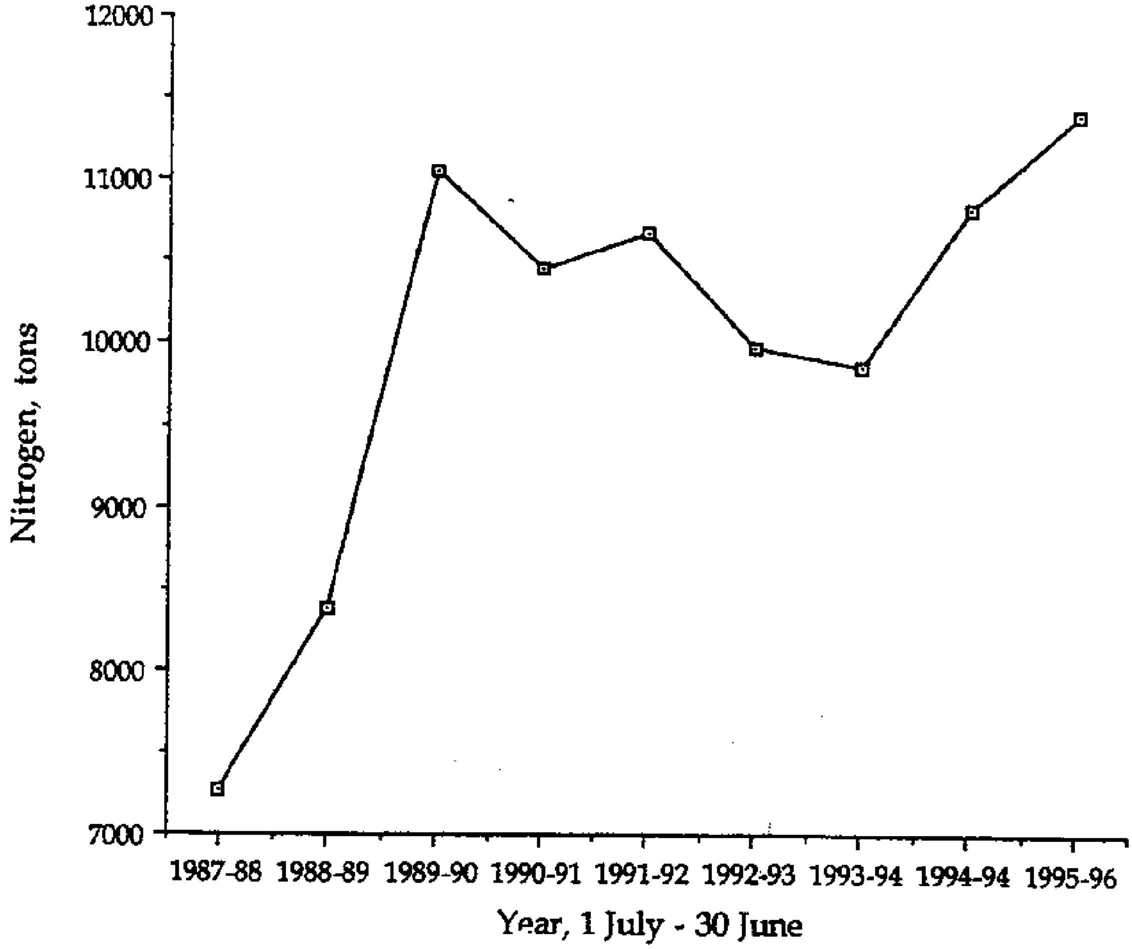

Figure 4-1. Annual nitrogen fertilizer sales in Sussex County, Delaware for the period 1987 through 1996 (Delaware Department of Agriculture, 1988-1997).

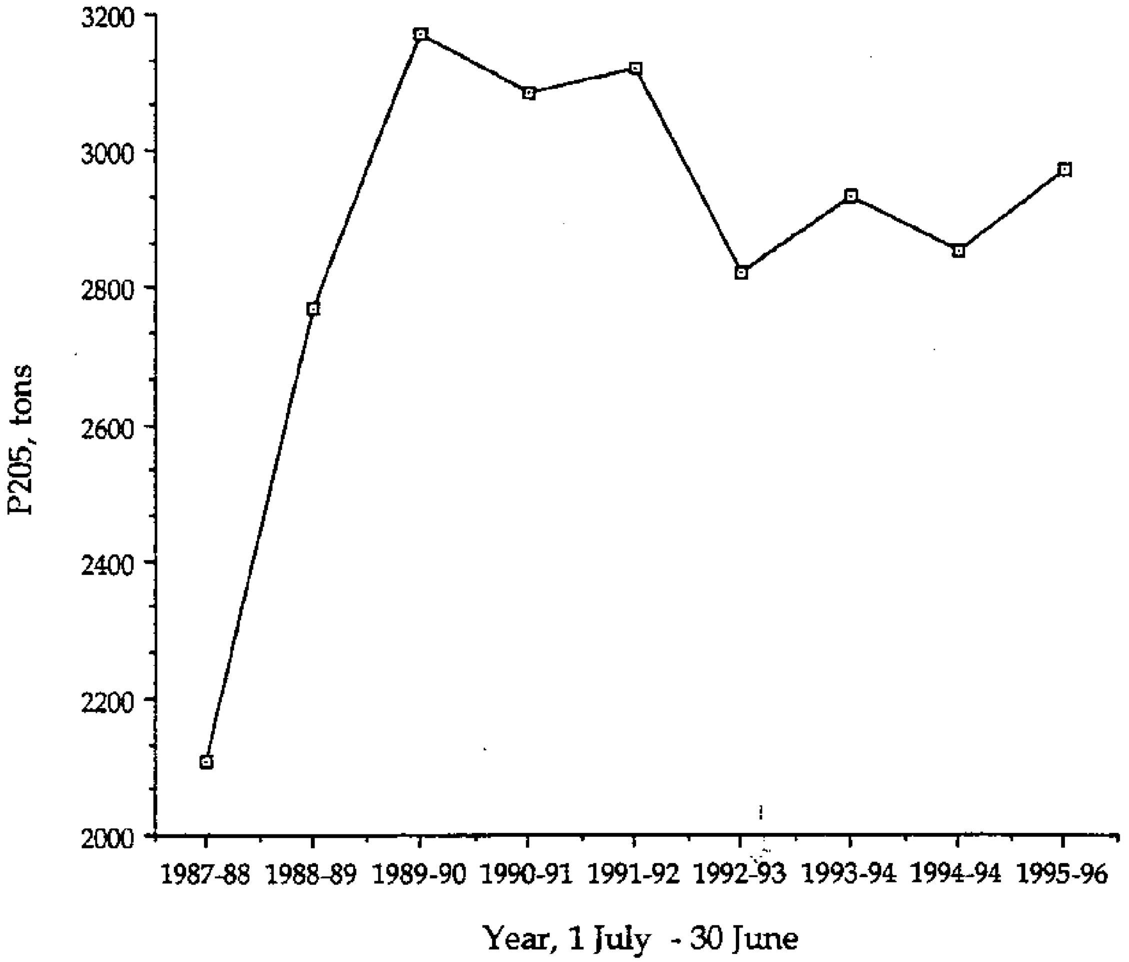

Figure 4-2. Annual phosphorus fertilizer sales in Sussex County, Delaware for the period 1987 through 1996 (Delaware Department of Agriculture, 1988-1997).

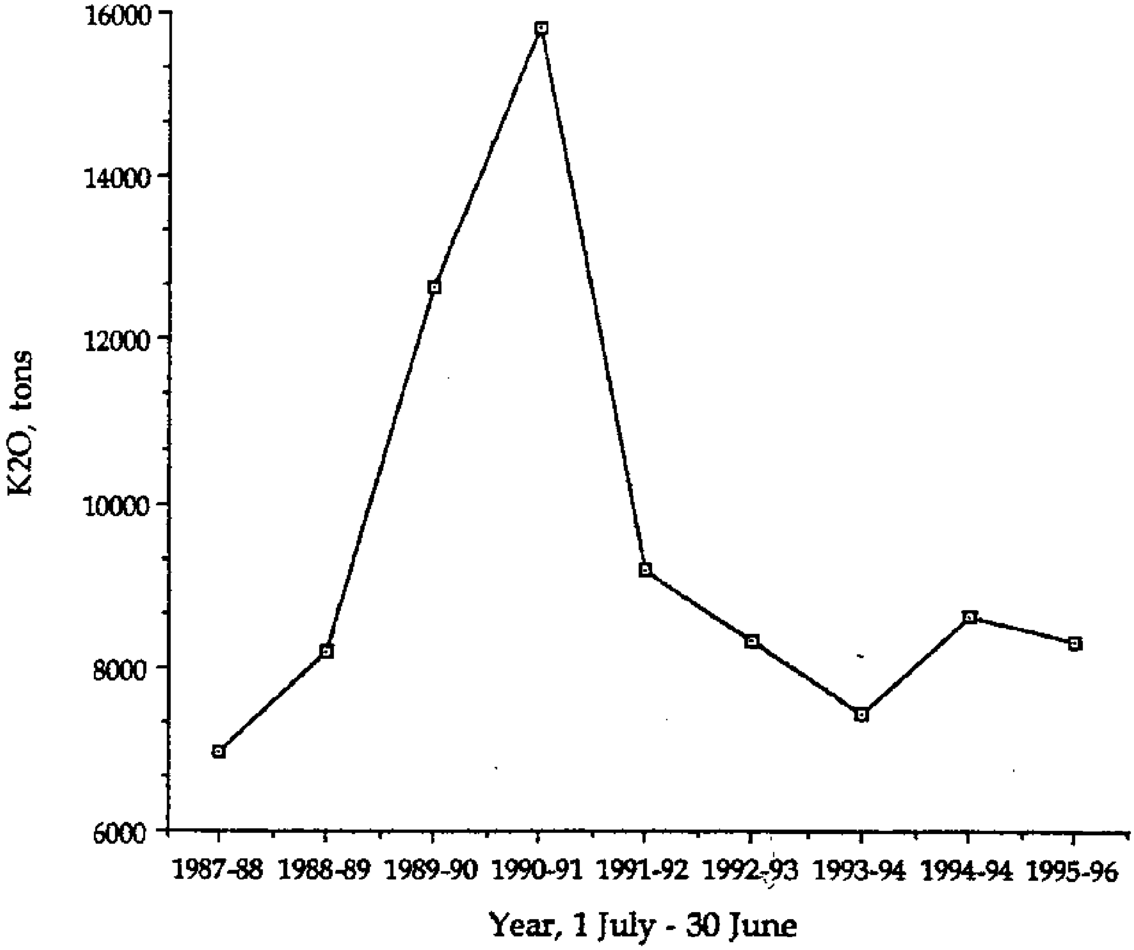

Figure 4-3. Annual potassium fertilizer sales in Sussex County, Delaware for the period 1987 through 1996 (Delaware Department of Agriculture, 1988-1997).

