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THE ECONOMIC POTENTIAL OF ESTABLISHING A POULTRY LITTER HANDLING INDUSTRY

by

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(ABSTRACT)

Rapid increases in poultry litter production in concentrated areas has caused litter to be overapplied to nearby cropland at higher rates than the agronomic requirements of crops. Surface and ground water pollution has resulted due to leaching and runoff of nutrients in the litter. One solution to this litter disposal problem is to move litter from areas of concentrated poultry production (litter-surplus areas) to adjoining areas that have the capacity to absorb more litter for fertilizer and animal feed (litter-deficit areas).

A linear programming feed cost minimization model was used to estimate the value of litter as a feed for beef stockers and beef cows. The value of litter in beef and stocker rations were estimated by determining the value of alternative feeds replaced by litter. The value of litter for use as fertilizer was estimated by determining the value of commercial fertilizer replaced by litter in selected crop rotations. The services and costs required to make litter available for fertilizer and feed were estimated. A linear programming cost minimization model was used to estimate the costs of moving varying amounts of litter from surplus to deficit counties in Virginia for use as fertilizer.

Results indicated that it is economically feasible to establish a poultry litter handling industry. Results indicated more profit potential in moving litter for fertilizer than for feed. The profit potential to a litter handling firm is affected by several factors including the price of commercial fertilizer, waste management requirements, and litter storage subsidies. In order to increase the use of poultry litter for use as fertilizer and feed, it is necessary to educate farmers and the public about the nutritive and economic value of litter as a fertilizer and animal feed.

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Chapter I: Introduction and Problem Statement

I.1. Problem Statement

Poultry production is a rapidly increasing industry which produces large quantities of meat for American dietary requirements. The value in nominal dollars of broiler production in the U.S. increased from $4,502 million in 1982 and to $6,176 million in 1987. The value in nominal dollars of turkey production increased from $1,255 million in 1982 to $1,701 million in 1987. The number of broilers produced increased from 4,149 million in 1982 to 5,003 million in 1987 while the number of turkeys raised increased from 165 million in 1982 to 240 million in 1985 (Bureau of the Census, 1989b).

Poultry is an important industry for Virginia's economy. Virginia ranked sixth in the number of turkeys raised and tenth in the number of broilers raised in the United States in 1988 (Virginia Agricultural Statistics, 1989). The number of commercial broilers produced in Virginia increased from 140,072,000 in 1982 to 175,748,000 in 1988 (Virginia Agricultural Statistics, 1989).

The annual average number of layers decreased from 3,929,000 in 1982 to 3,659,000 in 1988. Egg production in Virginia decreased from 929 million in 1982 to 911 million in 1988. The number of turkeys raised increased from 10,081,000 in 1982 to 16,300,000 in 1988 (VAS, 1989). In 1988, gross receipts from broilers and turkeys were $264,940,000 and $116,447,000, respectively.

The major poultry-producing counties in Virginia are Accomack, Amelia, Augusta, Cumberland, Isle of Wight, Nottoway, Page, Rockingham, Shenandoah, Southampton, and the city of Suffolk. Rockingham County accounted for about 66 percent of turkey production in the state in 1987 while Augusta, Page, and Shenandoah counties accounted for 18, 2, and 10 percent, respectively. About 40 percent of the broiler production in the state was accounted for by Rockingham County in 1987 while Page, Accomack, Amelia, and Shenandoah Counties accounted for about 16, 9, 7, and 5 percent, respectively (VAS, 1988). Cumberland, Isle of Wight, Nottoway, Southampton, and Augusta Counties, and the city of Suffolk accounted for about 4, 2, 3, 2, 2, and 1 percent respectively of state broiler production in 1987 (VAS, 1988).

There are several poultry-processing companies including Rocco, Tyson Foods, Perdue Farms, Wampler, and Rockingham operating in Virginia. These companies are referred to as integrators since they contract with poultry growers to produce poultry for their processing plants and own the feed processing plants that supply feed for the birds.

The poultry industry has been able to gain the benefits from economies of scale through vertical integration. Integrators contract with poultry growers to produce poultry for their processing plants. The vertical integration is a vehicle for transferring decision authority from one or more stages to a single stage. Output decisions, coordination of product flow, and integration of stages can then consider the total interests of the vertical subsystem (Marion, 1985). In broiler production, for example, integrators typically own the hatching facility, feed mill, and processing plant and contract for hatching egg production and for broiler growing (Marion, 1985). Typically, contracts between integrators and broiler growers call for the integrator to retain ownership of the birds, provide feed, medication, and certain other inputs, pick up fed broilers at the farm, and deliver them to the processing plant. Growers maintain ownership of their facilities but largely operate as employees of the integrators. They are generally paid so much per pound produced, regardless of market price, although there are incentives for feed performance. Thus, the integrator retains most of the risk of broiler price and feed price fluctuations; however, they also have almost total control over the production process (Marion, 1985).

One of the consequences of a vertically integrated poultry industry has been the spatial concentration and increased size of poultry operations in an effort by integrators to minimize the costs of fed-bird pick-up at the farm and delivery to the processing plants, and distribution of processed poultry products to wholesale and retail markets (Aho, 1989). In certain areas, the spatial concentration and rapid growth in poultry production has resulted in production of large amounts of poultry litter whose crop nutrient content exceeds nutrient requirements of crops grown on the adjoining agricultural land. Poultry litter is a mixture of manure passed through the bird and bedding material used in the poultry house.[1] Due to the lack of adequate agricultural land in such fast growing poultry production areas, growers have traditionally disposed of litter by spreading it on adjoining farm land at higher rates per acre than the agronomic requirements of crops. Where litter is over-applied, a large proportion of the nutrients in manure is not utilized. For example, nitrogen in the nitrate forms in litter may be lost due to leaching, particularly on coarse-textured soils (sands, loamy sands, and sandy loams). The leaching loss of nitrogen is a substantial economic loss and is also known to cause ground water pollution. For example, a study by Liebhardt et al. (1979) in Sussex County, Delaware, revealed that the nitrate content of the groundwater acquifer was raised considerably above 10 ppm (the U.S. health standard) as a result of excessive applications of poultry manure. Nitrate in water is considered to be a problem in infants because it is reduced to nitrite which binds to hemoglobin. Hemoglobin in such a condition transports less oxygen and a condition known as methemoglobinemia (common names: cyanosis or blue baby syndrome) can result from high nitrate levels. The U.S. Environmental Protection Agency has set 10 mg/L N as a safeguard against methemoglobinemia in infants (Ritter, 1988). Excessive rates of litter application higher than plant requirements may also cause some economic loss due to reduction in crop yield caused by salt build-up from heavy application rates (USDA, 1979). Salinity

[1] Poultry manure refers to the poultry excreta alone and poultry litter includes bedding material in addition to poultry excreta.

problems and/or ammonium toxicity caused by high poultry litter application rates adversely affect germination, emergence and seedling growth, thereby reducing crop yield (Sims and Harris, 1986).

Another problem associated with excessive amounts of poultry litter is the practice of broadcasting litter and leaving it exposed to the sun, rain, wind, and snow. This practice causes loss of nitrogen due to ammonia volatilization and loss of phosphorus and potash due to surface runoff. Hence, the practice of broadcasting poultry litter causes some economic loss in terms of nitrogen lost from volatilization and it also pollutes the surface water due to surface runoff. Sims and Harris (1975) report that surface applications of poultry manure (no tillage) can result in nitrogen losses through volatilization. Estimates show that average volatilization losses of total nitrogen from solid manures are 21 percent if the manure is broadcast without incorporation compared to 5 percent if it is incorporated (Midwest Plan Service, 1975).

With the production of large amounts of poultry litter, cleaning of poultry houses frequently does not coincide with: available open cropland or with proper field conditions that permit operation of equipment or with nutrient needs of crops (Collins, 1987). Consequently, growers tend to stockpile litter without any cover in the open. Litter stockpiling creates offensive odors, loss of nutrients, and water pollution which may lead to nuisance suits by neighbors and may repel other businesses from the area (Roller, 1988). In the future, lack of proper litter disposal may pose a constraint to growth of the poultry industry in certain areas. For example, one major poultry producing area, Rockingham County, has taken legal steps to ensure environmentally safe disposal of poultry litter. A zoning ordinance, in effect beginning July 1, 1988, was passed to encourage the orderly and responsible growth of its poultry industry (Rockingham County, 1988). An excerpt from that ordinance is as follows:

> Section 17-178 of this ordinance requires a poultry grower to have a nutrient management plan in order to get a permit for a poultry facility constructed after July 13, 1988. For each poultry facility already in operation or approved by the County prior to July 13, 1988, this ordinance requires that a nutrient management plan be on file with the Zoning Administrator on or before June 30, 1994. After June 30, 1994, no poultry facility shall operate without such a nutrient management plan. The nutrient management plan has to make provision for the safe disposal or use of 100 percent of the animal waste produced by each poultry facility. Disposal or use shall be accomplished by means of land application at approved locations and agronomic rates, as established by the Virginia Cooperative Extension Service and other appropriate agencies. Alternative disposal methods may be used, as approved by appropriate state and local agencies. The nutrient management plan shall also provide for a site for the storage of poultry wastes located on the same parcel as the poultry house where wastes are produced. The site shall: 1) be located on an impermeable base, out of all drainages and protected from the elements; 2) be approved by a professional engineer registered in Virginia and

> may include a permanent structure also approved by a registered professional engineer, 3) have sufficient capacity to accommodate, for at least four consecutive months, 100 percent of the waste produced by each poultry house in operation on the parcel during the four month period in which the maximum possible number of clean-outs of that poultry house may occur.

This ordinance may constrain future growth of the industry if growers cannot comply with litter storage and disposal requirements.

The geographic concentration of the poultry industry creates problems for litter disposal in many poultry producing areas because more is produced than can be used locally for feed or fertilizer. As a result, proper disposal may require the transfer of litter from litter-surplus farms to litter-deficit farms outside the poultry producing area. Such transfer might be cost effective if markets for litter were developed and users were willing to pay more than the cost of supplying litter to them. A market for poultry litter could result in more widespread use of poultry litter as both fertilizer and animal feed and increase the economic value of poultry litter. An organized market for litter to be used as commercial fertilizer and animal feed has not developed for several reasons, four of which are mentioned here: (1) uncertain nutrient quality of litter; (2) lack of services needed to make litter available for fertilizer and feed; and (3) reluctance of many farmers to use litter as a nutrient source. According to Perkins et al. (1964), manures vary widely in nutrient composition as a result of type of bird, kind of feed consumed, climatic conditions, management of the poultry house, and system of handling the manure upon removal from the poultry house. Although variability of nutrient content may be reduced in integrated operations that tightly control management of the house and diet of the bird, many farmers do not handle and store litter in ways that preserve its nutrient content. As a result, variability in nutrient content of poultry litter introduces risk when it is used as either fertilizer or animal feed supplement. Farmers may not use litter if they are unsure how it affect crop yields or animal performance. This concern about the variability of nutrient content in poultry litter can be solved by having litter tested.

The utilization of poultry litter as fertilizer, animal feed, or soil amendment has also been constrained by its high bulk relative to its value. Because of litter's bulk, the cost of transportation is a major component of the total cost of poultry litter acquisition by users and constrains the distances that litter can be moved economically from its place of origin to its place of use. Some services need to be provided to facilitate the movement of litter from its place of origin to its place of utilization and to facilitate application of litter. For example, poultry litter requires special machinery to be effectively stored and applied. Many farmers who use commercial fertilizer have the delivery and application done by fertilizer dealers. These farmers may not have the right machinery needed to effectively transfer and apply litter to the field. As will be discussed later, standard farm manure spreading equipment may not be able to apply litter accurately at the rates required for crop production. A private poultry litter handling firm may be able to provide the necessary services to promote the utilization of poultry litter as a soil amendment, fertilizer, or animal feed supplement. Such a firm may be able to spread the investment cost for machinery and equipment by serving a large group of customers thus capturing the benefits of economies of scale.

Another barrier to the development of litter markets has been the reluctance by many crop farmers to consider its use for fertilizer due to its offensive odor and also due to lack of recognition of nutrient value of litter by farmers (Holden, 1989). In addition, they may feel that using poultry litter for fertilizer makes them appear unscientific or "behind the times" to their neighbors.

A second potential use of poultry litter is as livestock feed. There is evidence that poultry litter has been used in cattle-feeding programs in Virginia since at least 1962 (Gerken, 1977). But poultry litter is still not widely used as animal feed. One reason for this lack of widespread use of litter as animal feed might be concern for unknown potential hazards from medicinal drugs, molds, heavy metals other than copper, or disease causing pathogens that might be present in litter. Another problem is that poultry litter cannot be fed to all kinds of animals. For example, copper toxicity limits the use of litter for sheep (Gerken, 1977). Farmers are also concerned about consumer reaction against meat if it is known that litter is used to produce it. Distances between poultry and beef producers may cause the the cost of transporting litter to be high relative to its value. These costs may limit the number of livestock producers who can take advantage of poultry litter as feed. Additional information on the potential benefits and costs of feeding poultry litter is required to determine if there is potential to expand the use of litter for feed. Services such as acquisition, transportation and storage may be needed to encourage livestock producers to use litter. A poultry litter handling industry might be able to provide such services and information.

Transferring litter from litter-surplus counties in to litter-deficit counties in Virginia could help reduce ground and surface water pollution at both the origin and the destination of litter. By transferring litter from litter-surplus areas to litter-deficit areas for use as fertilizer, the nutrient loadings in surface and ground water in the litter-surplus areas are reduced. Moreover, the transfer of litter from litter-surplus to litter-deficit areas may also reduce water pollution in the litter-deficit areas by substituting litter for the more leachable commercial fertilizer. The transfer of litter also puts a positive price on litter, thereby increasing the net returns from poultry production.

Improper use, handling and storage of poultry litter are known to cause ground and surface water pollution due to nitrate leaching and runoff (Ritter, 1988). Hence, the social cost of improper use of poultry litter is actually higher than the private losses from improper use. However, no one individual reaps all the benefits of preventing pollution through proper disposal of litter. As a result, the market does not provide full incentives to private entrepreneurs for insuring proper disposal of litter. Private entrepreneurs may be unwilling to invest in pollution abatement unless they are forced by law to do so because they cannot internalize all the benefits of such investments. Because society as a whole benefits from pollution control, the government may wish to take steps to insure that litter is being handled, stored, processed, and utilized in an environmentally safe manner. However, there is a lack of informations on what steps by the government would be most effective in promoting environmentally safe use of poultry litter. Steps that have been taken by the government in Virginia include: increasing the awareness of farmers and the general public about the economic value of poultry litter through educational programs, subsidizing the cost of poultry litter storage construction, and providing free manure testing to show farmers the nutrient content of poultry litter so that it can be applied at rates to meet the needs of the crop being grown.

This study will address the problem of transferring poultry litter from litter-surplus to litter-deficit areas for use as animal feed as well as crop fertilizer. This study will also address the government policies required to promote the transfer of litter from surplus to deficit areas.

I.2. Value of Poultry Litter: Form, Time, and Place

The potential to transfer litter from surplus to deficit areas depends on its value to the user. The value of poultry litter can be increased by creating time, place and form utility (Bressler and King, 1970). Time utility can be created by storing the product for future use. Thus a market may be viewed as extending through time with a consistent structure of prices interrelated through storage costs. Likewise, a market may be viewed as extending through alternative and successive forms of a product with a consistent structure of prices interrelated through processing costs - the costs of changing product form (Bressler and King, 1970). Place utility is created by extending a single market over a large geographic area with a market-wide structure of prices interrelated through transportation costs.

Certain forms of nitrogen are more economically useful and less environmentally damaging than other forms. For example, inorganic nitrogen supplied by commercial fertilizers may be more susceptible to leaching losses than that supplied by organic sources such as poultry manure or poultry litter. The organic matter content of the nitrogen source affects the loss and availability of nitrogen. The presence of organic matter in litter promotes the process of immobilization thereby slowing down the rate of release of nitrate nitrogen. As a result, a slow and steady flow of nitrate nitrogen is made available for uptake by plants and the leaching loss of nitrate nitrogen is reduced (Bartholomew, 1965). Moreover, the organic content of litter also helps reduce nitrogen loss due to denitrification because the process of immobilization reduces the rate at which nitrate is converted into nitrogen and nitrogen oxides. Litter can be processed in order to stabilize and increase the average availability of its nitrogen content and to reduce the variability of nutrient content. Hence, processing litter results in creation of form utility.

The value of litter can be increased by storing for a period of time. Litter cannot be applied at all times in the cropland. It has the highest economic value if it is applied at appropriate time so as to make nutrients available to plants when they need them the most. Therefore, the time value of litter is increased by holding it until the right time for its application.

The key problem in the utilization of poultry litter has been the inability of the growers and farmers to move litter from litter-surplus to litter-deficit areas. In this study, a litter-deficit area is assumed to be an area where litter production is less than the amount that could potentially be used for fertilizer and animal feed. A litter-surplus area is defined as an area where more litter is produced by local poultry operations than can be used for fertilizer and feed in that area. By transferring litter from surplus to deficit areas, the litter handling firm is essentially creating place utility because surplus litter has no value in the surplus area but has economic value as a crop fertilizer in the deficit area. The transfer of litter from a litter-surplus area to a litter-deficit area will be economically feasible so long as the willingness of farmers in the litter-deficit area to pay for a ton of litter exceeds the total cost of litter acquisition, collection, storage, processing, delivery, and application. The main constraint in moving litter from litter-surplus to litter-deficit areas is recognized to be the cost of transportation, which in turn is affected by the bulkiness of litter. Hence, ways to reduce the mass and volume without considerable loss of nutrients may need to be explored. If the transfer cost remains higher than the price differential even after processing of litter, a government subsidy may be required to promote movement of litter to litter-deficit areas for application over a larger surface area. Alternatively, poultry producers may be required to subsidize litter disposal in order to be allowed to continue or expand production.

Making litter available to farmers at the right time, in the right form and at the right place requires provision of services. A poultry litter handling industry may be able to provide these services to farmers. However, there is a lack of information about the most effective method of providing these services to farmers. Changing the form of poultry litter will incur some processing costs. Likewise, creating place utility in the product will incur some transportation costs. Increasing time utility of the product will incur some storage costs. The attractiveness of creating time, form, and place utility of poultry litter will depend on the cost of storing, processing, and transporting litter as well as prices of the end products. It is necessary to identify the effects on costs and returns of changing the form, time, and place characteristics of litter in order to make it available to farmers.

I.3. Objectives

The objectives of this study are:

1. To determine the economic profit potential of establishing a poultry litter handling industry to facilitate transfer of litter from surplus to deficit areas for use as fertilizer and livestock feed.

   A sub-objective of objective one is to determine the optimal methods of organizing such an industry in terms of services provided and means of providing those services. In particular, this study will look at the cost-effectiveness of providing composted litter compared to raw litter for use as fertilizer.

2. To evaluate government policies that may effectively promote the use of litter as crop fertilizer and animal feed.

I.3. The Study Area

The study focuses on the areas in Virginia where most poultry production occurs and where the greatest opportunities for increased use exist. The 11 counties and one city shown in Table I.1 are the major poultry producing counties in Virginia. Table I.1 shows the number of poultry and dairy cows produced in different counties in 1987 (Bureau of the Census, 1989a). The 11 counties and 1 city shown in Table I.1 account for about 96 percent of the broiler production in the state. Since dairy manure competes with poultry litter as fertilizer, dairy cows were included to account for the nutrients available from dairy cows. Ten counties in Table I.1 account for about 95 percent of the dairy cows in Virginia. Rockingham County accounts for the largest proportion (51.54 percent) of the state's dairy cows.

The crop nitrogen requirements were estimated for each of the 12 litter-producing counties for the existing crop rotations. The amount of nitrogen available from dairy manure in each of

Table I.1. Number of poultry birds and dairy cows by county (in thousands)[a].

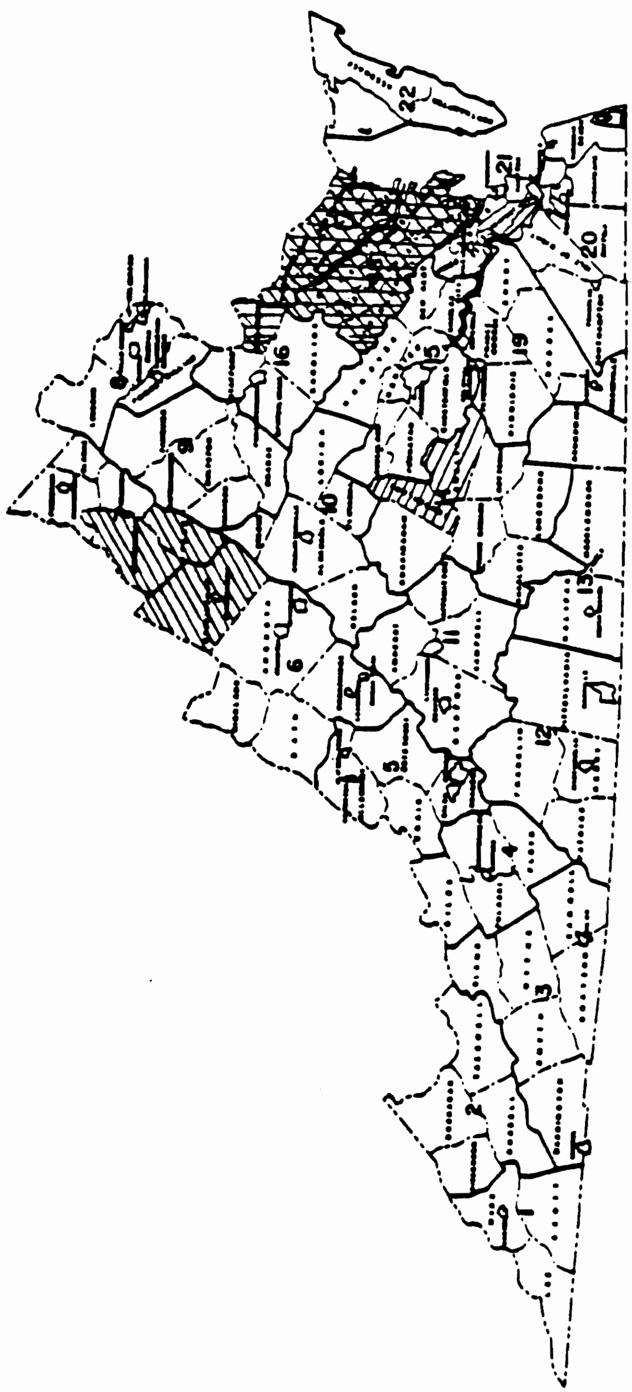
County name	Chicken hens[c]	Chicken pullets[d]	Broilers	Turkey[b] hens	Turkey toms	Dairy cows
Accomack[e]	80.09 (2.06)	80.09 (1.85)	13,650 (9.55)			
Amelia[e]	137.0 (3.53)	137.0 (3.18)	10,260 (7.17)			
Augusta	216.3 (5.57)	86.7 (2.01)	1,679 (1.17)	1,822.7 (18.59)	607.6 (18.59)	12.4 (26.23)
Buckingham	72.7 (1.87)		3886 (2.72)			0.262 (0.55)
Cumberland	102.6 (2.64)	644.0 (14.94)	6003 (4.19)			1.165 (2.45)
Isle of Wight	1.19 (.03)		3,420 (2.39)			0.014 (0.00)
Nottoway	73.0 (1.88)		3,581 (2.5)			1.678 (3.53)
Page	118.4 (3.05)	302.8 (7.03)	2,555 (15.77)	235.9 (2.41)	78.6 (2.41)	0.906 (1.91)
Rockingham	1,345.4 (34.67)	788.2 (18.29)	57,715.3 (40.37)	6,443 (65.74)	2,147.6 (65.74)	24.5 (51.54)
Shenandoah	203.8 (5.25)	182.0 (4.22)	7,599 (5.31)	103.1 (10.52)	343.5 (10.52)	3.39 (7.13)
Southampton	0.14 (.003)		3,234.4 (2.26)			0.30 (0.63)
Suffolk City	0.18 (.004)		3,163 (2.21)			0.40 (0.84)
Virginia	3,881	4,309	154,036	9,800	3,266	47.5