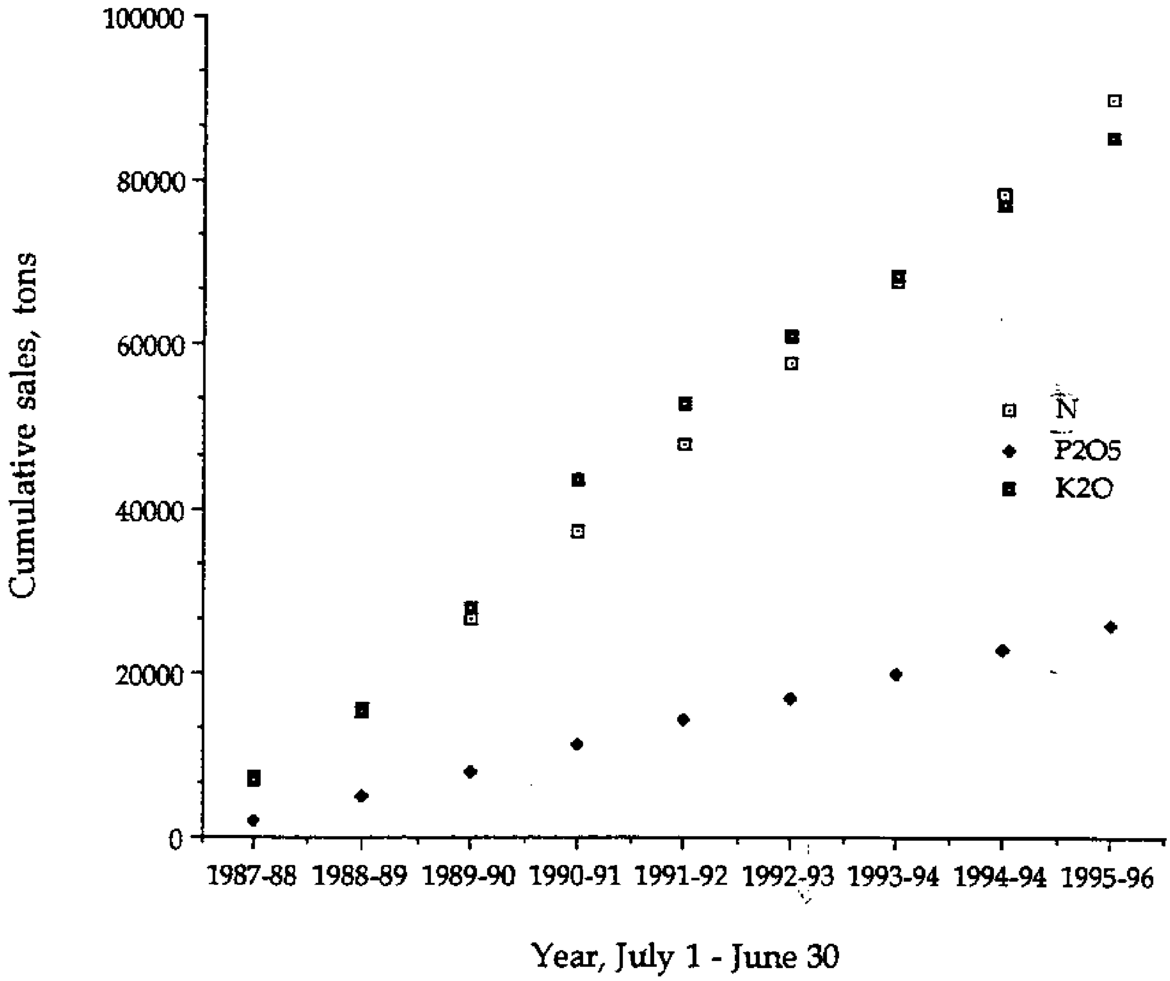

Figure 4-4. Cumulative sales of fertilizer nitrogen, phosphorus, and potassium in Sussex County, Delaware for the period 1987 through 1996.

nutrients during the time period analyzed. Otherwise, the year-to-year differences would not be random and tend to cancel out. The non-linear nature of the relationship for potassium suggests some small decrease in sales.

It could be argued, with some justification, that geographical location of sale does not necessarily imply use in that location. For example, it is reasonable to assume that some commercial fertilizer materials sold in Delaware are used in Maryland. Sales in one county with use in another may even be more likely. It also appears reasonable to assume, however, that movement across geographical boundaries occurs in both directions and at least roughly balance. Thus, these estimates are reasonable best estimates.

It also could be argued, again with some justification, that not all fertilizer materials sold are used in production agriculture. Obviously some fraction is used for turf, gardening, etc. The magnitude of this fraction is unclear since only sales and not intended use are reported. Discussions with fertilizer industry representatives suggest that non-agricultural use is no greater than 5 to 10 percent nationally and probably is less in rural areas. Since any attempt to separate total fertilizer sales in to agricultural and non-agricultural use categories would have been arbitrary, no attempt was made. Thus, it should be understood that the results of all computations based on total sales may be overestimates to some degree.

ANIMAL MANURES

As discussed in Chapter 3, the production of broiler or meat type chickens is the predominate form of animal agriculture in the Inland Bays drainage basin as well as the rest of Sussex County. Thus, this industry also is the principal source of animal wastes and associated primary plant nutrients in this region. While other forms of animal agriculture; dairy, beef, and swine; also are present in the Inland Bays drainage basin, animal numbers in Sussex County suggest that the resulting nutrients are insignificant. In the 1992 Census of Agriculture (U.S. Department of Commerce, 1993), the number of hogs and pigs in Sussex County was reported to be only 52,403, and the reported numbers of dairy cattle and beef cattle were only 2,660 and 13,368, respectively. Between 1982 and 1992, numbers of both dairy and beef cattle deceased significantly and the number of hogs and pigs increased only slightly. Therefore, these species were not considered in this study as they were viewed as insignificant sources of primary plant nutrients in comparison to poultry.

In theory, estimating broiler litter (manure plus bedding) production and the potentially recoverable nitrogen, phosphorus, and potassium contained in these wastes should be a relatively simple task given previous efforts in this area. In Table 4-2, the results of several efforts to quantify typical properties of broiler litter are summarized. There also have been a number of attempts to estimate typical quantities of excreted nitrogen, phosphorus, and potassium and also total and volatile solids per unit of broiler production. These estimates, expressed on a per 1000 kg live weight at processing basis, are summarized in Table 4-3.

The differences among these estimates is not surprising considering the variables that can affect the quantities of total and volatile solids and nitrogen, phosphorus, and potassium excreted and the resulting concentrations in litter. These variables include the type and initial amount of bedding material used, frequency of litter removal, and diet formulation and feed utilization efficiency. All of these variables have changed significantly with time. One example is the increase of number of flocks raised before bedding material is replaced. Currently, 10 or more flocks is not unusual in contrast to five or fewer flocks only a few years ago. Thus, the time period between bedding material replacement has increased from annually to two or more years. Number of flocks also varies regionally reflecting differences in availability and cost of litter materials. A second is the changes in the genetics of the broiler chicken and diet formulation and feed utilization efficiency. As noted by Rhinehart (1996), average broiler age at processing decreased from 72 to 48 days between 1960 and 1995 with average weight increasing from 1.80 to 2.20 kg. Concurrently, average feed conversion decreased from 2.27 to 1.95 kg feed per kg of broiler at processing.

The data bases assembled include reported values that span several decades in some cases. For example, the work of Edwards and Daniel (1992) includes

Table 4-2. Estimates of broiler litter primary plant nutrient content, percent of total solids.

Source	Total nitrogen	Ammonia nitrogen	Total phosphorus	Potassium
Gerry (1968)	5.5	—	0.86	—
Westerman *et al.* (1985)	3.6±0.9*	0.5±0.2	1.8±0.5	2.2±0.5
Bandel (1989)†	4.3 0.3—10.3#	1.1 nd—2.5	2.1 0.3—3.8	2.6 0.1—6.7
Stephenson *et al.* (1990)	4.0 2.3—6.0	—	1.6 0.6—3.9	2.3 0.7—5.2
Malone (1992)	3.9 1.2—7.7	1.1 0.1—2.0	1.9 0.7—3.6	2.4 0.8—4.9
Edwards & Daniel (1992)§	5.4	0.3	1.9	2.7
USDA (1996)	2.6	—	1.3	1.5

*Mean ± standard deviation.
†Personal communication cited by Sims and Wolf (1994).
#Range of values.
§ Basis not stated.

Table 4-3. Estimates of broiler manure production rates expressed on a kg per 1000 kg live weight at processing basis.

Source	Total solids	Volatile solids	Total Nitrogen	Total Phosphorus	Potassium
Gerry (1968)	464	384	25.5	4.0	—
Miner & Smith (1975)	419	294	28.4	6.4	8.8
Barth (1985)	322	278	—	—	—
ASAE (1988)	539	416	27.0	7.4	9.8
Midwest Plan Service (1994)	449	378	32.2	12.2	—
Sims & Wolf (1994)	397	—	16.3	6.0	8.7
USDA (1996)	490	368	27.0	8.3	11.3

citations from 1959 to 1988. Thus, the differences among means in Tables 4-2 and 4-3 are not surprising. Neither are the ranges of values noted in Table 4-2 that span more than an order of magnitude in some cases. The lack of consistency among these estimates justifiably raised the question of validity and concern about the magnitude of potential under- or over-estimates when these values were translated into county, state, and regional estimates of potentially recoverable primary plant nutrients. This is due to the magnitude of broiler production in this region. Based on the broiler production estimates for the Inland Bays drainage basin (Table 3-2), a difference of one kg in manurial nitrogen per 1000 kg broiler live weight at processing translates into 185 tons of potentially recoverable nitrogen in the region. This is equal to 10.6 percent of the estimated nitrogen fertilizer use in the Inland Bays drainage basin based on the mean of annual sales in Sussex County for 1987 through 1996. For phosphorus, this difference translates into 424 tons of P_2O_5 which is equal to 54.7 percent of the average annual phosphorus fertilizer use in this region for the same period of time. Both estimates were based on the estimate that the Inland Bays drainage basin contains 27 percent of the cropland in Sussex County (Tables 2-5 and 2-6) and the assumption that both nitrogen and phosphorus fertilizer use is uniform throughout the county.

This concern led to the exploration of two alternative approaches to estimate the significance of the region's broiler industry as a source of nitrogen, phosphorus, and potassium for crop production. One was a theoretical approach based on a simple mass balance approach where consumption of each of these nutrients in a typical broiler feeding program minus retention equals excretion. The second was an experimental approach involving the determination of recoverable quantities of litter nitrogen, phosphorus, and potassium following the completion of each of a series of three feeding trials.

In the first approach; feed consumption, diet composition, and live weight at processing were used to calculate feed efficiency and intake of nitrogen, phosphorus, and potassium in a series of feeding trails. Three integrator feeding programs, which were used as control diets in these feeding trials, were used. Least cost feed formulation was used to specify diet compositions. In Table 4-4, the results of these calculations are summarized. As shown, feed efficiency was remarkably consistent with a coefficient of variation of only

Table 4-4. Representative nitrogen, phosphorus, and potassium intake and feed conversion efficiency in broiler production derived from feeding trial results (Martin and Malone, 1997).

Integrator	Feed efficiency, kg/kg	Consumed, kg/1000 kg live weight at processing		
		Nitrogen	Phosphorus	Potassium
A	1.8	56.2	10.8	12.1
B	1.8	51.0	10.2	11.8
A	2.0	60.7	11.9	15.3
A	2.0	59.3	11.6	14.9
A	1.9	57.8	11.3	14.6
A	2.1	63.3	12.6	15.7
A	1.9	57.4	11.1	14.2
C	2.0	66.4	12.4	14.0
Mean±SD	1.9±0.1	59.0±4.4	11.5±0.8	14.1±1.3

five percent. In addition, the mean for the series of trials of 1.9 kg of feed per kg of broiler at processing is close to the value of 1.95 cited by Rhinehart (1996) as typical for the industry. The coefficient of variations for nitrogen, phosphorus, and potassium are slightly higher. This appears primarily to be a reflection of differences in diet composition given the differences in intake among the feeding trails using Integrator A's feeding program.

A review of the literature revealed a paucity of information about the nitrogen, phosphorus, and potassium content of live broiler chickens. However, results of a study by Yi *et al.* (1996) examining strategies for improving phytate phosphorus availability in corn and soybean meal diets for broilers did provide the necessary data to estimate the nitrogen and phosphorus content of broilers. The results presented included the crude protein and phosphorus content of the diets used, feed consumption, weight gain, and nitrogen and phosphorus retention. Retention was based on differences between consumption and excretion. These data permitted calculation of broiler nitrogen and phosphorus content (Table 4-5) as percentages of live weight and suggest that 64.4 percent of nitrogen and 34.8 percent of phosphorus consumed is retained.

Table 4-5. Estimates of broiler nitrogen and phosphorus content, percent of live weight*.

Trial	Nitrogen	Phosphorus
9	3.6	0.4
10	3.9	0.4
11	3.8	0.5
12	3.9	0.4
13	3.7	0.4
14	4.0	0.5
15	3.8	0.5
16	4.0	0.4
Mean±SD	3.8±0.1	0.4±0.05

* Calculated from data presented by Yi *et al.* (1996).

The estimates of broiler nitrogen and phosphorus content on a live weight basis of 3.8 percent and 0.4 percent, respectively, are somewhat higher than the values reported in the Atlas of Nutritional Data on United States and Canadian Feeds (National Academy of Sciences, 1971). Those values for whole broiler chickens (Ref. No 5 07 945) are 18.6 percent crude protein, which translates into 3.0 percent nitrogen, and 0.2 percent phosphorus. No value is listed for potassium content.

It is unclear if these values include or exclude blood, feathers, and enviscera but reported values for the protein content of whole broiler chickens by Chambers and Fortin (1984) suggest they do not. From two successive trails, they reported the protein content of bled, plucked, and eviscerated carcasses without leaf fat to be 17.5 and 17.4 percent. Similar values have been reported by Cogburn (1991) and others. Thus, the estimated value of 3.8 percent nitrogen (Table 4-5), which translates into 23.8 percent crude protein, appears to be a reasonable estimate of the nitrogen content of a live broiler chicken. This conclusion is based on the high protein content of both blood and feathers. Results of a study of broiler offal and carcass yield (Brake *et al.*, 1993) indicate that blood and feathers comprise 3.8 percent and 4.5 percent, respectively, of the live weight of broiler chickens.

While the calculated phosphorus content of 0.4 ± 0.05 percent (Table 4-5) is substantially higher than the National Academy of Sciences (1971) value of 0.2 percent, it is close to the value of 0.385 percent for chicken fat-free body tissue suggested by Scott *et al.* (1976). It also is almost identical to the value of 0.4 percent calculated from data presented by Qian *et al.* (1997) for control diets suggesting that 0.4 percent is a reasonable estimate of the phosphorus content of a live broiler chicken.

It was attempted to confirm these estimates of nitrogen and phosphorus excreted per 1000 kg live weight at processing experimentally through sampling and analysis of litter initially and following the completion of a series of three feeding trials. In each trial, feed consumption and live weight at processing were measured in up to 10 replicates of 60 birds at placement. From diet formulations, which were standard diets used as controls in these feeding trials, total intake of nitrogen, phosphorus, and also potassium were calculated. For each trial, litter was weighed, mixed, and sampled initially and following completion of the feeding trial. Each sample was then analyzed for the following: total and volatile solids, total nitrogen, ammonia nitrogen, total phosphorus, and potassium using standard methods. This approach permitted calculation of nitrogen, phosphorus, and potassium accumulated during each trial per 1000 kg live weight at processing. The results obtained are summarized in Table 4-6.

Although there was little variation among replicates in each feeding trial, the degree of variation among the three feeding trials in the recovery of phosphorus and potassium consumed was unexpected. The reason or reasons for this degree of variation is unclear. However, the mean value for phosphorus recovery of 58.4 percent is close to the theoretical value of 65.2 percent based on the previously described estimate of the phosphorus content of a live broiler chicken. Since both phosphorus and potassium are not subject to microbial mediated loss as is nitrogen, it appears reasonable to assume that 81.9 percent of the potassium consumed should be excreted. This is based on the assumption that the errors in phosphorus and potassium recovery are comparable.

Table 4-6. Comparison of broiler nitrogen, phosphorus, and potassium consumption and recovery in litter including cake (Martin and Malone, 1997)

		kg/1000 kg live weight at processing		
Trial No.		Nitrogen	Phosphorus	Potassium
1	Consumed	56.2	10.8	12.1
	Recovered	15.6	6.6	9.6
	% recovered	27.7	61.1	79.3
2	Consumed	51.0	10.2	11.8
	Recovered	19.4	4.7	9.0
	% recovered	38.0	46.1	76.3
3	Consumed	60.7	11.9	15.3
	Recovered	9.0	8.1	9.9
	% recovered	14.8	68.1	64.7
% recovered, mean±sd		26.8±11.6	58.4±11.2	73.4±7.7

Also, the pattern of recovery of nitrogen was unexpected. It was anticipated that nitrogen recovery in trials one and two would be comparable since new bedding material was used in each of these trials. The lower percentage of nitrogen recovery for trial three was expected since the bedding material used was litter from the previous trial. As noted by Scott *et al.* (1976), approximately 50 percent of the nitrogen excreted by the chicken is in the form of uric acid. Since many microorganism possess the ability to synthesize uricase, uric acid can be readily hydrolyzed in litter, and also in soils, producing ammonia and carbon dioxide as end products. Since pH values can increase to values in excess of 8.0, much of this ammonia can be lost to the atmosphere by volatilization. Other nitrogenous compounds excreted, such as unadsorbed amino acids, also are subject to microbial degradation with ammonia in excess of microbial needs for growth and reproduction as an end product. Thus, it is reasonable to assume that up to 50 percent of the nitrogen excreted by broiler chickens can be lost to the atmosphere during manure accumulation, handling, and application to cropland.

Estimates of the nitrogen, phosphorus, and potassium contained in the broiler manure produced annually in the Inland Bays drainage basin are summarized in Table 4-7. As noted, these estimates are based on the previously discussed estimate of broiler production capacity in the drainage basin (Table 3-2) assuming an average bird weight at maturity of 5.2 pounds and 5.5 flocks produced per production facility per year. The previously discussed values for the nitrogen, phosphorus, and potassium content of broiler manure when excreted were used. Given the previously discussed potential for nitrogen loss via ammonia volatilization, it is probable that no more the 50 percent of the nitrogen values listed in Table 4-7 are available ultimately for crop production.

In Table 4-8, annual broiler manure nitrogen, phosphorus, and potassium production per acre of cropland is summarized. As shown in this table, there is a substantial difference among the three major watersheds in this drainage basin reflecting the differences in the spatial distributions of both broiler production and cropland acreage. The ability of broiler manure to satisfy field crop production requirements in each of these watersheds will be examined in the following chapter.

Table 4-7. Estimates of the primary plant nutrients contained in broiler manure produced annually in the Inland Bays drainage basin, tons/year*.

Sub-basin	Nitrogen	Phosphorus	Potassium
Rehoboth	215	75	118
Indian River	2,331	810	1,277
Little Assawoman	1,344	467	736
Total	3,890	1,352	2,131

*Based on estimated broiler production potential at 5.5 flocks per year, Table 3-2.

Table 4-8. Estimates of the primary plant nutrients contained in broiler manure produced annually in the Inland Bays drainage basin, lb/cropland acre/year*.

Sub-basin	Nitrogen†	Phosphorus	Potassium
Rehoboth	27.1	9.4	14.8
Indian River	104.2	36.2	57.1
Little Assawoman	317.1	110.2	173.6
Average	112.6	39.1	61.7

*Based on estimated broiler production potential at 5.5 flocks per year, Table 3-2.
†Based on the assumed loss of 50 percent of excreted broiler manure nitrogen.

CHAPTER 5

ESTIMATES OF PRIMARY PLANT NUTRIENTS RECOVERED IN FIELD CROP PRODUCTION

Broiler manure in combination with the minimal quantities of other animal manures produced in the Inland Bays drainage basin is one of the two major sources of nitrogen, phosphorus, and potassium available for crop production. The other is commercial fertilizer materials imported into the drainage basin. An additional source of nitrogen is the quantity of this nutrient fixed as the result of legume production. The efficiency in utilizing both the available nitrogen and phosphorus in crop production ultimately determines the impact of these nutrients on water quality in the drainage basin. Thus, the quantities of both of these nutrients, as well as potassium, recovered annually in crops harvested is of interest.

The Inland Bays drainage basin is primarily a grain producing region. The principal crops produced are corn, soybeans, wheat, and barley as feed grains for use by the poultry industry. Some grain sorghum also is produced but acreage is limited. Oil is extracted from soybeans before this grain is incorporated into broiler feeds. While some vegetable and fruit production also occurs in the drainage basin, acreage is relatively insignificant when compared to feed grain acreage. Vegetable production is primarily for processing, but some fresh market production also occurs. Principal vegetable crops include peas, lima beans, sweet corn, spinach, and melons. Due to relatively limited amount of vegetable and fruit acreage, nutrient recovery in the production of these crops was excluded from this analysis. Thus, estimates of nutrient recovery were limited to feed grains.

Generally, the same crop is not planted in a given field in consecutive years. Rather, a different crop is planted to control insect, disease, and weed populations. This practice is known as crop rotation. The typical field crop rotation in the Inland Bays drainage basin appears to be corn followed in the next year by wheat or barley and short season soybeans with full season soybeans in the third year. A fourth year of soybeans before returning to corn is not unusual nor is two years of corn before returning to wheat or barley. Occasionally, peas and/or lima beans may be included in a crop rotation. It is probable that the typical rotation is employed on no more than 40 percent to 50 percent of the field crop acreage in the drainage basin with a variety of permutations employed on the remaining acreage.

Several factors influence field crop rotations employed by individual farmers. One is anticipated crop prices including the difference between corn and soybean prices. If, for example, it is anticipated that soybean prices will be more attractive than those for corn, full season soybeans may be planted for a second year instead of corn. A second is the availability of irrigation. Generally, irrigated corn is more profitable than irrigated soybeans, but dry land soybeans are generally more profitable than corn without irrigation. Currently, area of irrigated cropland in the Inland Bays drainage basin or Sussex County is unknown. Sales information obtained from equipment dealers indicates, however, that use of irrigation has increased substantially in Sussex County in recent years.

A third factor that has been important is the presence and density of the soybean cyst nematode. This pest can dramatically reduce soybean yields and traditionally has been controlled by a crop rotation with several years without soybeans. However, this precludes following corn with wheat or barley which then normally would be followed by short season soybeans. The result is continuous corn for several years. The development of soybean varieties with resistance to the soybean cyst nematode should begin to reduce the influence of this pest on crop rotations in the future.

The factors influencing field crop rotations noted above contribute to the relative areas of each of the principal field crops planted in a given year. They also influence year-to-year changes in patterns of field crop production. The acreages of different field crops are important since they influence the potential for nutrient recovery from broiler and other animal manures. For example, soybean production does not require nitrogen fertilization since the soybean plant is a legume with the ability to fix atmospheric nitrogen through a symbiotic relationship with a species of the bacteria *Rhizobium*. Therefore, soybean production does not provide the opportunity to utilize available manurial nitrogen unless manure is used to supply needed phosphorus or potassium. Then, the nitrogen available will be utilized. Otherwise, it actually increases the pool of nitrogen in the animal-crop production system since fixation normally exceeds the amount recovered in the harvested grain. In addition, the amounts of phosphorus and potassium in the drainage basin are increased through the importation of these elements in the form of commercial fertilizers to satisfy the need for these nutrients.

The impact of crop selection on the nitrogen, phosphorus, and also potassium content of the harvested grain is illustrated in Table 5-1. This table was developed assuming yields that typically would be realized with generally adequate soil moisture and temperatures which would satisfy growing degree day requirements. The values used to calculate the nitrogen, phosphorus, and potassium content for each crop per acre based on the yields indicated are summarized in Table 5-2.

As can be seen in Table 5-1, a three year rotation of corn, wheat and short season soybeans, and full season soybeans has the potential of removing 234 pounds of nitrogen per acre from the commercial fertilizer-animal manure nitrogen pool. However, it also has the potential of adding at least 302 pounds of nitrogen per acre to the total inventory of nitrogen if animal manure is not used as a source of phosphorus and potassium. This is due to nitrogen fixation by soybeans and assumes no excess fixation of nitrogen which typically occurs. In addition, this rotation requires minimum inputs of 69 pounds per acre of phosphorus and 119 pounds per acre of potassium assuming 100 percent utilization efficiencies which are unrealistically low. These additions will be in the form of commercial fertilizer if residual phosphorus and potassium levels in the soil are inadequate.

In Table 5-3, field crop acreage for Sussex County, Delaware for the years 1988 through 1994 is summarized. Since the Delaware Department of Agriculture does not separate full season from short season soybean acreage, full and short season acreages were determined by assuming that the total small grain, wheat and barley, acreage equaled short season soybean acreage. Then full

Table 5-1. The impact of crop selection on the nitrogen, phosphorus, and potassium content of the harvested grain.

Crop	Yield, bu/a	lb/a/yr Nitrogen	Phosphorus	Potassium
Corn	150	126	23	26
Wheat	75	108	17	16
Short season soybeans	30	113	11	29
		221	28	45
Barley	100	96	16	19
Short season soybeans	30	113	11	29
		209	27	48
Full season soybeans	50	189	18	48

Table 5-2. Assumed densities and nitrogen, phosphorus, and potassium contents of corn, soybeans, wheat, and barley*.

Grain	International reference number	Density lb/bu	Percent Nitrogen	Phosphorus	Potassium
Corn	4-02-935	56	1.5	0.27	0.31
Soybeans	5-04-610	60	6.3	0.60	1.61
Wheat	4-05-211	60	2.4	0.38	0.36
Barley	4-00-549	48	2.0	0.33	0.40

*National Academy of Sciences, 1971.

season soybean acreage was assumed to be the difference between the reported total soybean acreage and the short season acreage.