[a]Source : Census of Agriculture, 1987. The numbers in parentheses are percent of Virginia totals.
[b]"Turkeys sold" category was divided into "Turkey hens" and "Turkey toms" in the ratio of 75:25 based on the Rockingham County number of turkey toms and turkey hens.
[c]"Hens and pullets of laying age" are considered as layers.
[d]"Pullets not of laying age" are considered as pullets.
[e]Since breakdown by "Pullets not of laying age" and "Hens and pullets of laying age" was not disclosed, "The hens and pullets sold" category was broken down into two equal halves for these two counties.

these counties was subtracted from crop nitrogen requirements. The deficit was met by nitrogen in poultry litter. Then the excess litter available was assumed to be available for export to litter-deficit counties. Five out of 12 counties in Table I.1 were determined to be litter-surplus counties. These counties were Amelia, Cumberland, Page, Rockingham, and Shenandoah, and are shown as the single-shaded area in Figure I.1. These surplus counties were determined using the procedure described in Chapter IV. Total nitrogen available from dairy manure and poultry litter was estimated for each of the 12 counties. Other counties adjacent to the litter-surplus counties were analyzed as to their capacity to use litter for animal feed.

The Northern Neck and the Middle Penninsula, which is the double-shaded area in Figure I.1, was chosen to be the litter-deficit area for the purpose of this study. The counties belonging to the Northern Neck and the Middle Penninsula are Essex, Gloucester, King George, King and Queen, King William, Lancaster, Mathews, Middlesex, Northumberland, Richmond, and Westmoreland. These counties were selected as the demand area because of the importance of crop production in this area and the homogeneous crop rotation practice in used in this area. The homogeneous crop rotation greatly simplified the task of determining the potential value and amounts of poultry litter that could be used in deficit areas. A benefit of promoting poultry litter in this area would be the substitution of organic source to promote substitution of organic source of nutrients such as poultry litter for the more readily leachable commercial fertilizer which has been linked to pollution of water in the Chesapeake Bay (U.S Environmental Protection Agency, 1983). This area has little animal agriculture which could provide livestock manure as an alternative source of plant nutrients. Therefore, there is a potential for transfer of litter from surplus counties to this area for use as fertilizer.

This dissertation is organized into five additional chapters. Chapter two presents the technical relationships involving the use of poultry litter as fertilzer and feed. Chapter three presents the conceptual framework for the empirical procedures used to determine the profit potential of establishing a poultry litter handling industry. Chapter four deals with the procedures involved in achieving objectives one and two. Chapter five presents the results of analyses and policy implications of these results. Chapter six presents the summary and conclusions.



Key: Single cross-hatched counties are litter-surplus counties and double cross-hatched counties are litter-deficit counties.

Figure 1.1. Map of the Study Area.

Chapter II: Management of Poultry Litter for Fertilizer and Feed

II.1. Introduction

The profit potential of establishing a poultry litter handling industry will depend on what price its customers are willing to pay for litter compared to the costs incurred in making it available.[2] Willingness to pay for litter will depend on its economic value as a source of plant nutrients and as animal feed. Researchers in the past have tried to assess the value of poultry litter as a fertilizer (Zindel and Flegal, 1971; Wilkinson, 1979) and as animal feed (Zimet et al., 1988; Gerken, 1977; Smith and Wheeler, 1979). In order to accurately assess the economic value of poultry litter as a fertilizer and animal feed, it is necessary to understand the technical dimensions of litter formation including use of grain in poultry feed through the final use of litter by plants in the soil. The purpose of this chapter is to review the biological, chemical, and physical processes affecting the availability of nutrients to plants and animals and to discuss management strategies to increase the economic value of poultry litter.

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[2] If poultry producers or integrators were required to provide such subsidies for safe disposal in order to continue operating they would enhance the profit potential of the industry.

Poultry litter may be used as animal feed or as a source of plant nutrients. When it is used as animal feed, it produces meat as well as livestock manure which can also be used as a source of plant nutrients. The nutrients taken up by plants may be used to feed poultry and livestock. Thus the nutrients pass through a continuous cycle during which several transformations take place. Some nutrients are lost and some are stored in the soil. The chemical, biological and physical processes affecting availability of nutrients to plants are reviewed first. Then the technical aspects of using poultry litter as animal feed are reviewed.

II.2. Poultry Litter as a Fertilizer

Grains are the major component of poultry feed. The nutrients contained in grain are only partially utilized by poultry with the rest excreted as manure. Growers or other crop producers may utilize the manure mixed with bedding material as fertilizer. Once on the land, the nutrients (mainly nitrogen) go through several transformations which affect the amount available to plants, amount lost through different outlets, and the amount remaining as residual nitrogen. The economic value of poultry litter can be increased by increasing the amount of nutrients available to plants and by decreasing the loss of nutrients. This availability and loss of nutrients is best understood by reviewing the nitrogen cycle. The nitrogen cycle is a complex biological and chemical cycle involving such diverse factors as microorganisms, lightning, and application method (Valiulis, 1986).

II.2.1. The Nitrogen Cycle

Nitrogen can be in in gas, liquid, and solid states, and in several forms such as urea, anhydrous, nitrate, and ammonium. The form and the state of nitrogen determines the amount of nitrogen available to plants in the year of application, the amount of nitrogen lost due to leaching, volatilization, and surface run-off, and the amount available in the following years after application.

There are four stages in the nitrogen cycle. The first stage referred to as *fixation*, may be biological or chemical. Biological fixation refers to the symbiotic relationship in legumes in which the *Rhizobium* bacteria transform nitrogen in the air into a stable form (Valiulis, 1986). In industrial fixation, fertilizer plants combine nitrogen from the atmosphere with hydrogen to form ammonia. The second stage of the nitrogen cycle, *ammonification* (also called mobilization or mineralization) is the process where the organic residues are broken down by soil organisms. As a result, ammonia is released, which, in the presence of moisture, immediately converts to ammonium (Valiulis, 1986). The ammonium form of nitrogen is valuable because it does not leach. Poultry litter has organic matter which is negatively charged, and hence attracts and holds the ammonium ions which are positively charged. Moreover, ammonium is usable directly by plants. When temperatures rise above 50 degrees F in well-aerated and properly limed (pH of 6.5 to 7.0) soils, nitrifying bacteria begin to convert ammonium to nitrate (Valiulis, 1986), a process called *nitrification*. Nitrate is the most usable form of nitrogen by plants. Unfortunately, nitrate leaches very easily because the negatively charged nitrate ions are not attracted to the negatively charged clay particles and organic matter in the soil the way ammonium is.

The final stage in the nitrogen cycle, *denitrification*, is the process whereby nitrate is converted back into elemental nitrogen and nitrogen oxides, which then escape to the air (Valiulis, 1986). Denitrification occurs quickly in poorly aerated, very moist, or waterlogged soils and is accomplished by soil bacteria feeding on organic matter. Denitrification is not desirable from an economic point of view because it represents a loss of nitrogen. *Immobilization*, a process whereby organic crop residues tie up available ammonium or nitrate while the residues decompose, is beneficial from both economic and environmental perspectives because it reduces nitrogen loss. However, if much more nitrogen is immobilized than the amount mineralized, then the soil may end up with a nitrogen deficit for crop production. Nitrogen tied up by immobilization is released back to the cycle when the organic matter starts to decompose. Thus the process of immobilization helps reduce nitrate leaching by reducing the rate at which ammonium is converted into nitrate and by reducing the rate at which nitrate is converted into nitrogen and nitrogen oxides.

Volatilization is the loss of a liquid form of nitrogen into the atmosphere as a gas. Denitrification is a special case of volatilization. Volatilization also refers specifically to the loss of nitrogen as ammonia gas from broadcast applications. For example, if poultry litter is broadcast without incorporation, some of the nitrogen is likely to be lost due to volatilization. Thus the challenge inherent in the nitrogen cycle is to have the nitrogen in the most usable form at the moment the crop needs it. An understanding of how nitrogen changes and what conditions promote these changes will help in minimizing groundwater pollution and economic loss of nitrogen in litter and maximizing crop uptake and yield for a given application of nitrogen.

II.2.2. Implications of the Nitrogen Cycle

The nitrogen cycle determines the availability and the loss of nitrogen and has implications for the way litter should be managed. For example, the ammonium form of nitrogen is usable by plants and does not leach. As mentioned, under favorable temperature, soil, and moisture conditions, ammonium converts easily into a nitrate form which is very mobile in water (Brady, 1974). Thus a rate of nitrification in excess of the rate of uptake by plants may result in the loss of nitrogen due to leaching of nitrates and denitrification. This implies that litter should not be applied at rates that result in more nitrogen being applied than plant requirements. According to Broadbent and Clark (1965), denitrification losses may occur rapidly and extensively or continuously in small amounts over an extended period of time. Further, the continuing small losses of nitrogen may remove 10 to 15 percent of the total yearly commercial fertilizer nitrogen input. The rapid and extensive losses of nitrogen occur especially when soils containing nitrate and readily decomposable organic matter are exposed simultaneously to warm temperatures and excessive moisture. For example, Valiulis (1986) indicates that if water stands on the soil for two or three days during the growing season, most of the nitrate will be lost. Waterlogging conditions in the field should be avoided especially during warm weather. Volatilization loss of nitrogen means that incorporating poultry litter at application will have economic benefits in terms of preventing nitrogen loss.