Table 5-3. Sussex County, Delaware field crop acreage, 1988 through 1994*.

Year	Corn	Full Season Soybeans	Short Season Soybeans†	Wheat	Barley
1988	60,000	103,100	45,900	30,500	15,400
1989	56,500	106,000	61,000	38,000	23,000
1990	70,000	96,500	45,500	32,000	13,500
1991	70,000	117,700	52,300	35,000	17,300
1992	70,000	85,300	55,200	36,200	19,000
1993	79,800	72,100	50,600	32,000	18,600
1994	82,400	68,900	52,900	36,000	16,900
Mean	69,814	92,800	51,914	34,243	17,671
± SD	8,716	16,776	4,979	2,554	2,786

*Delaware Agricultural Statistics Service

†Soybeans following small grains.

As shown in this table, there is some variation with time in cropping patterns in Sussex County. Theoretically, corn, full season soybean, and short season soybean in combination with wheat or barley acreages should be equal each year if all grain producers followed the typical rotation described above. As shown in Table 5-3, the mean full season soybean acreage for these years is substantially higher than mean corn acreage with the difference reflected in the acreage used for small grain and short season soybean production. A probable result of this apparent bias toward soybean production, for one or more of the reasons discussed above, is higher application rates of broiler manure on land used for corn production.

In Table 5-4, field crop production in Sussex County for the years 1988 through 1994 is summarized, and production is summarized. As shown in this table, there is considerable year-to-year variation in the production of each crop in this county. While this variation is, to some degree, a reflection of changes in the number of acres of each crop (Table 5-3), it also is a reflection in growing conditions. Periods with less than adequate precipitation to meet crop needs in summer months occur frequently in this county as well as in other counties on the Delmarva Peninsula. Corn yields are most severely impacted by inadequate moisture especially during pollination. Thus, the lack of timely precipitation can significantly reduce corn yields. Soybean production also is affected by periods of inadequate moisture, but normally to a lesser degree. Abnormally low winter temperatures, especially in the absence of snow cover which is typical, also can reduce wheat and barley yields. It is the lack of adequate precipitation that is primarily responsible for the wide variation in corn yields shown in Figure 5-1. Since it was not possible to separate full season and short season production as discussed above, it was not possible to separately plot the year-to-year variations in these yields. As shown in Table 5-5, precipitation was significantly below normal in June, August, and September 1988 and in July and August in 1993.

Table 5-4. Sussex County, Delaware field crop production, 1988 through 1994, bu*.

Year	Corn	Soybeans	Wheat	Barley
1988	4,161,000	3,909,000	1,495,000	987,500
1989	5,631,000	4,694,000	1,440,000	988,000
1990	7,753,000	4,650,000	1,530,000	840,000
1991	7,394,500	5,831,000	1,736,000	1,104,000
1992	8,135,800	4,417,000	1,849,500	1,224,300
1993	6,892,300	2,878,000	1,668,600	976,500
1994	9,864,200	4,101,200	1,762,200	840,400
Mean	7,118,829	4,354,314	1,640,186	994,386
± SD	1,692,976	830,596	142,419	126,959

*Delaware Agricultural Statistics Service

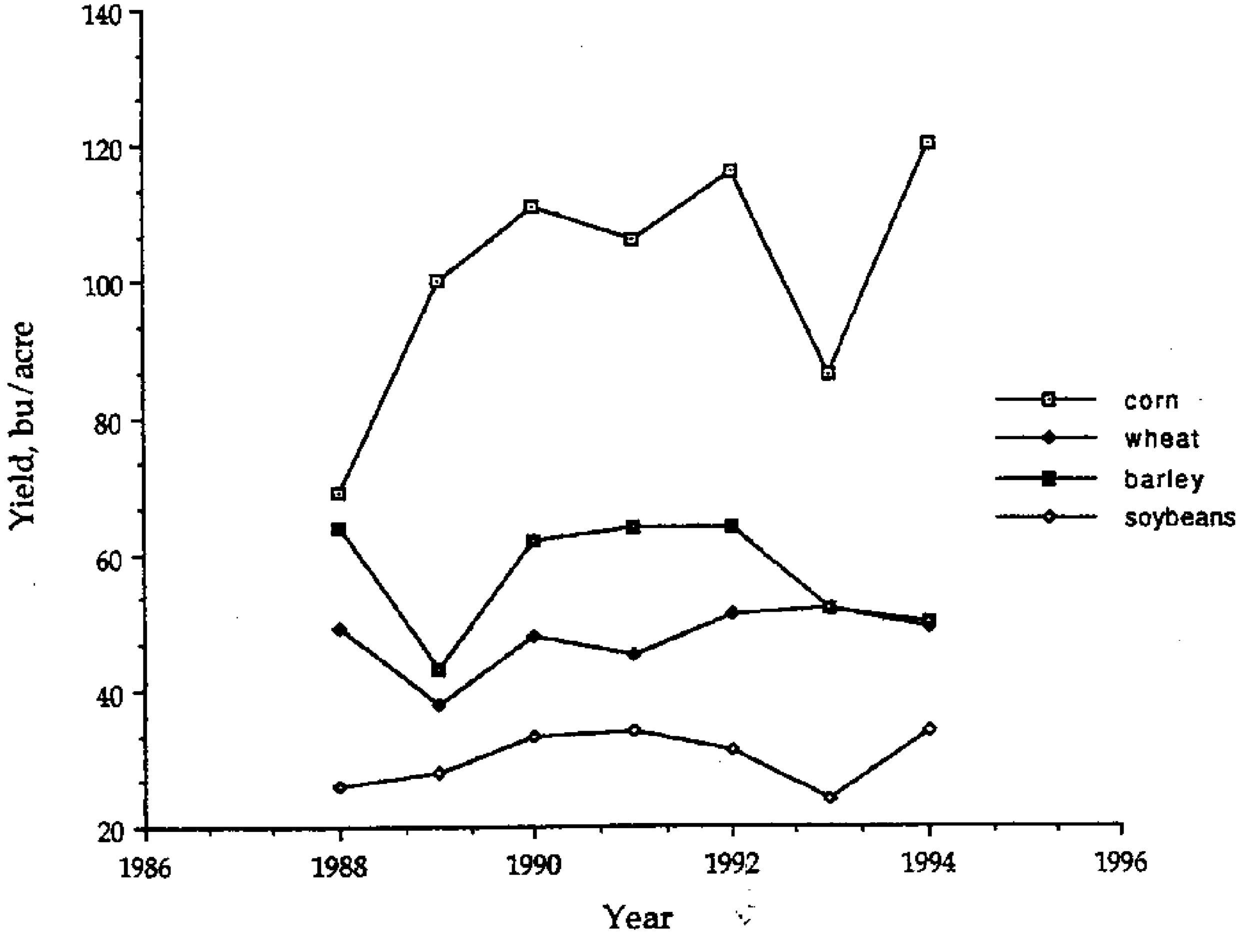

Figure 5-1. Variation in average annual corn, soybean, wheat, and barley yields in Sussex County, Delaware for 1988 through 1994.

Table 5-5. Monthly precipitation in Sussex County, Delaware for 1988 through 1994, inches*.

Month	Normal†	1988	1989	1990	1991	1992	1993	1994
January	3.67	3.88	2.66	3.16	5.29	1.28	3.53	3.71
February	3.15	3.78	2.86	1.93	1.10	3.45	2.22	6.87
March	3.99	3.03	8.06	3.50	6.69	3.29	7.56	9.50
April	3.44	2.62	5.53	3.39	3.42	1.65	4.81	2.99
May	3.65	3.95	3.81	7.21	1.43	3.75	3.75	3.34
June	3.41	0.97	5.39	1.62	2.19	2.73	4.04	3.72
July	3.70	6.48	8.70	6.63	5.96	3.29	2.11	4.74
August	5.46	3.30	6.70	7.16	4.61	8.83	4.00	5.02
September	3.41	2.21	6.59	2.67	3.90	4.78	3.93	3.76
October	3.27	2.63	4.02	3.16	2.55	1.71	4.57	0.80
November	3.18	4.29	3.61	1.88	1.12	3.47	3.11	4.34
December	3.46	0.40	1.65	3.46	4.66	3.63	4.05	1.52

*Georgetown, Delaware

†20-year mean

The nitrogen, phosphorus, and potassium content of each of the major field crops harvested in Sussex County from 1988 through 1994 are summarized in Tables 5-6 though 5-8. These quantities were calculated using the production estimates presented in Table 5-4 assuming the characteristics presented in Table 5-2. The results of these nitrogen, phosphorus, and potassium recovery estimates illustrate the significance of variation in crop production patterns and yields on year-to-year differences in nutrient utilization. The magnitudes of these differences also are illustrated in Figure 5-2.

Table 5-6. Nitrogen content of field crops harvested in Sussex County, Delaware—1988-1994, lb.

Year	Corn	Soybeans	Wheat	Barley	Total w/o soybeans
1988	3,495,240	14,776,020	2,152,800	948,000	6,596,040
1989	4,730,040	17,743,320	2,073,600	948,480	7,752,120
1990	6,512,520	17,577,000	2,203,200	806,400	9,522,120
1991	6,211,380	22,041,180	2,499,840	1,059,840	9,770,700
1992	6,834,072	16,696,260	2,663,280	1,175,328	10,672,680
1993	5,789,532	10,878,840	2,402,784	937,440	9,129,756
1994	8,285,928	15,502,536	2,537,568	806,784	11,630,280
Mean	5,979,816	16,459,308	2,361,867	954,610	9,296,242
± SD	1,422,099	3,139,651	205,083	121,881	1,573,057

Table 5-7. Phosphorus content of field crops harvested in Sussex County, Delaware—1988-1994, lb.

Year	Corn	Soybeans	Wheat	Barley	Total
1988	629,143	1,407,240	340,860	156,420	2,533,663
1989	851,407	1,689,640	328,320	156,499	3,025,866
1990	1,172,254	1,674,000	348,840	133,056	3,328,150
1991	1,118,048	2,099,160	395,808	174,874	3,787,890
1992	1,230,133	1,590,120	421,686	193,929	3,435,868
1993	1,042,116	1,036,080	380,441	154,678	2,613,315
1994	1,491,467	1,476,432	401,782	133,119	3,502,800
Mean	1,076,367	1,567,533	373,962	157,511	3,175,365
± SD	255,978	299,014	32,471	20,110	434,846

Table 5-8. Potassium content of field crops harvested in Sussex County, Delaware—1988-1994, lb.

Year	Corn	Soybeans	Wheat	Barley	Total
1988	722,350	3,776,094	707,616	189,600	5,395,660
1989	977,542	4,534,404	671,328	189,696	6,372,970
1990	1,345,921	4,491,900	660,960	161,280	6,660,061
1991	1,283,685	5,632,746	767,016	211,968	7,895,415
1992	1,412,375	4,266,822	876,960	235,066	6,791,223
1993	1,196,503	2,780,148	775,656	187,488	4,939,795
1994	1,712,425	3,961,759	816,480	161,357	6,652,021
Mean	1,235,829	4,206,268	753,717	190,922	6,386,735
± SD	293,900	802,355	73,000	24,376	899,275

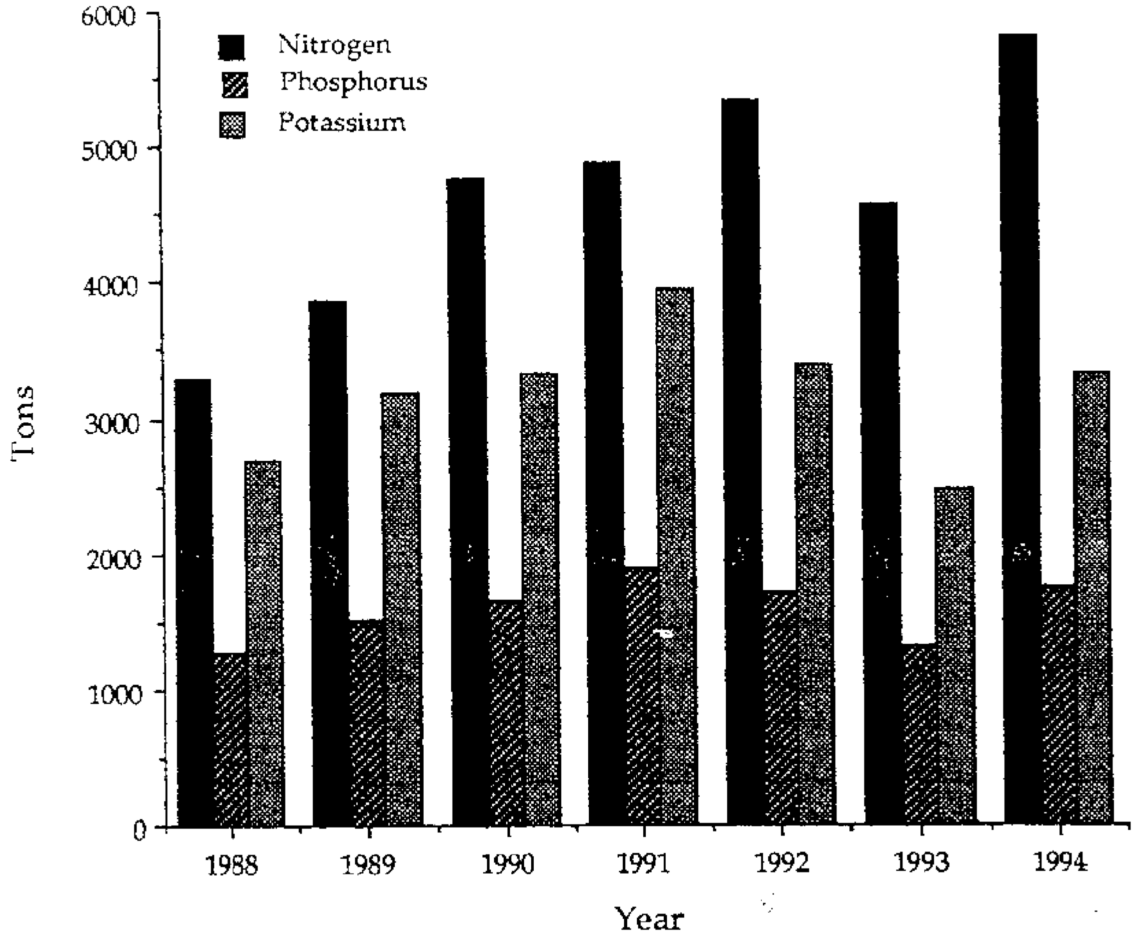

Figure 5-2. Variation in nitrogen, phosphorus, and potassium content of field crops harvested in Sussex County, Delaware from 1988 through 1994.

CHAPTER 6

PLANT NUTRIENT BALANCES

As discussed earlier, the nitrogen, phosphorus, and potassium utilized for field crop production in the Inland Bays drainage basin are obtained from two principle sources, commercial fertilizer materials and broiler litter. In Table 6-1, the estimated annual quantities of these primary plant nutrients potentially available from broiler litter are compared with average annual quantities recovered in harvested field crops. The nitrogen recovered in harvested soybeans is excluded from the nitrogen comparison based on the assumption that all soybean nitrogen recovered is derived from the microbial fixation of atmospheric nitrogen. This is a conservative assumption since: 1) residual nitrogen from the disposal of broiler litter in years prior to soybean production is unrealistically considered to be nil and 2) some broiler litter is used as a source of phosphorus and potassium for soybean production. Thus, phosphorus and potassium recovery in field crops with and without soybean production is presented. In addition, loss of nitrogen through ammonia volatilization during storage, handling, and following spreading of broiler litter is not considered. As discussed earlier, this loss typically has been assumed to be between 30 percent and 50 percent.

Given the estimate of broiler production per acre of cropland in the Rehoboth Bay, Indian River Bay, and Little Assawoman Bay watersheds (Table 3-2), the substantial surpluses of broiler manure phosphorus and potassium in the Indian River Bay and Little Assawoman Bay watersheds (Table 6-1) is not surprising. The inability of broiler manure to satisfy the nitrogen, phosphorus, and potassium demand for field crop production in the Rehoboth Bay watershed also was an expected result given the estimated broiler production per acre of cropland in this watershed. The relatively small surplus of broiler manure nitrogen in the Indian River Bay watershed when losses of this nutrient during storage, handling, and spreading are considered was unexpected, however. Also unexpected was the magnitude of the surplus of broiler manure nitrogen in the Little Assawoman Bay watershed even when unavoidable losses are considered. These results clearly indicate that the significance of the broiler industry as sources of both nitrogen and phosphorus entering adjacent surface and ground waters differs greatly among these three watersheds.

Table 6-1. Comparisons of broiler manure plant nutrient content with recovery in field crops in the Inland Bays drainage basin, tons/year.

	Broiler manure*	Field crops	Field crops w/o soybeans
Nitrogen			
Rehoboth Bay	215	—	344
Indian River Bay	2,331	—	967
Little Assawoman Bay	1,344	—	186
Drainage Basin	3,890	—	1,497
Phosphorus			
Rehoboth Bay	75	117	60
Indian River Bay	810	330	167
Little Assawoman Bay	467	64	32
Drainage Basin	1,352	511	259
Potassium			
Rehoboth Bay	118	236	80
Indian River Bay	1,277	664	227
Little Assawoman Bay	736	128	44
Drainage Basin	2,131	1,028	351

* Nitrogen as excreted. Loss of 30 percent to 50 percent during storage, handling, and application commonly assumed.

In spite of the disparity in recovery of broiler manure nitrogen, phosphorus, and potassium through field crop production among the three major watersheds in the Inland Bays drainage basin, overall efficiencies for the basin differ little from those for Sussex County (Table 6-2). In both the drainage basin and the county, 38 percent of broiler manure nitrogen is recovered in harvested field crops excluding soybeans. With soybeans included, recovery of phosphorus is 38 percent in the Inland Bays drainage basin is 38 percent versus 36 percent for the county. The values for potassium are 46 percent versus 48 percent.

Table 6-2. Comparisons of broiler manure plant nutrient content with recovery in field crops in Sussex County, Delaware, tons/year (Martin, 1998).

	Broiler manure*	Field crops	Field crops w/o soybeans
Nitrogen	12,200	—	4,648
Phosphorus	4,357	1,588	804
Potassium	6,681	3,059	891

* Nitrogen as excreted. Loss of 30 percent to 50 percent during storage, handling, and application commonly assumed.

Absent from Table 6-1 is estimates of commercial fertilizer nitrogen, phosphorus, and potassium use for field crop production in the Inland Bays drainage basin because sales data only are available on a county basis. If, however, application rates for Sussex County are representative of the rates used in this drainage basin, the additional input of these nutrients is 93.1 pounds of nitrogen, 11.7 pounds of phosphorus, and 73.5 pounds of potassium per cropland acre. These estimates are based on means of sales for the period 1987 through 1996 (Table 4-1). These application rates translate into the potential additional nitrogen, phosphorus, and potassium inputs summarized in Table 6-3.

Table 6-3. Estimates of commercial fertilizer nitrogen, phosphorus, and potassium use in the Inland Bays drainage basin, tons/year.

Nitrogen	
Rehoboth Bay	739
Indian River Bay	2,082
Little Assawoman Bay	395
Total	3,216
Phosphorus	
Rehoboth Bay	93
Indian River Bay	262
Little Assawoman Bay	50
Total	404
Potassium	
Rehoboth Bay	584
Indian River Bay	1,644
Little Assawoman Bay	311
Total	2,539

When estimates of primary plant nutrient inputs from both broiler litter and commercial fertilizers are combined and compared to recovery through field crop production (Table 6-4), recovery efficiencies become remarkably low. Without any allowance for loss of nitrogen from broiler manure, recovery efficiency is 21 percent in the drainage basin and increases only to 29 percent when a 50 percent loss of broiler manure nitrogen is assumed. Recovery efficiencies for phosphorus and potassium are 29 percent and 22 percent, respectively. It is notable that commercial fertilizer phosphorus inputs approach estimated recovery in field crops. These comparisons suggest that broiler manure is not the only significant source of nitrogen and phosphorus with the potential of impairing surface and ground water quality in the Inland Bays drainage basin. Clearly, commercial fertilizers are also a significant source.

Table 6-4. Summary of estimates of primary plant nutrient input and recovery through field crops in the Inland Bays drainage basin, tons/year.

	Inputs			Recovered	
	Broiler Manure	Commercial Fertilizer	Total	Field Crops	Field Crops w/o Soybeans
Nitrogen					
Rehoboth Bay	215	739	954 (846)*	—	344
Indian River Bay	2,331	2,082	4,413 (3,248)	—	967
Little Assawoman Bay	1,344	395	1,739 (1,067)	—	186
Drainage Basin	3,890	3,216	7,106 (5,161)	—	1,497
Phosphorus					
Rehoboth Bay	75	93	168	117	60
Indian River Bay	810	262	1,072	330	167
Little Assawoman Bay	467	50	517	64	32
Drainage Basin	1,352	404	1,756	511	259
Potassium					
Rehoboth Bay	118	584	702	236	80
Indian River Bay	1,277	1,644	2,921	664	227
Little Assawoman Bay	736	311	1,047	128	44
Drainage Basin	2,131	2,539	4,670	1,028	351

* Assuming a 50 percent loss of broiler manure nitrogen.

In analyzing nitrogen and phosphorus recovery efficiencies in harvested field crops for all the counties with reported values for broiler production on the Delmarva Peninsula, Martin (1998) found that both decreased logarithmically as broiler production per acre of cropland increased. As shown in Figures 6-1 and 6-2, recovery efficiencies for both nutrients in each of the three major watersheds in the Inland Bays drainage basin and also for the drainage basin follow the same pattern of decline as broiler production per cropland acre increases. Interestingly, phosphorus recovery efficiencies in the Inland Bays drainage basin are remarkably close to the regression line shown which does not include the Inland Bays estimates. With the exception of the Rehoboth Bay watershed, it appears that recovery efficiencies of nitrogen in the Inland Bays drainage basin are somewhat lower than those for the region as indicated by the regression line shown. Again, this regression line does not include the Inland Bays estimates. Thus, it can be concluded that the three watersheds in the Inland Bays drainage basin are not unique but rather typical of the region. This suggests that the estimates of commercial fertilizer nitrogen and phosphorus use in the three Inland Bays watersheds are reasonable.

The low nitrogen and phosphorus recovery efficiencies in both the Indian River Bay and Little Assawoman Bay watershed are not surprising given the intensity of broiler production per acre of cropland in both watersheds. Because of the limited capacity to recover both of these nutrients through field crop production, clearly the potential for substantial movement of nitrogen into both surface and ground water and phosphorus primarily into surface waters is high.

In considering the mass balances for nitrogen presented in this chapter, it should be recalled that estimates of loss from broiler manure during storage, handling, and application were generally excluded. As previously noted, a loss of between 30 percent and 50 percent as volatilized ammonia commonly is assumed. However, no estimates of inputs of nitrogen through wet and dry atmospheric deposition were included. It is highly probable that a significant fraction of the ammonia nitrogen volatilized in this drainage basin is not exported. In addition, inputs of nitrogen through atmospheric deposition from outside this watershed also are probably significant.