Both immobilization and ammonification occur continuously under favorable conditions for biological activity (Bartholomew, 1965). The rate of ammonification in excess of immobilization is estimated to be about 2 to 4 percent of the total soil nitrogen per year in temperate zone soils. According to Keeney (1983), the nitrogen mineralized in some soils can provide a significant portion of total crop needs. The process of immobilization may promote nitrogen uptake efficiently by plants because it helps slow the rate of release of nitrogen so it is more nearly matched to the rate of plant uptake. In this way, the process of immobilization in the presence of organic matter can potentially help to reduce nitrate leaching. Net mineralization over immobilization of a nitrogen source such as litter depends on its carbon-nitrogen ratio. If the poultry litter has a high carbon-nitrogen ratio, there is a net immobilization for an extended period of time. If the carbon-nitrogen ratio for poultry litter is low, inorganic nitrogen may be liberated early in the decomposition phase. According to Bartholomew (1965), organic matter with a carbon-nitrogen ratio of 22:1 or below, corresponding to a total nitrogen content of about 2 percent, is associated with rapid net mineralization, while higher carbon-nitrogen ratios are associated with net immobilization. The optimal carbon to nitrogen ratio refers to that combination of carbon and nitrogen at which the rate of mineralization is not so high as to cause leaching loss of nitrogen and yet is high enough to allow nitrogen to be made available to the crop. If the carbon to nitrogen ratio is higher than the optimal ratio then some kind of nitrogen source could be added. If the carbon to nitrogen ration is lower than the optimal ratio then some kind of carbon source could be added as part of the litter processing stage. Testing litter's carbon to nitrogen ratio may be needed to accurately assess its nutrient content and the application rate rate required to meet crop needs.

II.3. Management of Poultry Litter for Use as Fertilizer

Litter has value as a crop fertilizer because it contains nitrogen, phosphorus, and potash, as well as valuable micronutrients such as calcium, magnesium and sulfur (Wilkinson, 1979). Further, litter is high in organic matter that can improve the productivity of soil by increasing water infiltration rates, reducing soil losses to wind and water erosion, promoting easier tillage, and reducing impedance to seedling emergence and root penetration (Mazurak, Zingy and Chepil, 1953; Barnett et al., 1979; Wilkinson, 1979).

Table II.1 presents average nutrient contents of raw and composted poultry litter. The average and ranges of values for raw litter nutrients are those reported by the Water Quality Laboratory at Virginia Polytechnic Institute and State University based on 73 samples collected in 1988. The nitrogen, phosphate, and potash content of litter varied widely depending on factors such as the method of handling and storage as well as type of bedding material used. Organic and inorganic amounts of nitrogen reported in the table are based on the assumption of 60 percent organic and 40 percent inorganic content. These percentages are used by Givens (1987) for broiler litter and are very close to those reported by Sims and Harris (1986).

Composting reduces weight and volume of litter by an average of approximately 50 percent (Naber, 1989; Rynk, 1989). Phosphate and potash content are not affected by composting (Sweeten, 1988). Some nitrogen will be lost due to volatilization of ammonia nitrogen (Sweeten, 1988). The amount of loss depends on factors including the carbon-nitrogen ratio, temperature, and pH of litter. Estimated average loss is approximately 30 percent of total nitrogen (Brinton, 1989). The remaining nitrogen is approximately 80 to 90 percent organic and 10 to 20 percent inorganic (Brinton, 1989).

The estimated nutrient content of composted litter reported in Table II.1 reflects these assumptions. The potash and phosphate content of composted litter reported in Table II.1 are double relative to raw litter because composting is estimated to reduce litter weight by 50 percent without affecting phosphate and potash content. The nitrogen value is calculated by taking the

Table II.1. Nutrient content of raw and composted poultry litter.

	Nutrient content (lbs/ton)		
	Raw litter[a]		Composted litter[b]
Nutrient	Average	Range	Estimated[c]
Phosphate	40.67	18 to 63	81.34
Potash	30.27	20 to 40	60.54
Total nitrogen	58.16	43 to 73	81.42
Inorganic[d] nitrogen	23.26		16.24
Organic nitrogen	34.90		64.96

[a]Source for raw litter: Department of Agricultural Engineering, Water Quality Laboratory, Virginia Polytechnic Institute and State University. Based on 73 samples in 1988.

[b]Source for composted litter: Edward Nabor, Department of Poultry Science, Ohio State University; Will Brinton, Woods End Research Laboratory, Maine.

[c]Range for nutrient content of composted litter not available because the figures presented are estimates based on assumptions made about nutrient, volume and weight loss due to composting.

[d]Inorganic and organic contents calculated assuming 60% organic and 40% inorganic nitrogen content for raw litter, and 80% organic and 20% inorganic nitrogen for composted litter.

average nitrogen content of two tons of raw litter, 116.32 pounds, and reducing it by 30 percent to 81.42 pounds. Inorganic and organic nitrogen contents are assumed to be 20 and 80 percent, respectively.

Although poultry litter is rich in plant nutrients, realization of its full economic value depends on how it is used, where it is used, when it is used, and how much is used. Litter's economic value can be increased by proper handling and processing. However, these steps may also entail additional costs.

In order to maximize his net economic benefit, a manager of poultry litter should aim at saving nutrients until the marginal cost of saving the last unit of nutrient is equal to the marginal revenue from that unit of nutrient. Different management alternatives must be considered to determine which are most effective for increasing the economic value of litter. The first step in the management of litter starts at the poultry house.

II.3.1. Management of Litter in the Poultry House

Several aspects of housing management affect litter nutrient content. First, control of moisture is essential to prevent nutrient loss. Excessive spillage of water from water feeders causes litter caking thereby making it difficult to clean the poultry house. Also, the volatilization loss of nitrogen increases with the increase in water spillage. Ammonia release reduces bird performance and requires increased ventilation (Brodie and Carr, 1988). Therefore, the entry of surface water and leaky waterers should be prevented. The use of adequate amounts of bedding material that dries manure rapidly helps to reduce the volatilization loss of nitrogen. A well-ventilated and well-insulated poultry house keeps the poultry house odorless while reducing the moisture content and nutrient losses caused by volatilization of ammonia (Shipp et al., 1985). Preventing excessively high temperature inside the poultry house is also very important in reducing volatilization loss of nitrogen.

II.3.2. Storage of Poultry Litter

Provision of storage provides flexibility in the rate and the timing of litter application so as to match the nutrient availability to the critical periods of crop nutrient requirements and assure maximum nutrient uptake by plants. In order to maintain litter quality and minimize nutrient loss until the time of application, litter may need to be stored in a storage structure with roof or covered with plastic. Shipp et al. (1985) suggest that poultry manure should never be stored directly on soil for more than a month. They suggest that a good way to prevent nutrients from leaching out of manure and into the soil is to store manure on a liner of plastic or concrete. Storing manure under black plastic saves nutrients, protects ground water and allows for easier spreading (Delmarva Poultry Industry, 1987). Sims (1983) reported that poultry litter covered by black plastic contained 59 lbs. of total nitrogen per ton after six months in storage compared with 53 lbs. for uncovered manure. Further, covered litter had a 45.5% moisture content compared with 65% for uncovered litter. Keeping the litter drier makes it easier and more economical to apply as well. Hence, permanent and temporary storage facilities may be utilized to make the litter more valuable to the producer.

Soil types, drainage, access and topography are considerations that must be addressed when developing a specific storage facility (Shenandoah Valley Conservation District News, 1986). Also, the temperature, rainfall, snow, wind velocity, and humidity significantly affect the type and cost of storage facility to be built for litter storage. For example, in areas where annual precipitation is not heavy and soil is impermeable, stockpiling litter with a plastic cover may suffice for the purpose of litter storage. In areas where soil is not impermeable a ground liner may be essential to prevent leaching losses of nitrogen. Similarly, in areas where snow and rain are heavy, a permanent roofed storage structure may be the best type of storage facility (Shenandoah Valley Conservation District News, 1986).

II.3.3. Testing and Processing of Litter

The nutrient content of poultry litter depends on the type of bedding material used, type of feed fed to the birds, moisture content of litter, number of clean-outs of poultry house in a year, and the type of bird (Shipp et al., 1985). The nutrient content of litter must be determined by laboratory testing which will enable the farmer to decide on the rate of litter application to meet crop requirements. The nutrient analyses will provide information on nitrogen, phosphate, and potash, and the breakdown of total nitrogen into inorganic and organic nitrogen. A farmer can have his poultry litter or dairy manure analyzed by a commercial laboratory at a cost of $20 to $30 per sample (Ritter, 1988). At present the water quality laboratory at Virginia Polytechnic Institute and State University provides free manure testing service to farmers in Virginia. At a private laboratory, a farmer producing 500 tons of poultry litter could expect to spend approximately $360 per year for manure analysis in order to be reasonably sure of litter nutrient content. This estimate is based on the assumptions that (1) the poultry house is cleaned six times a year, (2) two samples of poultry litter are analyzed at each cleaning, and (3) each sample analysis costs approximately $30 (Collins, 1988).

A form of litter processing called composting is a biological decomposition process that converts organic matter to a stable, humus-like product under controlled conditions (Merkel, 1981). Humus contains nitrogen, phosphorus, and sulfur in organic forms that are not available to plants. When the humus is decomposed by soil microorganisms, these nutrients are changed to inorganic forms that plants can absorb (CAST, 1980).

Based on oxygen availability, there are two methods of composting: anaerobic and aerobic. Anaerobic composting is governed by anaerobic bacteria that operate in the absence of atmospheric oxygen. The process is characterized by lower temperatures compared to aerobic composting, the production of odorous gases, and longer composting times (Merkel, 1981). Anaerobic composting yields partially oxidized and reduced compounds which may continue to undergo further decomposition. The end products of anaerobic decomposition include organic fatty acids, aldehydes, alcohols, hydrogen sulfide and ammonia. These compounds can result in serious odor nuisance (Sweeten, 1988). Moreover, decomposition does not take place evenly in the pile. This problem becomes more serious if the volume of litter to be composted is large. For all of these reasons, aerobic rather than anaerobic composting was considered in this study.

Holden (1986) defines aerobic composting as the controlled decomposition of organic residues in the presence of oxygen, carbon, nitrogen, and water. Organic matter with its indigenous population of bacteria and fungi will start to decompose when moisture conditions are favorable. An acceleration of microbial activity occurs, utilizing the carbon, nitrogen, and other nutrient elements. The microbial activity oxidizes the organic matter resulting in the generation of heat which is conserved within the compost pile. This process causes the internal temperature of the pile to rise from the mesophilic stage (between ambient and $40^{\circ}C$) into the thermophilic stage (between $40^{\circ}C$ and $60^{\circ}C$) (Merkel, 1981). Decomposition continues until the temperature begins to drop and finally returns to ambient conditions. During these temperature changes, the volume decreases considerably and the organic matter is converted into an odorless, granular substance called humus. Aerobic composting is characterized by high temperature, the absence of foul odors, and a short composting period. The high temperatures have a sterilizing effect by destroying weed seeds and pathogenic organisms. Furthermore, the reduction of new organic matter concentrates the mineral content. With mass and volume reduced, the end product is more efficiently transported. The finished compost is homogeneous in nutrient distribution and physical condition making for easier handling and application. However, composting involves expenses for equipment and operation.

Based on the method of operation, aerobic composting may be carried out in an enclosed digester or in elongated piles called windrows. Enclosed digesters are mechanical composters that provide aeration by some type of continued tumbling or stirring action. Some methods combine stirring with forced aeration. Enclosed digesters require a high capital investment and utilize a great deal of energy. Composting times for enclosed digesters are 10 to 15 days (Merkel, 1981). The windrow method of aerobic composting is characterized by piling the organic wastes in windrows placed in the open or covered with a roof. Aeration is provided by stirring and mixing the composter with a front-end loader or a specially designed rototiller type of implement. If the windrows are properly mixed, the process will be aerobic and the composting time required is about 6 weeks (Merkel, 1981).

The most important factor that controls the rate at which composting proceeds is the carbon to nitrogen ratio (Merkel, 1981). As composting begins, the microorganisms require carbon as a source of energy for growth and nitrogen for protein synthesis. According to Golueke (1977), the optimum carbon-nitrogen ratio with most municipal wastes falls within 25 or 30 to 1. The more the carbon-nitrogen balance (or ratio) deviates from the optimum, especially in the upper range, the slower the composting proceeds. If the carbon is present in a form highly resistant to bacterial attack, it is of little use to microbes. Hence, if a waste has a large percentage of carbon in a resistant form, the permissible carbon to nitrogen ratio can be higher than 25:1. Examples are wastes having a heavy concentration of paper, fiber, wood, or straw. The carbon to nitrogen ratio and the time required for composting can be lowered by adding a nitrogen source such as manure or activated sludge. Poultry manure is richer in nitrogen content than other animal manures like cow manure, and therefore, the use of bedding material helps to capture some inorganic nitrogen that would otherwise have been lost due to volatilization. The principal deleterious effect of too low a carbon to nitrogen ratio is the loss of nitrogen through the production of ammonia.

Aerobic composting may cause loss of nitrogen (ammonia), especially when carbon-nitrogen ratios are below 20:1. Furthermore, overaeration may retard or stop microbial activity. Castellanos and Pratt (1981) reported that composting reduces the value of the manure as a nitrogen fertilizer. They compared mineralization of poultry manure with other animal manures in an evaluation of laboratory indices of nitrogen availability. The results of their analyses indicated that composting the manure reduced the rate and quantity of mineralization. The results showed that composted chicken manure had much less total nitrogen than fresh chicken manure, and that nitrogen was about half as available as the nitrogen in the fresh manure in the first year after litter application. They asserted that the composted material was about one fifth as valuable in supplying mineral nitrogen as fresh manure per unit weight in the first year after application. However, the residual nitrogen must be included as part of the amount of nitrogen available from a poultry litter application. Composted litter may have more residual nitrogen than untreated litter. They also report that composting reduces odors and creates better physical properties.

Another study by Inman *et al.*, (1982) indicated that nitrogen was lost from compost-treated soils. Inman *et al.* investigated the effect of composted sewage sludge on nitrate nitrogen, phosphates, and electrical conductivity (EC) levels in soil water collected at three depths (15, 45, and 100 cm). A stabilizing effect of composted sewage sludge was observed and attributed to the fact that nitrogen mineralization in soils amended with compost and sludge (and, therefore, possible loss of nitrogen as nitrate-nitrogen is a relatively slow process. The uptake of inorganic nitrogen by plant roots also serves to further buffer leaching losses of nitrate nitrogen.

The potential for composting poultry litter may be better than composting of poultry manure because the loss of ammonium nitrogen should be less for litter than for manure due to litter's high carbon content compared to manure. According to Contnoir (1983), absorbent litter results in low ammonia losses from composting. Economic analysis is needed in order to determine the feasibility of composting. If costs of composting (including nitrogen losses) are greater than its benefits, then it may have limited use for bulk fertilizer. However, it may still be useful to prepare litter for sale in bagged form for home and garden use because of odor reduction.

II.3.4. The Rate of Litter Application

Rates of litter application should meet but not exceed the crop's nutrient needs (Bradford, 1974; Burwell *et al.*, 1977; Tan *et al.* 1975; Sims and Harris, 1986; Liebhardt *et al.*, 1979). Applying litter at higher rates than crop requirements may cause leaching loss of nitrogen, build up of phosphorus and potash in the soil, salinity problems and/or ammonium toxicity. Salinity and/or ammonium toxicity may adversely affect seed germination, emergence and seedling growth, thereby reducing crop yields (Sims and Harris, 1986). The amount of litter which can be effectively used by the soil depends on the crop's nutrient requirements, nutrients already in the soil, and the nutrient content of litter (North Carolina Agricultural Extension Service, 1982). Moreover, calculation of the rate of litter application should consider that all of the applied nitrogen is not available in the year of application. In case of commercial fertilizer nitrogen, almost all of the nitrogen is released in the year of application but only about 50 to 60 percent is actually taken up by plants (Keeney, 1982). The rest is lost to leaching, denitrification, and immobilization. About 75 percent of the inorganic nitrogen in poultry litter is plant available in the year of application if litter is not incorporated (Givens, 1987). If litter is incorporated immediately after application, then about 95 percent of inorganic nitrogen in litter is plant available (Givens, 1987). Only about 50 percent of the organic nitrogen in litter is plant available in the year of application (Keeney, 1982), with 12, 5, 2, and 2 percent being plant available in the second, third, fourth, and fifth years after litter application, respectively. Therefore, the rate of litter application will have to be based on nutrient analyses of litter samples and soil tests and tailored to the rate and the timing of nutrients available to plants from litter. Variations in nitrogen availability from litter may require the farmer to adjust the rate of application every year based on weather, soil, and litter conditions instead of applying at a constant rate every year. For example, if rainfall is above normal then more nitrate nitrogen may be lost to leaching, and a higher than average application will have to be applied in the following year to meet crop requirements.

II.2.3.5. The Method of Litter Application

The method of application affects the amounts of nutrients, especially nitrogen, which are available to the plant. The unstable inorganic nitrogen present as uric acid accounts for 70 percent of the total nitrogen in poultry manure (Klausner and Bouldin, 1985). This uric acid is rapidly converted to urea and nitrogen is easily volatilized from the manure if conditions of moisture, pH and temperature are favorable. Immediate incorporation of solid manure before it dries minimizes volatilization losses and allows soil microorganisms to decompose the waste sooner (Hensler *et al.*, 1970). Therefore, some sources recommend that manure either be broadcast and immediately incorporated or applied by liquid injection to reduce runoff and ammonia volatilization losses

(North Carolina Agricultural Extension Service, 1982). Volatilization loss of ammonia nitrogen may be reduced by adding carbon. Contnoir (1983) indicates that absorbent litter lowers ammonia losses implying that volatilization loss of nitrogen will be less for poultry litter than for poultry manure. Hay, straw and corn cobs are considered to be good at absorbing moisture and retaining nitrogen, while saw-dust is generally less effective (Contnoir, 1983).

The economic feasibility of incorporation will depend on the litter content of manure, cost of incorporation, and the value of the amount of ammonia nitrogen saved by incorporation. If the cost of incorporation is higher than the value of nutrients saved by incorporation, then this option is not economically feasible. For example, Collins (1988) showed that the economics of incorporation may not be attractive, especially with poultry litter because of the relatively low fraction of total nitrogen in the ammonia form. This conclusion was based on the assumption that an acre can be disk harrowed (12 ft disk harrow @ $0.90 per hr.) with a 90 hp tractor in 0.22 hours (tractor cost, @ $6.85 per hr.). Assuming labor at $5.00 per hour, total cost of disking applied waste was found to be $2.81 per acre, regardless of the amount applied. According to Collins (1988), this operation would reduce ammonia loss from litter from about 25 percent to 5 percent. Average ammonia content of broiler litter in Virginia, based on laboratory tests was assumed to be about 14 pounds per ton. By disking litter in following application, ammonia loss can be reduced from 3.5 lbs to 0.7 lbs per ton for a savings of about $0.59 per ton of litter applied (assuming nitrogen price to be $0.21 per pound). At least 4.75 tons of litter containing an average of 14 pounds of ammonia nitrogen per ton would have to be applied before disking would begin to pay. As will be shown in this study (Chapter IV) application rates required for representative crop rotations are less than 4.75 tons per acre implying that incorporation may not be profitable. The cost-benefit figures might change significantly with a change in the assumptions of the analysis. For example, the cost of incorporation may be reduced by incorporating poultry litter when the field is being tilled for planting or sowing and eliminating the additional disking requirement.

II.3.6. The Timing of Litter Application

Proper application timing is important to maximize the value of poultry litter. According to one study, up to 50 percent of inorganic nitrogen in poultry litter was mineralized in three to six weeks after application (Reddy *et al.*, 1979). About 50 percent of organic nitrogen in the manure is released during a growing season (about 24 weeks). With a spring application, the majority of this nitrogen will be released during the first 3 to 4 weeks after application (Sims and Harris, 1986). Once mineralized, the nitrogen is subject to leaching loss if not used by the plant. The optimal time to apply animal waste such as poultry litter is, therefore, shortly before planting time (Swoboda, 1977; Sutton *et al.*, 1975; North Carolina Agricultural Extension Service, 1982; Sims and Harris, 1986). It is recommended that litter be applied two weeks before planting in order to avoid toxic effects of ammonia on seedlings or young plants (North Carolina Agricultural Extension Service, 1982). Winter applications of manure are not advisable because of the potential for nitrogen losses. Fall application of manure should be minimized in regions with sandy soils and mild winters where winter crop nutrient uptake is reduced and leaching can occur throughout the year (North Carolina Agricultural Extension Service, 1982). When temperatures drop below 40 degrees F in the winter, mineralization and nitrification cease, thereby reducing leaching loss of nitrogen from litter applied in fall (Brady, 1974). Weather also affects the uptake and losses of nitrogen from litter and litter applications should be adjusted according to the weather and soil conditions. Application of litter during heavy rainfall periods decreases the carryover nitrogen compared to application during the dry season. Cold dry springs can reduce microbial activity and thus the release of organic nitrogen in the manure, or heavy spring and summer rains may cause losses of nitrogen by leaching (Sims and Harris, 1986).

II.4. Management of Poultry Litter for Use as Animal Feed

Poultry litter can be used as livestock feed supplement and has been used in cattle feeding programs in Virginia since at least 1962 (Gerken, 1977). Studies examining the economic value of using poultry litter as animal feed (Smith and Wheeler, 1979; Thompson and Cross, 1978; Russell et al., 1987; Zimet et al., 1988; and Bosch and Kiracofe, 1989) indicate that poultry litter has economic potential as animal feed. The chemical composition and digestibilities of each component of poultry litter should be determined before ration formulation. These factors determine the type of animal that poultry litter should be fed to, the amount that can be efficiently mixed in the feed ration, the form in which it will be used in the ration (e.g., as an energy source vs. a protein source), and the method of processing to be employed. Parameters to be considered include dry matter, protein equivalents, gross energy, and minerals (Arndt et al., 1979).