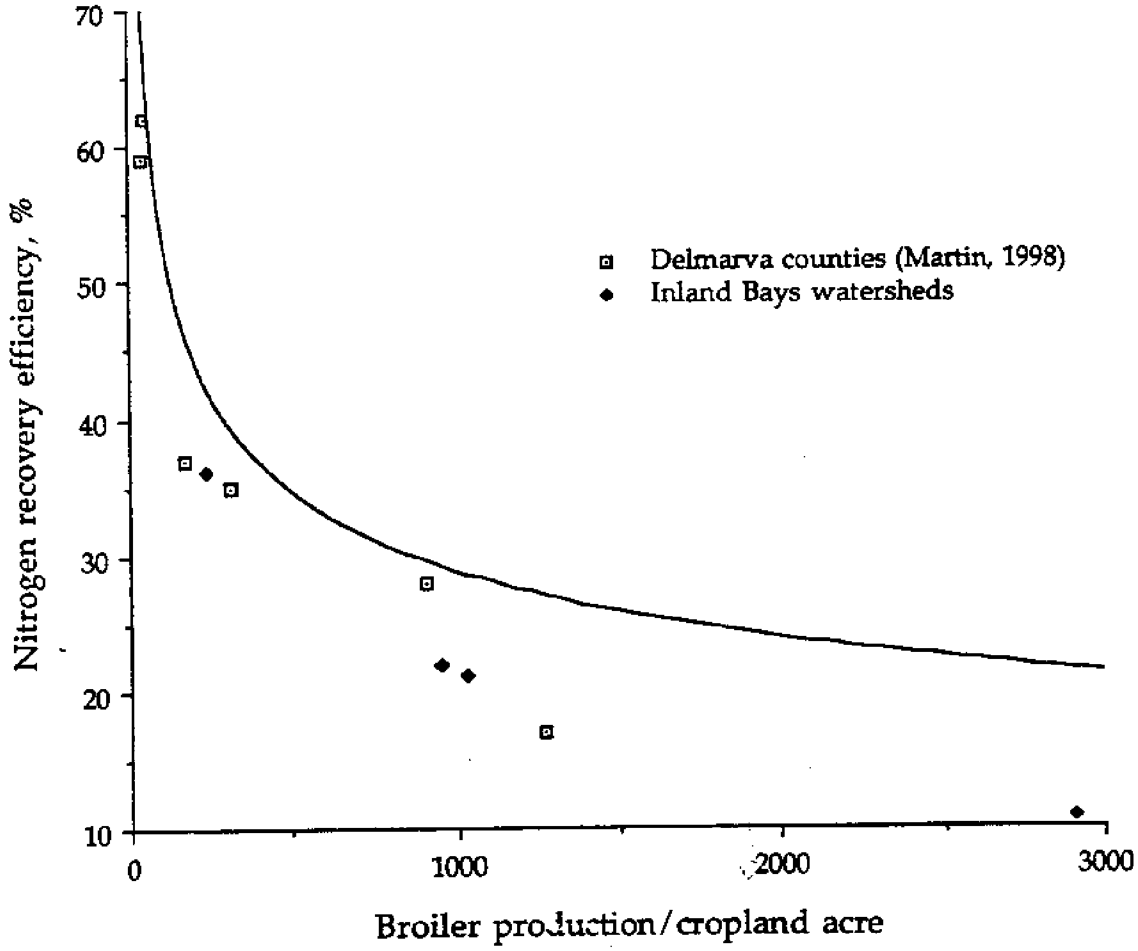

Figure 6-1. Commercial fertilizer and broiler manure nitrogen recovery efficiency in harvested corn, wheat, and barley as a function of broiler production per cropland acre.

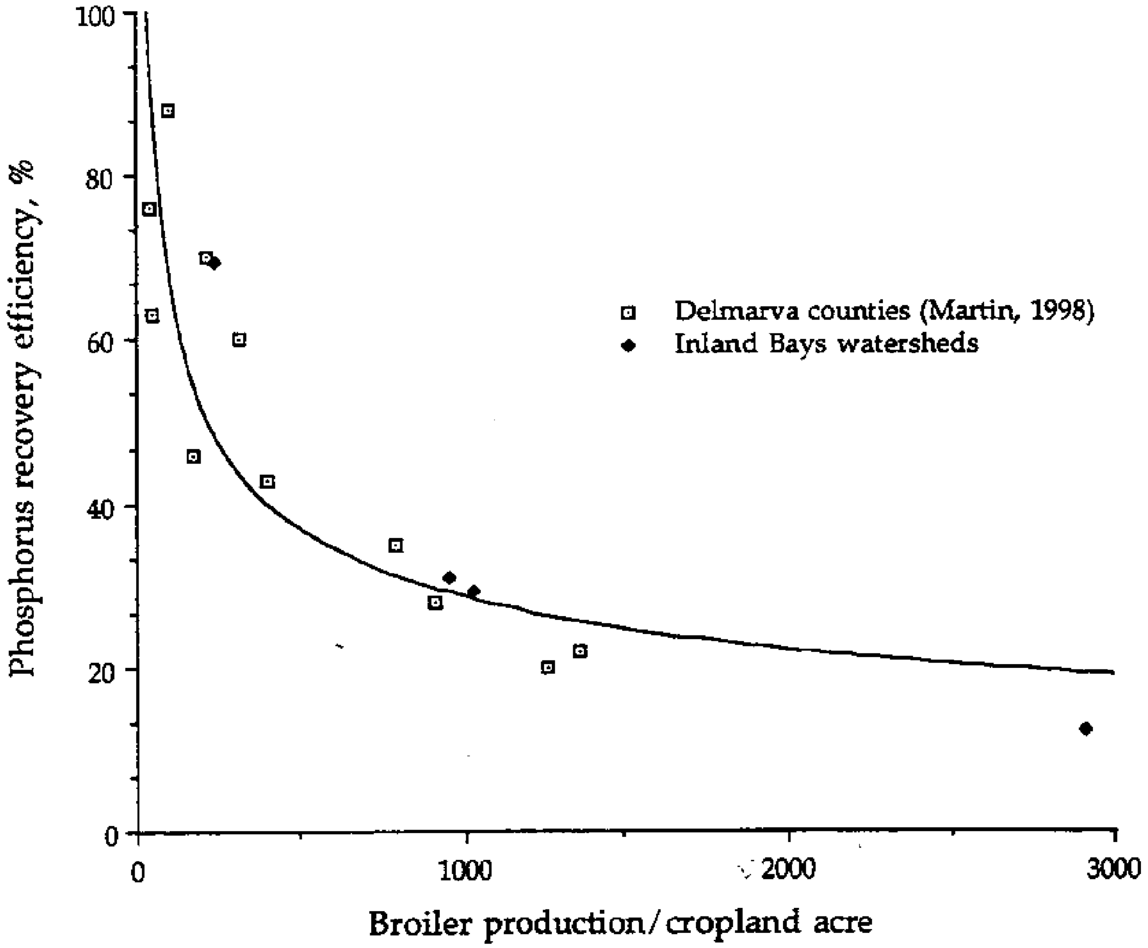

Figure 6-2. Commercial fertilizer and broiler manure phosphorus recovery efficiency in harvested corn, soybeans, wheat, and barley as a function of broiler production per cropland acre.

It should be recognized that inputs of primary plant nutrients from either animal manures or commercial fertilizers can never be completely recovered through crop production. This is due to various unavoidable losses such as leaching losses, losses in surface runoff, and losses resulting from various biological and chemical processes in the soil. Included in the last category is the loss of nitrogen through denitrification and immobilization of phosphorus through chemical reactions with iron, aluminum, manganese, calcium, and magnesium in the soil.

A sense of the levels of these losses for nitrogen and phosphorus, which are unavoidable, can be obtained from Figures 6-1 and 6-2. Average nitrogen recovery efficiency for five Delmarva counties with minimal broiler production is about 56 percent (Figure 6-1). For phosphorus (Figure 6-2), average recovery efficiency for these five counties is about 69 percent.

In closing, it should be remembered that the nutrient recovery efficiencies estimated in this chapter are average values derived from crop yields for the period 1988 through 1994. As discussed in Chapter 5, there was considerable year-to-year variations in these yields due to differences in precipitation and temperature with corn yields most significantly affected. Thus, nutrient recovery efficiencies will be above average with ideal growing conditions but can be significantly lower with below average precipitation or temperatures or both.

CHAPTER 7

DISCUSSION

BACKGROUND

The results of the plant nutrient balances presented in Chapter 6 clearly indicate the need for an alternative or combination of alternatives to land application in both the Indian River Bay and Little Assawoman Bay watersheds for the disposal of a significant fraction of the broiler manure produced in both watersheds. One alternative that has been mentioned frequently is to transport broiler manure to areas where it could be used as a substitute for commercial fertilizers, an idea frequently referred to as redistribution. A second complimentary alternative is to add inorganic fertilizer materials to balance primary plant nutrient content and then pelletize the end-product to facilitate use in conventional fertilizer application equipment. Other possible options include composting to enhance marketability as a horticultural material, use as a boiler fuel for energy production, and use as a feedstuff. Two of these options, redistribution of this material as produced or after fortification with inorganic fertilizer materials, are discussed below.

DIRECT REDISTRIBUTION

A number of studies have assessed the feasibility of redistributing broiler manure for use as a substitute for commercial fertilizer, *e.g.*, Bosch and Napit (1991) and Harsch (1995). Conceptually, the idea of transporting broiler as well as other animal manures from areas of intensive production to areas where an opportunity exists for substitution of commercial fertilizers is attractive. This idea only is attractive economically, however, if demand exists at a price that is competitive with commercial fertilizers. Thus, the sum of acquisition, handling, transportation, and application costs can be no greater than the cost of commercial fertilizer to provide the same nutrients. Ideally, the sum of these costs should be somewhat less to provide some degree of profit for a broker as compensation for the service rendered.

Although, broiler manure can contain significant quantities of nitrogen, phosphorus, and potassium as well as a variety of trace nutrients, concentrations are low when compared to commercial fertilizers. Also, nutrient concentrations can be highly variable due to a number of factors including: 1) moisture content with "cake" or "crust" typically having a higher moisture content that the remaining material, 2) number of flocks raised on the litter (the number of grow-out cycles), as well as diet formulation, as discussed in Chapter 4, and 3) bird performance. Crust or cake is the solidified manure and litter which accumulates under waterers and feeders and is removed after each flock of birds. Although it is somewhat difficult to assign a typical monetary value per unit weight to broiler manure based on plant nutrient content, it is necessary to assign such a value to determine the maximum cost of utilization or the point when the cost of this material to the user begins to exceed the cost of commercial fertilizer.

In a study of broiler manure production, Malone *et al.* (1992) determined the weight and density of cake removed and the remaining manure and litter after each of 18 grow-out cycles over a three-year period under commercial conditions. In this study, the effect of type of watering system was evaluated. For the nipple system, which now is the standard system in the broiler industry on the Delmarva Peninsula, manure production for two broiler integrators was measured. Malone *et al.* found little difference between the two integrators in both cake and the remaining manure after each grow-out cycle. After six grow-out cycles, they found net manure production, including cake removed after each grow-out cycle, to be 6.43 wet tons for integrator A and 6.54 wet tons for integrator B per 1,000 birds of production capacity. At the beginning of this study, 2.01 wet tons and 1.38 wet tons of pine sawdust per 1,000 birds of production capacity were placed, respectively, in the two broiler houses used for this segment of the study. Adding the average of these two values, 1.74 wet tons, to the manure produced results in the values of 8.17 and 8.28 wet tons of waste from six grow-out cycles per 1,000 birds of production capacity or an average of 247 wet tons for a 30,000-bird capacity house.

On the basis of the estimates of excreted primary plant nutrients presented in Chapter 4, the manure excreted over six grow-out cycles in a 30,000 bird capacity broiler house contains 18,968 pounds of nitrogen, 6,774 pounds of phosphorus, and 10,431 pounds of potassium. Assuming a value of $0.23 for N, $0.31 for P_2O_5, and $0.16 for K_2O based on current (1998) fertilizer prices on the Delmarva Peninsula and a loss of 50 percent of the nitrogen excreted, the manure and litter from this house would have an estimated value of $9,002.33 or $36.45 per wet ton. On this basis, a tractor trailer load of 50,000 pounds would have an estimated value of $911.25. Obviously, values on a wet ton basis will vary inversely with manure moisture content.

This type of analysis, which has been performed a number of times in the past, is too simplistic, however, for the following reason. It assumes that a demand exists at this price, but the marketplace demonstrates this to be untrue. As discussed below, there is little demand for broiler manure at this price.

Unfortunately, it is almost impossible to determine the actual monetary value of broiler manure even in a small geographical area such as the Inland Bays drainage basin because the market for this material is unstructured and highly fragmented. One method to estimate the monetary value of broiler manure is the labor, equipment, and transportation costs that contract clean-out services and local grain producers are willing to incur in removing manure from broiler houses in exchange for this material. Many broiler producers on the Delmarva Peninsula traditionally have contracted for crust removal and total house clean-out on this basis.

Conversations with several individuals experienced in manure removal from broiler production facilities suggest that 56 hours is a reasonable estimate of personnel and equipment requirements for removal of manure and litter, including crust, accumulated in a 30,000 bird capacity, clear-span house over a period of two years. At $40 per hour for labor and equipment, this translates into a cost of $2240. Assuming an accumulation of 494 tons of manure over this time period, the cost per ton for removal is $4.53. Bosch and Napit (1991) estimated clean-out cost to be $4.15 per ton including transportation of 10 miles at $0.10 per ton per loaded mile. When spreading costs of $1.50 per ton, as estimated by Bosch and Napit, are included, the value of \$6.00 per ton appears to be a reasonable estimate of the perceived value or "willingness to pay" for broiler manure in the Inland Bays drainage basin as well as elsewhere on the Delmarva Peninsula.