Some indications of the level and variability of nutrient content in the broiler litter can be seen in Table II.2. Poultry litter is rich in nitrogen, containing on average about 31 percent crude protein and 23 percent digestible protein on a dry basis (Bhattacharya and Taylor, 1975). Table II.2 indicates that in addition to containing protein, poultry litter is also a good source of digestible energy and other nutrients especially calcium and phosphorus. Protein nitrogen makes up about 40 to 50 percent of the total nitrogen in broiler litter (Bhattacharya and Fontenot, 1966; Bhattacharya and Taylor, 1975). According to Free (1977), poultry litter can be used as a protein supplement in feed lot rations with little loss of rate of gain.

Ruminants are the ideal target to use poultry litter as animal feed (Arndt et al., 1979) because of their ability to utilize non-protein nitrogenous compounds (NPN) which comprises most of the protein equivalents in animal excreta (Fontenot, 1977). Ruminants are better equipped (enzymatically) to degrade the high levels of nucleic acids present in animal excreta than non-ruminants (Condon, 1979) and as result can efficiently utilize both the protein and non-protein forms of nitrogen in broiler litter. Moreover, the ruminants can also utilize fiber contained in poultry litter because the microbial activity of the rumen can release energy from residual fiber

Table II.2. Nutrient content of broiler litter[a].

Component	Broiler Litter
Dry matter (%)	84.7 ± 4.2
Composition of dry matter	
Crude protein (%)	31.3 ± 2.9
True protein (%)	16.7 ± 2.4
Digestible protein (ruminants) (%)	23.3
Crude fiber (%)	16.8 ± 1.9
Ether extract (%)	3.3 ± 1.3
Nitrogen free extract (%)	29.5 ± 1.6
Digestible energy, kcal/gm	2440.0
Metabolizable energy, kcal/gm	2181.0
Total digestible nutrients (%)	59.8
Ash (%)	15.0 ± 3.2
Calcium (%)	2.4
Phosphorus (%)	1.8 ± 0.4
Magnesium (%)	0.44
Sodium (%)	0.54
Potassium (%)	1.78
Iron, ppm	451.0
Copper, ppm	98.0
Manganese, ppm	225.0
Zinc, ppm	235.0

[a]Source : Bhattacharya and Taylor, 1975.

(cellulose) in the litter and release other nutrients which may be encapsulated or entrapped by fiber. Broiler litter is not a satisfactory feed for non-ruminants such as horses, swine, or poultry since they are unable to utilize non-protein nitrogen compounds (Gerken, 1977).

Broiler litter may also serve as an important source of energy, especially for ruminants. Broiler litter with peanut hulls and wood shavings as base materials was shown to contain 60 percent total digestible nutrients (TDN), 2,440 kcal digestible energy, and 2,181 kcal metabolizable energy per kilogram on a dry basis for ruminants (Bhattacharya and Fontenot, 1966). Poultry litter also contains substantial levels of calcium and phosphorus, which can reduce the amount of supplemental sources needed in ruminant rations. It contains substantial amounts of most of the trace minerals as well.

Sheep may suffer from copper toxicity if fed litter for a long period of time. Recommendations suggest feeding litter to sheep no more than 60 days to guard against build-up of excessive liver copper levels (Gerken, 1977). Poultry litter is not recommended to be fed to milk-producing dairy animals and its use should be discontinued 15 days prior to slaughter of cattle or sheep (Gerken, 1977). These precautions are recommended in order to avoid contamination of milk and meat products by drug residues and herbicides. Herbicides may pass through an animal's digestive system and retain harmful properties, or a compound can be metabolized to have such properties (Costa et al. 1974, Minchinton et al. 1973). For this reason, Virginia regulations for dried poultry waste in manufactured feeds stipulate a 15 day withdrawal before litter-fed animals go to slaughter (Gerken, 1977).

II.4.1. Processing of Poultry Litter for Feed

The attractiveness of using poultry litter as animal feed depends on how well litter is managed. The use of litter in rations requires that litter be evaluated with respect to chemical and nutritive content and digestibility just as any other feed source. Chemical and nutritive content and digestibility of poultry litter in turn depend on the management practices adopted. For example, proper care should be taken to ensure that litter is free of nails, wire, glass, rocks, dirt, or other foreign material. Proper management requires frequent and total collection of excreta to avoid nutrient losses because at least one-half of the nitrogen present in animal excreta is said to be in the urine (Arndt et al., 1979).

Processing of poultry litter for use as animal feed is beneficial for increasing palatability, recovering nutrients, pathogen destruction, and odor and fly control. Runkle (1975) and Arndt (1977) give extensive literature reviews on methods of processing, handling, and recycling of animal excreta. Chemical treatment of poultry litter combined with immediate harvesting and refeeding increases animal acceptability and reduces losses (Arndt et al., 1979). This method does not require storage; litter is deodorized; and the energy and labor requirements are low. But this method requires daily harvesting and processing. Short shelf life of the treated litter does not permit extensive stockpiling. Moreover, this method requires mixing equipment and involves the cost of chemicals (Arndt et al., 1979).

Another potential method of processing poultry litter is heat treatment. According to Fontenot et al. (1971), poultry litter can be sterilized by processing at 150 degrees C for three hours or longer. However, Caswell et al. (1972) have shown that heat processing the litter results in a marked reduction in crude protein content.

Smith and Wheeler (1979) indicate that ensiling poultry litter is the most economically advantageous method of controlled processing of litter for feed. They claim that the use of litter with corn silage - corn grain feeding systems presents the greatest opportunity to more efficiently utilize nitrogen and minerals in litter. Ensiling is characterized by the production of heat and organic acids, followed by quiescence at which time pH of the fermented mass becomes stable at 4 (Barnett, 1954). Ensiling litter alone or with other feedstuffs results in heat production which helps in reducing or eliminating pathogens like *E. coli* in broiler litter (Gerken, 1977). Fontenot et al. (1971) used ensiling of broiler litter alone and found that this method of processing lowered or eliminated coliform counts. Further, addition of broiler litter to corn forage or high moisture corn grain was found to have improved the palatability of the ensiled material.

According to Free (1977), poultry litter can be ensiled by deep-stacking with a moisture level of around 35 percent or in upright concrete or trench types silos. Ensiling poultry litter by deep stacking may be the least expensive method of ensiling. Deep stacking can be accomplished in a shed or in the open with a plastic covering. According to Gerken (1977), about 80 percent of the litter used for livestock feeding in Virginia is processed by deep stacking before feeding with the remainder being ensiled alone or with corn forage. Ensiling permits stockpiling and controls pathogens after three weeks of ensiling. Further, ensiling fits with many existing feeding systems and the nutrient loss is low. In this study it is assumed poultry litter is ensiled by the deep-stacking method before it is fed to cattle. This method was selected because of its wide use in Virginia and the advantages listed above.

II.4.2. Value of Poultry Litter as Animal Feed

The value of poultry litter is found to be higher when used as a protein source than as an energy source (Smith and Wheeler, 1979). Because of litter's relatively low energy content, using more of it may cause slower gains to be achieved meaning higher interest and labor costs for feeding the animal. However, it may be economical to opt for a slower gain if the feed cost savings are sufficient (Bosch and Kiracofe, 1989).

Free (1977) estimated the value of litter based on nutrient content as $59.22 per ton assuming 24 percent protein and 55 percent total digestible nutrient (TDN) content. However, his analysis did not consider the need to fit litter within a balanced ration with constraints such as limits on dry matter consumption. The value of litter depends on how it is being used within the ration. Thompson and Cross (1978) developed least cost rations for fattening beef which included litter. An upper limit on poultry litter as a percent of the dry matter in the ration was imposed. As the upper limit was varied from 0 to 50 percent, total feed costs declined at a decreasing rate as the litter was first substituted for other protein sources and then other energy sources. Bosch and Kiracofe (1989) expanded on prior research by estimating the responsiveness of litter use in the ration to changes in price of litter and of competing feeds. Bosch and Kiracofe (1989) found that significant amounts of litter were used in the beef finishing ration but that the amount used was quite sensitive to its prices as well as the prices of corn silage and corn grain. As the price of litter increased, litter use in the ration declined rapidly due to: (1) the switch to faster rates of gain which required higher energy feeds; and (2) the substitution of relatively lower cost competing feeds for litter with the rate of gain held constant. None of the previous work has, however, considered the costs of handling, storing, and feeding litter relative to other feeds. These costs may affect the minimum-cost ration composition significantly. Therefore, this study looks at the value of litter as feed considering the costs of storage, handling and feeding.

Chapter III: Conceptual Model

III.1. Introduction

The economic feasilibility of establishing a poultry litter handling industry requires that the costs of providing the end product to the user at the right time, in the right form, and in the right place be less than the amount users of poultry litter are willing to pay for the end product. Determination of the economic feasibility of establishing such an industry requires analysis of the costs of providing litter and willingness of farmers to pay for litter to determine if there is a price at which a positive quantity of litter will be cleared by the market.

III.2. Conceptual Model of the Competitive Litter Handling Firm

In this study the poultry litter handling firm is assumed to be operating in a perfectly competitive market and facing a perfectly elastic demand for litter. Assuming that no subsidies are available for the safe disposal of litter, a litter handling firm would have economic incentives to enter the industry if it faces a price greater than or equal to the minimum average cost (AC) as shown in Figure III.1.

A profit-maximizing firm operating in a perfectly competitive environment produces at the output level at which marginal cost is equal to marginal revenue. Assuming the firm is too small to affect the market price of litter by its action, the marginal revenue of litter is equal to the price users are willing to pay for litter. Under perfect competition, the firm supplies that amount of litter at which the price it receives for litter is equal to its marginal cost of production. However, Figure III.1 shows that the firm should not produce at output levels at which marginal cost is decreasing. For example, if marginal cost is decreasing and is less than price, the firm can increase profits by increasing production because marginal revenue is greater than marginal cost. The firm cannot produce if market price is lower than average variable cost, AVC(y), because it will incur a loss. The firm will shut down unless marginal revenue covers at least the variable costs. The shut-down condition is given by

$$AVC(y) = \frac{C_v(y)}{y} \quad > \quad P \tag{1}$$

where y is output and $C_v(y)$ is total variable cost as a function of output. Equation (1) implies that if average variable costs are greater than P, the firm would be better off producing zero units of output. Only the portions of the marginal cost curve that lie above the average variable cost curve are possible points on the supply curve. Thus the competitive firm's supply will be that part of the marginal cost curve that is upward sloping and lies above the average variable cost curve.

Assuming farmers are willing to pay a price of OP dollars per ton, then the output level chosen by the litter handling firm would be OQ tons of litter and the profit to the firm would be given by the shaded area in Figure III.1. However, upper limits on litter output in litter-surplus areas may limit the total amount that can be handled by the firm to something less than OQ.