A recent survey of Delmarva Peninsula broiler producers (Michel *et al.* 1996) shows, however, that a significant fraction of broiler producers in this region has to pay for manure removal. This suggests negative valuation. Forty-one percent of the respondents to this survey indicated that they pay from less than \$3 to over \$10 per ton for this service. In addition, five percent of the respondents to this survey reported that they sold their manure. Reported prices received ranged from less than \$3 up to \$25 per ton. Thus, the estimate of "willingness to pay" presented above is, at best, an average of a wide range of valuations.

One fundamental reason may account for the substantial difference between the estimated monetary value of broiler manure based on primary plant nutrient content and the estimated value in this region based on the "willingness to pay" estimated above. It is that supply greatly exceeds demand, which reflects the reluctance of crop producers to use broiler manure as a substitute for commercial fertilizers. This reluctance can be attributed to the following. Unlike commercial fertilizer, broiler manure is highly variable in nutrient content with substantial spatial variation even within a single broiler production facility. Even it reasonably accurate average values for the primary plant nutrient concentrations can be determined through intensive sampling and analysis, variation between and within truck or spreader loads is unavoidable without complete mixing of at least the manure removed from a single or preferably several broiler houses. The time lag associated with nutrient analyses also can be a problem.

A second problem is that broiler manure has a relatively low nitrogen content in relation to phosphorus and potassium. This is due, in part, to nitrogen losses resulting from ammonia volatilization during the accumulation of manure in broiler production facilities, as discussed in Chapter 4, and also subsequent removal and spreading. Although rapid incorporation into the soil after spreading will reduce ammonia volatilization to a degree, use of no-till or minimum tillage practices precludes incorporation in many instances. To maximize phosphorus and potassium utilization, an additional application of nitrogen fertilizer with the associated spreading cost is required. In addition, fractions of both nitrogen and phosphorus are in organic forms leading to uncertainty as to time of availability. Crop producers, therefore, generally view the uncertainty of the availability of these two nutrients associated with the use of broiler manure as a substitute for commercial fertilizer to be substantial, and heavily discount the monetary value of this material.

A third problem is one of logistics. On the Delmarva Peninsula, total clean-out of broiler houses normally occurs only once every two to three years due to the cost of the pine sawdust used as initial litter material. Currently, a total clean-out every two years appears to be the predominant cycle. In the absence of an aggregator or broker, a crop producer would have to contract with several broiler producers to ensure a constant annual supply. In addition, each broiler producer logically would desire some assurance of a long-term commitment before terminating an existing arrangement for disposal. Also, total house clean-outs, which generate the bulk of manure, commonly occur during the late fall and early winter. Cake or crust is generated throughout the year following each grow-out cycle. Thus, some type of storage facility, preferably at the site of use is desirable to insure timely availability to the crop producer. Historically, cost-share funds for manure storage structures have been available only to broiler producers, and then only for structures with the capacity to store cake or crust. Even if cost-share funds were made available to crop producers utilizing broiler manure, current levels only partially offset the cost of the storage structure, which would have to be considerably larger than currently used storage structures. This cost would obviously further increase the cost of using this material in place of commercial fertilizer. Bosch and Napit (1991) estimated the annual cost of storage for six months to be $1.82 per ton.

Transportation cost often is cited as the principal impediment to the movement of broiler manure to areas where substantial quantities of commercial fertilizer currently are being used. Published cost estimates have ranged from $0.05 (Hardy, 1994) to $0.10 (Weaver and Souder, 1990) per ton per loaded mile for a 25-ton load with no back-haul. Recent (1998) price quotations obtained from several Sussex County, Delaware trucking companies averaged $0.08 per ton per loaded mile. Obviously, transportation cost is a function of distance, but its significance is a function of the value potential purchasers assign to this material in relation to the price broiler growers expect. This difference divided by the cost of transportation per ton-mile determines, at least in theory, the maximum distance that is economically feasible to move broiler manure. The absence of this difference explains why there currently is little movement of broiler manure out of the Inland Bays drainage basin as well as elsewhere on the Delmarva Peninsula. If broiler manure is available at no cost, the estimated "willingness to pay" of $4.53 per ton should allow movement of approximately 57 miles at a transportation cost of $0.08 per loaded ton mile. When there is an indication of demand, little manure has been available historically at no cost. This situation will probably change, however, if implementation of nutrient management plans for both nitrogen and phosphorus is mandated as currently proposed.

While there have been published reports of significant movement of broiler manure in other areas of the United States, review of these reports generally reveals either an overstatement of success or the reflection of a unique situation. For example, the success of the effort by Winrock International (Harsch 1995) in Arkansas to facilitate the redistribution of broiler manure was due, to a significant degree, to demand created by the precision leveling of rice fields to reduce irrigation costs. Following precision leveling, rice yields dropped substantially as the result of top soil removal. With the demonstration that yields could be substantially increased with the application of broiler manure, due primarily to the increase in soil organic matter content, a unique demand situation was created. In addition, transportation costs were reduced by the ability to back haul broiler manure following delivery of rice hulls, which is the principal litter material used by the Arkansas broiler industry. Harsch also noted the increase in nitrogen fertilizer prices due to the closure of two fertilizer plants in the rice producing region of Arkansas as factor stimulating demand for broiler manure as a source of plant nutrients. Even with this unique set of circumstances, it was admitted that redistribution was almost entirely from the broiler producing area of Arkansas relatively close to the eastern delta rice producing region and not from the more remote northwestern counties where broiler production is most intense.

Historically, most of the movement of broiler manure from areas of concentrated production has been for use as a feedstuff for beef cattle. Several decades of research at both Auburn University and Virginia Polytechnic Institute and State University have demonstrated that broiler manure can be substituted for a portion of conventional feedstuffs in beef cattle rations with no adverse effect on performance. Economic return depends on the cost of the broiler manure used. In 1983, Martin *et al.* estimated the maximum monetary value of broiler manure as a feedstuff for beef cattle to be $90 per ton based on the cost of conventional feedstuffs replaced. Since current costs for these feedstuffs differ little from 1983, $90 per ton still appears to be a reasonable estimate. Therefore, demand at $45 per ton, for example, will be substantial and transportation over a considerable distance can occur.

AMENDMENT WITH INORGANIC FERTILIZER MATERIALS

As discussed above, the relatively low nitrogen content of broiler manure in relation to phosphorus and potassium is one of the significant factors limiting the monetary value of this material as a source of plant nutrients for field crop production. Amending broiler litter with inorganic fertilizer materials and pelleting the resulting mixture to insure uniform nutrient content seemingly is a solution to this problem. Ransom *et al.* (1992) have shown that this process is technically feasible, and Taylor *et al.* (1996) have shown that crop response is equal to an inorganic fertilizer with a comparable primary plant nutrient content.

Currently, nutrient enhanced broiler manure is not competitive economically with inorganic fertilizers, however, due to handling, production, and storage costs. In an analysis of the economic potential of processing and marketing broiler manure, Hardy (1994) estimated the cost of pelleting and bagging to be $21.32 per ton. The estimated cost of pelleting alone was $15.32 per ton. When the additional costs of handling and storage in combination with cost of the inorganic fertilizer materials added are included, the resulting cost of this material exceeds that of a commercial fertilizer of comparable primary plant nutrient content. Thus, little demand for nutrient enhanced broiler manure has developed.

OPTIONS

From the broad perspective of establishing and maintaining a sustainable system for the production of broiler type chickens, the nutrients contained in broiler manure should be used in the production of the feed grains used by the broiler industry. As Martin (1998) has illustrated, this currently does not occur on the Delmarva Peninsula due to the difference in the spatial distributions of broiler and feed grains production. Thus, there is substantial use of commercial fertilizer nitrogen, phosphorus, and potassium in areas of the region, such as Kent County, Delaware, and the upper eastern shore counties in Maryland, where there is lower intensity broiler but extensive feed grain production. Conversely, excess quantities of these nutrients are present in areas of concentrated broiler production, such as the Indian River Bay and Little Assawoman Bay watersheds in the Inland Bays drainage basin.

Two approaches are possible to reconcile these differences in spatial distributions. One is the redistribution broiler production. Given the loss of current investment in infrastructure, this obviously is not a feasible option, at least in the short-term. The second is to facilitate the redistribution of the manure produced in those areas of concentrated broiler production. Obviously, intervention by government or the broiler industry will be necessary to facilitate redistribution of manure given the demonstrated inability of the market-place to accomplish this task. An example of this failure is the negligible impact of the Delmarva Poultry Industry, Inc.'s manure exchange program. To do so, one of two things must occur, however. Either the "willingness to pay" by feed grain producers for broiler manure as a source of plant nutrients must be increased to pay the costs associated with redistribution or a subsidy must be provided to pay these costs.

Ideally, it should be possible to increase the valuation of broiler as well as other animal manures as sources of plant nutrients through educational programs designed to demonstrate equivalency to commercial fertilizer materials. The results of past efforts by the Land Grant College System and agencies such as the Natural Resources Conservation Service suggest that this approach has been, at best, only marginally successful.

A second possible approach is to increase the cost of commercial fertilizer materials through taxation to make broiler manure more attractive economically as a source of plant nutrients. With this approach, an upward valuation of animal manures as sources of plant nutrients should occur and a less fragmented market for manures should evolve. In addition, the tax revenue generated could be used as a subsidy to at least partially offset transportation and other costs associated with manure distribution. By necessity, taxation would have to be, at a minimum, on a state-wide and preferably a regional or national basis. While taxing fertilizer materials to stimulate demand for manures as sources of plant nutrients may be conceptually attractive, resolving equity issues may be an impossible task.

The remaining option, providing a subsidy to offset the costs of handling and transportation associated with the movement of broiler manure from areas of concentrated production, such as the Inland Bays drainage basin, appear the most practical approach. Implementing such a subsidy program will not be a simple task, however, given the contentious question of the source of funding. One approach, which currently is being advocated by the U.S. Environmental Protection Agency, is for the broiler industry to marginally increase the price of chicken nationally with the revenue generated dedicated to addressing the problem of waste disposal. Unfortunately, the magnitude of the increase in the price of chicken necessary to generate the necessary revenue has not been determined or even estimated. The second is a direct government subsidy. The question of which approach is more desirable is primarily a political question and is beyond the scope of this study.

As mentioned earlier, the redistribution of broiler manure for use as substitute for commercial fertilizer is not the only option for addressing the problem of excess nutrients in areas such as the Inland Bays drainage basin. The use of this material as a feedstuff for ruminants, a fuel, or a horticultural material also are options. However, each of these options also involves costs that may or may not be recoverable in the market place.

CHAPTER 8

SUMMARY AND CONCLUSIONS

This study had two objectives. The first was to compare the quantities of nitrogen and phosphorus contained in broiler manure and commercial fertilizers utilized for field crop production in each of the three major watersheds in the Inland Bays drainage basin with the recovery of these primary plant nutrients in the crops harvested. The second objective was to evaluate the potential for exporting the excess broiler manure nitrogen and phosphorus from the drainage basin for use as a substitute for commercial fertilizers in areas with little poultry or livestock production.

The nitrogen and phosphorus contained in the broiler manure in each watershed was estimated from the estimates of annual broiler production capacity and the nitrogen and phosphorus content of the manure produced. Commercial fertilizer nitrogen and phosphorus use were based on average values per unit of cropland for Sussex County and the area of cropland in each watershed. Nitrogen and phosphorus recovered through harvested field crops was based on seven-year averages of yields in Sussex County for the four major field crops; corn, soybeans, wheat, and barley; produced in the drainage basin and the average nitrogen and phosphorus content of each crop.

The results of this study generally confirm the validity of previous assessments that also concluded the quantities of nitrogen and phosphorus in the broiler manure produced in the drainage basin substantially exceed requirements for crop production. The magnitudes, and thus significance, of the surpluses differ, however, among the three watersheds as shown in Table 6-4. For example, broiler manure nitrogen and phosphorus in the Rehoboth Bay watershed is not adequate to meet field crop production demands. In contrast, broiler manure nitrogen and phosphorus in both the Indian River through field crop production with current levels of soybean production exacerbating the problem of nitrogen surpluses.

Commercial fertilizer use increases the magnitudes of these surpluses. For example, the nitrogen and phosphorus from broiler manure and commercial fertilizers recovered annually in harvested field crops in the Little Assawoman Bay watershed averages only 17 percent and 12 percent, respectively. In other words, 83 percent of the nitrogen and 88 percent of the phosphorus used for crop production in this watershed remains in the soil after harvest and probably moves, at least partially, into adjacent surface or ground waters or both. In comparison, estimated nitrogen recovery in the Rehoboth Bay watershed is 41 percent and estimated phosphorus recovery is 70 percent. For the Indian River Bay watershed, average annual recovery is 30 percent for nitrogen and 31 percent for phosphorus. As discussed earlier, these recovery estimates are based on average yields for the period 1988-1994. Thus, there are years when recoveries of both nitrogen and phosphorus through field crop production are somewhat higher, but there also are years when recoveries are substantially lower. Also, these estimates for nitrogen recovery are based on the assumption that only 50 percent of broiler manure nitrogen is potentially recoverable through crop production due to losses during handling, storage, and application.

It was not an objective of this study to quantify the linkages between the surpluses of nitrogen and phosphorus and the deteriorated state of surface and ground water in each of the three major watersheds in the Inland Bays drainage basin. However, the magnitude of these surpluses, particularly in the Indian River Bay and the Little Assawoman Bay watershed, clearly suggests a strong relationship exists. In each of the three watersheds in this drainage basin, about 40 percent of the land is used for crop production.

As noted above, the second objective of this study was to evaluate the potential for exporting the excess broiler manure nitrogen and phosphorus from the drainage basin for use as a substitute for commercial fertilizers in areas with little poultry or livestock production. On the basis of nitrogen, phosphorus, and potassium content, a ton of broiler manure and litter after six grow-out cycles has an estimated value, based on current fertilizer prices, of $36.45 per ton. However, field crop producers, based on an indicated "willingness to pay," have assigned the substantially lower value to this material of about $4.50 per ton delivered to the site of application. As discussed in Chapter 7, several factors appear to contribute to this low valuation.

The absence of any significant movement of broiler manure from the Inland Bays drainage basin as well as elsewhere on the Delmarva Peninsula suggests that field crop producers in this region are willing to pay only a minimal charge for transportation. Even if broiler manure is available at no cost at the point of production, the valuation of $4.50 per ton limits movement to a little more than 55 miles based on an estimated transportation cost of $0.08 per loaded mile. To facilitate any significant movement of broiler manure from the Inland bays drainage basin for use as source of plant nutrients for crop production, one of two things must occur. The current valuation of broiler manure as fertilizer material by field crop producers must increase or transportation costs subsidized by a third party. Past efforts to accomplish the former with demonstrations of the ability of broiler manure to produce yields comparable to those obtainable with commercial fertilizers have had little success. While there have been published reports of significant movement of broiler manure in other areas of the United States, review of these reports generally reveals either an overstatement of success or the reflection of a unique situation.

The results of this study are based, by necessity, on available information and a number of assumption when the desired information was not available. Thus, it is acknowledged that there is degree of uncertainty associated with the calculated nutrient surpluses presented. However, this degree of uncertainty should not be viewed as a reason for dismissing the results and conclusions presented. Even if actual nutrient inputs are overestimated by 20 percent and recoveries underestimated by the same amount, the surpluses of nitrogen and phosphorus in both the Indian River Bay and Little Assawoman Bay watersheds remain substantial.

REFERENCES

A Comprehensive Conservation and Management Plan for Delaware's Inland Bays. 1995. Final Report submitted to the U.S. Environmental Protection Agency, Region III, Philadelphia, PA.

ASAE Standards, 35th Edition. 1988. Manure Production and Characteristics, ASAE Data: ASAE D384.1, American Society of Agricultural Engineers, St. Joseph, Michigan.

Barth, C.L. 1985. Livestock Waste Characterization—A New Approach. In: Agricultural Waste Utilization and Management. American Society of Agricultural Engineers, St. Joseph, Michigan. pp 286-294.

Bosch, D.J. and K.B. Napit. 1991. The Economic Potential for More Effective Poultry Litter Use in Virginia. Department of Agricultural Economics, Virginia Polytechnic Institute and State University, Blacksburg, Virginia. 73 pp.

Brake, J., G.B. Haverstein, S.E. Scheideler, P.R. Ferket, and D.V. Rives. 1993. Relationship of Sex, Age, and Body Weight to Broiler Carcass Yield and Offal Production. Poultry Science 72(6):1137-1145.

Cerco, C.F., B. Bunch, M.A. Cialone, and H. Wang. 1994. Hydrodynamics and Eutrophication Model Study of Indian River and Rehoboth Bay, Delaware. U.S. Army Corps of Engineers Waterways Experiment Station Technical Report EL-94-5. U.S. Army Corps of Engineers, Vicksburg, Mississippi. 262 pp.

Chambers, J.R. and A. Fortin. 1984. Live Body and Carcass Measurements as Predictors of Chemical Composition of Carcasses of Male Broiler Chickens. Poultry Science 63:2187-2196.

Cogburn, L.A. 1991. Endocrine Manipulation of Body Composition in Broiler Chickens. Critical Reviews in Poultry Biology 3(1991):283-305.

Delaware Agricultural Statistics Service. 1989-1995. Delaware Agricultural Statistics Summary. Delaware Department of Agriculture, Dover, Delaware.

Delaware Department of Agriculture. 1988-1997. Annual Fertilizer Tonnage Report. Dover, Delaware

Delaware State Planning Office. 1969. Environmental Study of the Rehoboth, Indian River, and Assawoman Bays. Unpublished report submitted to Delaware Governor Russell W. Peterson.

Edwards, D.R. and T.C. Daniel. 1992. Environmental Impacts of On-Farm Poultry Waste Disposal—A Review. Bioresource Technology 41(1992):9-33.

Gerry, R.W. 1968. Manure Production by Broilers. Poultry Science 47(1):339-340.

Hardy, W.E., Jr. 1994. An Analysis of the Economic Potential for Processin g and Marketing Poultry Litter. Final Report submitted to the Southeastern Poultry and Egg Association, Atlanta, Georgia. 68 pp.

Harsch, J. 1995. Poultry Litter Marketing and Utilization Project A Case Study 1992-1995. Winrock International, Morriton, Arkansas. 35 pp.

Loehr, R.C. 1974. Characteristics and Comparative Magnitude of Nonpoint Sources. Journal Water Pollution Control Federation 46:1849-1871.

Malone, G., T. Sims, and N. Gedamu. 1992. Quanity and Quality of Poultry Manure Produced Under Current Management Conditions. Final Report Submitted to the Delaware Department of Natural Resources and Environmental Control and Delmarva Poultry Industry, Inc. University of Delaware, Research and Education Center, Georgetown, Delaware. 96 pp.

Malone, G.W. 1992. Nutrient Enrichment in Integrated Broiler Production Systems. Poultry Science 71:1117-1122.

Martin, J.H., Jr., R.C. Loehr, and T.E. Pilbeam. 1983. Animal Manures as Feedstuffs: Broiler Litter Feeding Trials. Agricultural Wastes 7(1983):13-38.

Martin, J.H., Jr. and G.W. Malone. 1997. Unpublished data. Department of Animal and Food Sciences, University of Delaware, Newark, Delaware.

Martin, John H., Jr. 1998. The Development of a Regional Approach for Nutrient Management in Agriculture. Final Project Report submitted the Delaware Coastal Management Program, Department of Natural Resources and Environmental Control, Dover, Delaware.

Michel, K., J.R. Bacon, C.M. Gempesaw III, and J.H. Martin, Jr. 1996. Nutrient Management by Delmarva Poultry Growers: A Survey of Attitudes and Practices. Department of Food and Resource Economics Research Report, University of Delaware, Newark, Delaware.

Midwest Plan Service. 1994. Livestock Waste Facilities Handbook, 3rd Edition. Iowa State University, Ames, Iowa.

Miner, J.R. and R.J. Smith. 1975. Livestock Waste Management with Pollution Control. North Central Regional Research Publication 222, Midwest Plan Service, Iowa State University, Ames, Iowa. 89 pp.

National Academy of Sciences. 1971. Atlas of Nutritional Data on United States and Canadian Feeds. National Academy of Sciences, Washington, D.C.

Price, K.S. 1997. A Framework for a Delaware Inland Bays Environmental Classification. In: Proceedings of the Third Environmental Monitoring and Assessment Program (EMAP) Research Symposium, Albany, New York.

Qian, H., E.T. Kornegay, and D.M. Denbow. 1997. Utilization of Phytate Phosphorus and Calcium as Influenced by Micrbial Phytase, Cholecalciferol, and Calcium:Total Phosphorus Ratio in Broiler Diets. Poultry Science, 76(1):37-45.

Ransom, J.M. and R.C. Strickland. 1992. Enhancement of Broiler Litter to Improve Fertilizer Quality. In: Proceedings 1992 National Poultry Waste Management Symposium, J.P. Blake, J.O. Donald, and P.H. Patterson (eds.). Birmingham, Alabama.

Reckhow, K.H., M.D. Beaulac, and J.T. Simpson. 1980. Modeling Phosphorus Loading and lake Response Under Uncertainty: A Manual and Compilation of Export Coefficients. Report No. EPA 440/5-80-011, Office of Water Regulations and Standards, U.S. Environmental Protection Agency, Washington, DC.

Rinehart, K.E. 1996. Environmental Challenges as Related to Animal Agriculture—Poultry. In: Nutrient Management of Food Animals to Protect and Enhance the Environment, E.T. Kornegay, ed. CRC Press, Inc., Boca Raton, Florida. pp. 21-28.

Ritter, W.F. 1986. Nutrient Budgets for the Inland Bays. Final Report Submitted to the Delaware Department of Natural Resources and Environmental Control, Dover, Delaware.

Ritter, W.F. and G. Scheffler. 1977. Monitoring Nonpoint Source Pollution in Coastal Sussex County. Water Quality Task Report 2332.

Scott, M.L., M.C. Nesheim, and R.J. Young. 1976. Nutrition of the Chicken, 2nd ed. M.L. Scott and Associates, Ithaca, New York.

Sharpley, A.N., S.C. Chapra, R. Wedepohl, J.T. Sims, T.C. Daniel, and K.R. Reddy. 1994. Managing Agricultural Phosphorus for Protection of Surface Waters: Issues and Options. Journal of Environmental Quality 23(3):437-451.

Sims, J.T. 1993. Environmental Soil Testing for Phosphorus. Journal of Production Agriculture 6:501-507.

Sims, J.T. and D.C. Wolf. 1994. Poultry Waste Management: Agricultural and Environmental Issues. In: Advances in Agronomy, D.L. Sparks, ed. 52:1-83.

Stephenson, A.H., T.A. McCaskey, and B.G. Ruffin. 1990. A Survey of Broiler Litter Composition and Potential Value as a Nutrient Resource. Biological Wastes, 34 (1990) 1-9.

Taylor, R.W., D. Palmer, L. Carr, J. Kaufman, and J. Conaway. 1996. Growing Corn with Organically-Enhanced Fertilizer. In: Proceedings 1996 National Poultry Waste Maangement Symposium, P.H. Patterson and J.P. Blake (eds.). Auburn University Printing Service, Auburn University, Alabama. pp. 247-252.

U.S. Department of Agriculture. 1996. Agricultural Waste Characteristics, Part 651.0403. Agricultural Waste Management Field Handbook, Natural Resources Conservation Service, Washington, DC.

U.S. Department of Commerce, Economics and Statistics Administration, Bureau of the Census. 1993. 1992 Census of Agriculture Volume I, Geographic Area Series: State and County Data. U.S. Government Printing Office, Washington, DC.

Weaver, W.D. and G.H. Souder. 1990. Feasibility and Economics of Transporting Poultry Wastes. In: Proceedings 1990 National Poultry Waste Management Symposium. Raleigh, North Carolina. pp. 123-129.

Westerman, P.W., L.M. Safley, Jr., J.C. Barker, and G.M. Chescheir III. 1985. Available Nutrients in Livestock Wastes. In: Agricultural Waste Utilization and Management. American Society of Agricultural Engineers, St. Joseph, Michigan. pp 286-294.

Yi, Z., E.T. Kornegay, V. Ravindran, and D.M. Denbow. 1996. Improving Phytate Phosphorus Availability in Corn and Soybean Meal for Broilers Using Microbial Phytase and Calculation of Phosphorus Equivalency Vaues for Phytase. Poultry Science 75(2):240-249.