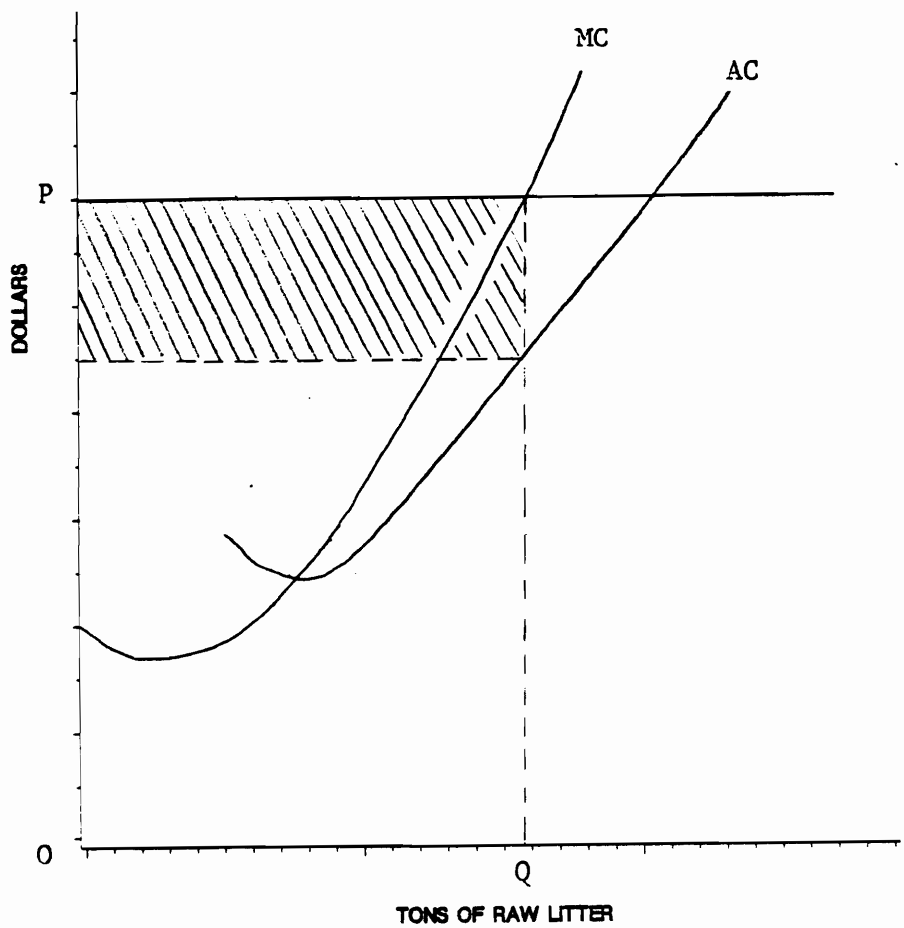

Figure III.1. Economic feasibility in a perfectly competitive market.

III.3. The Value of Litter as Feed and Fertilizer

In this study, the basic assumption used to value litter for use as feed and fertilizer is that litter can be substituted for feed or commercial fertilizer while holding constant the performance of the animal or crop. Therefore, the value of litter as fertilizer and feed can be imputed by calculating the amount of feed or commercial fertilizer savings resulting from the use of poultry litter while holding output constant. The amount of litter to be substituted for commercial fertilizer is based on the agronomic requirements of crops in a given crop rotation. The amount of litter to be substituted for animal feed is be based on the daily nutritional requirements of animals and palatability constraints.

The principle of input substitution states that one input can be substituted for another without changing the level of production. A diagram of an isoquant is useful in understanding this principle (Figure III.2). An isoquant is the locus of all combinations of x_1 and x_2 which yields a specified output level (Henderson and Quandt, 1980). The isoquant in Figure III.2 represents a specific level of production, q^o using inputs x_1 (poultry litter) and x_2 (commercial fertilizer). For a given output level, the production function becomes

$$q^o = f(x_1, x_2) \tag{2}$$

and its isoquant equation can be determined as

$$x_2 = h(x_1; q^o) \tag{3}$$

where q^o is the given level of output. Since the production function is continuous, an infinite number of input combinations lie on each isoquant.

The slope of the tangent to a point on an isoquant is the rate at which x_1 must be substituted for x_2 (or x_2 for x_1) in order to maintain the corresponding output level. The negative of the slope is defined as the marginal rate of technical substitution (RTS):

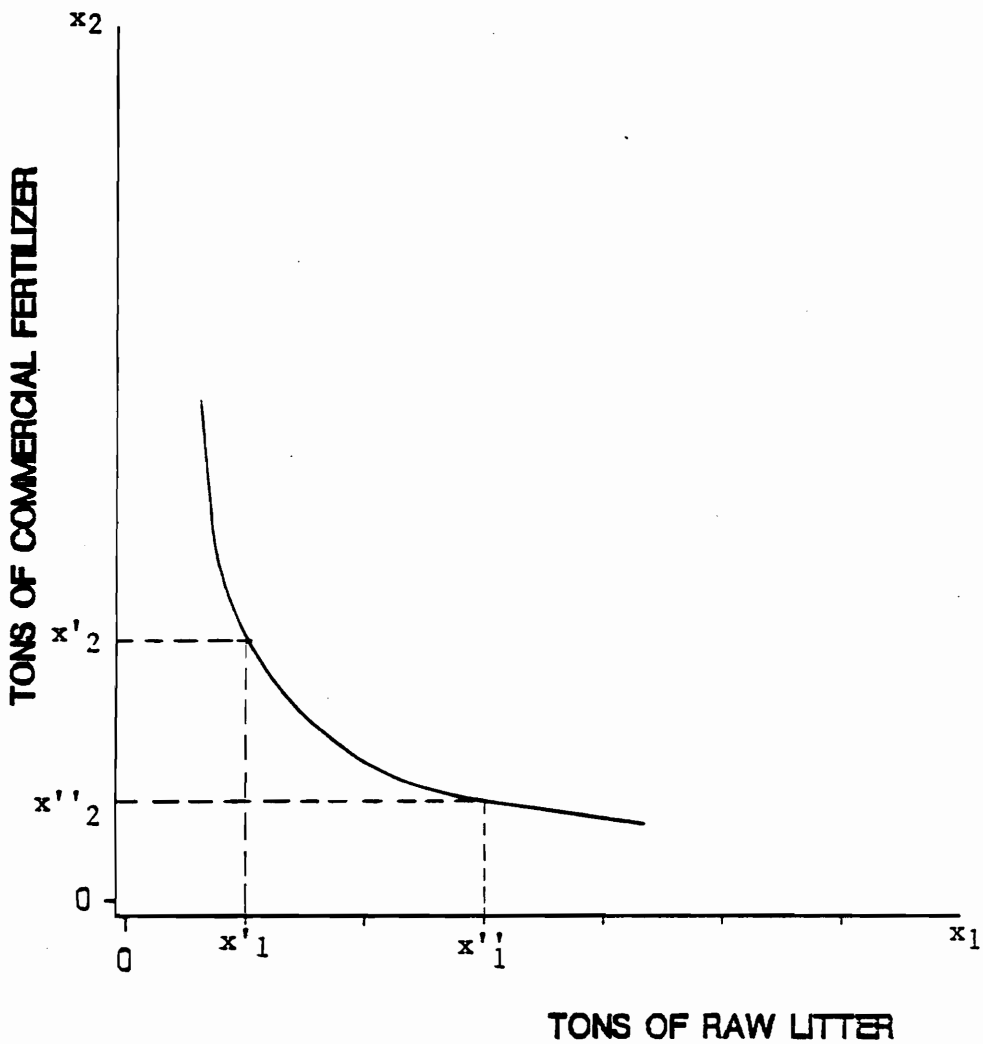

Figure III.2. The principle of input substitution.

$$RTS = -\,dx_2/dx_1 \tag{4}$$

The total differential of the production function is

$$dq = f_1 dx_1 + f_2 dx_2 \tag{5}$$

where f_1 and f_2 are the partial derivatives of q with respect of x_1 and x_2 (the marginal products of x_1 and x_2).

Since dq = 0 for movements along an isoquant, equation (5) becomes

$$0 = f_1 dx_1 + f_2 dx_2 \tag{6}$$

and the rate of technical substitution is

$$RTS = -\,dx_2/dx_1 = f_1/f_2 \tag{7}$$

The RTS at a point equals the ratio of the marginal product of x_1 (f_1) to the marginal product of x_2 (f_2) at that point. If RTS falls as one input is substituted for another, then the isoquant must be convex (Gould and Ferguson, 1980). The litter-commercial fertilizer isoquant is likely to be convex. As more litter is used, less and less commercial fertilizer is replaced because some of the nutrients in litter are no longer required to produce a given level of yield. Assume that a crop requires 120 pounds of nitrogen, 40 pounds of phosphate, and 30 pounds of potash to produce a 100-bushel corn yield. Assume further that one ton of litter contains 60 pounds of nitrogen, 40 pounds of phosphate, and 30 pounds of potash. Then the first ton of applied litter replaces 130 pounds of nutrients from commercial fertilizer (60 + 40 + 30). The second ton applied replaces only 60 pounds of commercial fertilizer since the potash and phosphate contained in the litter are no longer required to produce the 100-bushel yield.

If the price of commercial fertilizer (P_2) is known, and if the rate at which poultry litter (x_1) substitutes for commercial fertilizer (x_2) is known, then the willingness of the user to pay for different amounts of litter per unit of crop or livestock enterprise can be determined. If:

$$P_1 / P_2 = dx_2 / dx_1 \tag{8}$$

then, for a marginal increase in litter applied per acre of crop:

$$P_1 = P_2 dx_2 / dx_1 \tag{9}$$

The willingness to pay for an additional unit of litter (P_1) equals the value of commercial fertilizer replaced (P_2 dx_2) divided by the amount of litter added (dx_1).

The implication of equation (9) is that as the price of litter increases, the amount applied per acre will decline with the price of commercial fertilizer (P_2) constant because the RTS of litter for commercial fertilizer must increase as well to maintain the equality shown in equation (9). The RTS can be increased by using less litter, and more fertilizer.

The fact that litter has some nitrogen in the organic form which is released over several years has implications for the way litter is valued. Assuming that litter is applied each year, the amount of nitrogen available to plants in the current crop season is equal to the sum of nitrogen available from this year's litter application, as well as total carryover nitrogen, which is the nitrogen made available to the current crop from litter applied in previous years. For example, if organic nitrogen in litter is released over a five-year period, then total carryover nitrogen equals the nitrogen available from each of the five previous litter applications. This carryover nitrogen should be considered in determining the amount of commercial fertilizer that can be replaced by poultry litter. However the cost of waiting for this nitrogen (carrying cost) must be deducted from the value of litter. The carrying cost equals the value of the nitrogen contained in the litter times the relevant interest rate compounded over the number of years until the nitrogen is made available to the crop.

The value of litter will depend on how much is being substituted for commercial fertilizer. So, imputing a value of litter for a given crop requires an assumption about how much litter will be used. There is a basis for recommending that farmers apply litter up to the crop's nitrogen requirement. Overapplication of nitrogen is harmful because it is very mobile in the soil in the presence of water. Overapplication of potassium and phosphorus is less harmful to the environment than overapplication of nitrogen because potassium and phosphorus are relatively immobile in the soil and not likely to leach or run off into surface water unless the soil and/or manure in which the elements are contained are eroded away (Beegle, 1988). Because these elements are stable, they may have value to crops in future years if applied in excess of the current crop's needs. In that case, the value of phosphorus not required by the current crop is equal to its discounted value for the year that it is actually used by the crop.

Valuing litter for feed is similar to valuing it as fertilizer in the sense that in both cases, one input can be substituted for another input without affecting the output. For example, alternative combinations of litter and corn grain can be used to produce an acceptable gain in body weight. These combinations make up a production isoquant. The least cost production point on the isoquant depends on the feed input prices. A linear programming cost minimization model can be used to find the least cost ration. The objective function for the feed cost minimization model used in this study is as follows:

$$Minimize \quad \sum_{j=1}^{n} a_j X_j \tag{10}$$

where a_j are per hundredweight costs of feed acquisition, storage and feeding for j = 1 to n types of feed; and X_1 , X_2, ..., X_n are alternative feeds including poultry litter. The constraints of the feed cost minimization model are as follows:

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \qquad for \quad i = 1, 2, 3, ..., m \tag{11}$$

where a_{ij} is the amount of the i^{th} resource requirement contained by the j^{th} feed activity, X_j are the alternative feeds; and b_1, b_2, ... , b_m are the amounts of each resource required by the animal. These constraints include daily minimum requirements of dry matter, net energy for maintenance (or growth), protein, calcium, and phosphorus per animal. Output from the linear programming model will show the amount of litter to be used in the rotation at alternative litter prices as well as for alternative prices of competing feeds.

III.4. Estimation of the Cost of Providing Litter as Fertilizer and Feed

A poultry litter-handling firm buys raw litter from poultry grower, processes it, stores it, and delivers the end product to the users. The supply of litter by the litter handling firm to the users of the end product will depend upon the total costs (TC) of acquiring and collecting litter from growers (CC) as well as costs of litter processing (PC), storage (SC), delivery (DC), and application (AC) as shown in equation (12). The relationship between TC and the level of output must be obtained in order to determine what amount the firm will produce at a given price. Once the TC is known for each level of output, then marginal cost can be calculated for a change in output and compared with price to determine the farmer's profit maximizing output level as shown in Figure III.1. The firm's total cost is[3]

$$TC = CC + PC + SC + DC + AC \tag{12}$$

In determining the relationship between TC and output, the firm is assumed to minimize the total cost of producing any given level of output. In this study, a linear programming model was used to determine the least-cost method of transferring alternative levels of litter from litter producers to users as fertilizer. The objective function of the firm is assumed to be to minimize the costs as shown in equation 12 of transferring litter from litter producers in surplus areas to potential users in deficit areas.[4] The litter handling firm can choose to obtain litter from one or more of se-

[3] The analysis in this section draws on Bressler and King (1970).

[4] The cost of delivering litter from surplus to deficit areas for use as animal feed were not evaluated with the linear programming cost minimization model. Analysis described in Chapters IV and V indicated that there was greater economic potential to transfer poultry litter as fertilizer than as feed. Consequently, the cost minimization models of litter transfer were simplified by omitting the animal feed option.

veral surplus areas and to deliver litter to one or more of several deficit areas. The objective function can then be written:

$$Minimize \;\; TC = \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}X_{ij} \tag{13}$$

subject to:

$$\sum_{j=1}^{n} X_{ij} \leq X_i \qquad for \quad i = 1, 2, ..., m \tag{14}$$

$$\sum_{i=1}^{m} a_{ij}X_{ij} \leq X_j \qquad for \quad j = 1, 2, ..., n \tag{15}$$

$$\sum_{i=1}^{m}\sum_{j=1}^{n} X_{ij} \geq b \tag{16}$$

where: TC equals total cost of handling a fixed amount of litter; C_{ij} equals the per ton cost of transferring litter from the i^{th} surplus county to the j^{th} deficit county including costs of litter acquisition, collection, storage, processing, delivery and application; m is the number of litter-surplus counties; n is the number of litter deficit counties; X_{ij} represents the amount of litter transferred from surplus county i to deficit county j; X_i is the amount of litter available from surplus county i; X_j is the amount of nitrogen required in deficit county j; a_{ij} is the amount of plant available nitrogen obtained per ton of poultry litter; and b is a fixed parameter set equal to the nitrogen requirements in all litter-deficit counties that must be satisfied by litter.

The objective function coefficients in the litter marketing cost minimization model reflect the processing and storage alternatives considered in the analysis. For example, raw litter was assumed to require storage under roof and the objective function coefficient for the raw litter transfer activity includes the unit cost of litter storage but does not include composting costs. On the other hand, the composted litter transfer activity was assumed not to require storage under roof and its objective function coefficient does not include the unit cost of this type of storage.

Equation (14) requires that the amount of litter available from surplus county i is greater than or equal to the sum of the amounts shipped from i to all j destinations. Equation (15) requires that the amount of litter that can be absorbed by destination j be greater than or equal to the amounts shipped from i sources. Equation (16) requires that total shipments of litter from the litter-surplus to all the litter-deficit areas be greater than or equal to some fixed amount b.

The relationship between total cost and amount of litter handled was derived by parametrically changing the value of b. As b was increased, more litter was transferred and total cost increased. The marginal cost of transferring litter from surplus to deficit areas as shown in Figure III.1 was obtained from total cost curve.

Separate versions of the model described in equations 13 through 16 were run for raw and composted litter. The models differed by their C_{ij} values reflecting the costs of transferring raw or composted litter as well as by their a_{ij} coefficients reflecting the raw litter-nitrogen and composted litter-nitrogen ratios. This procedure allowed separate total cost relationships to be derived for raw and composted litter.

The profit to the litter handling firm from transferring litter from surplus to deficit areas can be obtained by determining the profit maximizing level of output, which is the output where MC equals marginal revenue (or where supplies from surplus counties are exhausted if this occurs before MC equals MR). Their profits are calculated by subtracting total costs from total revenues at this output level. Profits from making litter available to users in raw and composted forms are obtained in this way and then compared to find out which is more profitable.[5]

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[5] The possibility of composting a portion of total volume and handling a portion as raw litter was not considered in this analysis but could be investigated in further studies.

Chapter IV: Empirical Procedures for Estimating Cost and Value of Poultry Litter

IV.1. Introduction

This chapter presents the empirical procedures used to estimate the costs and value of poultry litter. The first half deals with the empirical procedures involved in the analysis of litter as fertilizer and the second half deals with the empirical procedures involved in the analysis of litter as animal feed supplement. The discussion of the empirical issues involving litter use as fertilizer includes procedures used to estimate the value of litter as fertilizer for representative crop rotations and procedures to estimate litter handling and processing costs. These costs were used to construct a linear programming cost minimization model for comparing costs of litter transfer with litter value. If the value of litter as fertilizer is less than the per unit cost of making litter available to farmers in the deficit areas, then there will be no profit potential of establishing a poultry litter handling industry. The discussion of the empirical issues involving litter use as feed includes procedures used in the analysis of the use of litter in least cost rations of beef cows and growing cattle, amount and value of litter in these rations, and handling and storage costs of litter feeding.

IV.2.1. Litter Value in Representative Crop Rotations

The fertilizer value of poultry litter in raw and composted form was calculated for various crop rotations prevalent in the litter-surplus and litter-deficit areas of Virginia. By "value" of litter is meant the maximum the crop producer could afford to pay for poultry litter as a substitute for commercial fertilizer without increasing his crop fertilizer costs. This procedure does not consider the micronutrients and organic matter content in litter and their contributions to crop growth. The procedure used to calculate the value of litter as a fertilizer was the same for all crop rotations and is illustrated with a corn grain-barley & wheat-soybeans rotation, a rotation that is widely used by farmers in the Northern Neck and Middle Peninsula (Norris, 1988).[6] For each crop rotation, the procedure used to value poultry litter was: (1) calculate crop nutrient requirements for a fixed yield level; (2) estimate the amount and cost of commercial fertilizer needed to fulfill these requirements; (3) estimate the amount of poultry litter needed to fulfill the requirements; and (4) impute a value per ton of poultry litter based on the savings in commercial fertilizer expense due to substitution of litter for commercial fertilizer. In calculating crop nutrient requirements, the amount of nutrients provided by previous crops in the rotation and by soil organic matter were considered. In imputing the value of litter, carrying costs of nitrogen available from prior litter applications were added to account for the time value of money. This procedure assumes that litter can be substituted for commercial fertilizer while holding crop yield constant as illustrated in Figure III.2. Where litter is applied, only the amount required to meet nitrogen requirements is added because of the mobility of nitrogen in the presence of water in soil.

Table IV.1 shows the nutrient requirements for a corn grain-barley & wheat-soybeans rotation (abbreviated CG-BA WH-SB) and the applications of commercial fertilizer, raw litter, and composted litter needed to meet those requirements. Nitrogen, phosphate, and potash requirements were taken from Norris (1988). Amounts of nitrogen available from soil organic matter and

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[6] The nutrient requirements for other crop rotations and the applications of commercial fertilizer, raw litter, and composted litter needed to meet those requirements are presented in Appendix A.

crop residues were also calculated. These amounts were deducted from crop nitrogen requirements and the remainder was assumed to be added in the form of litter or commercial fertilizer. The nutrient requirements shown in Table IV.1 represent amounts of nutrient additions required g 0.5 acre of from external sources for a representative acre of the rotation meaning 0.5 acre of corn, m0.185 acre of barley and 0.315 acre of wheat and 0.5 acre of soybeans.

The amount of nitrogen required for a representative acre of CG-BA & WH-SB rotation as shown in Table IV.1 was calculated as follows (Norris, 1988):

corn grain = 69 lbs per 0.50 acre

wheat = 21.10 lbs per 0.315 acre

barley = 13.69 lbs per 0.185 acre

soybeans = 71.50 lbs per 0.50 acre.

Most of the nitrogen requirements for soybeans (52.9 out of 71.5 pounds per 0.50 acre) are available from symbiotic fixation. The rest of the nitrogen requirements for soybeans are met by nitrogen available from soil organic matter, and crop residues. Assuming that an acre of soil organic matter provides about 30 lbs of plant available nitrogen in a crop season (Norris, 1988), then the amount of nitrogen available from soil organic matter to:

corn grain = 30 x 0.50 = 15 lbs per 0.5 acre,

wheat = 30 x 0.315 = 9.45 lbs per 0.315 acre,

barley = 30 x 0.185 = 5.55 lbs per 0.185 acre, and

soybeans = 30 x 0.50 = 15 lbs per 0.50 acre.

The amount of nitrogen available from decomposition of crop residues of soybeans, wheat, barley, and corn grain are 46, 22, 17.02, and 46 pounds per acre, respectively (Norris, 1988). Crop residues will decompose to release nitrogen at the rates of 15, 5, and 3 percent in the first, second, and third years after harvest (Keeney, 1983). Therefore, the amount of nitrogen available from crop residues to:

corn grain = (0.15 x 46 x 0.5 + 0.05 x 17.02 x 0.315 + 0.05 x 22 x 0.185
+ 0.03 x 46 x 0.5) x 0.50

Table IV.1. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of corn grain-barley & wheat-soybeans rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	69.17	69.17	69.17
Phosphate required (lb)	65.00	65.00	65.00
Potash required (lb)	100.00	100.00	100.00
Inorganic nitrogen application (lb)	111.56	38.12	19.27
Inorganic nitrogen available in Year 1 (lb)	69.17	28.59	14.45
Organic nitrogen application (lb)	0.00	57.18	77.07
Organic nitrogen available in year 1 (lb)	0.00	28.59	38.54
Organic nitrogen available from previous litter application (lb)	0.00	12.01	16.19
Total available nitrogen (lb)	69.17	69.17	69.17
Phosphate applied as commercial fertilizer (lb)	65.00	0.00	0.00
Phosphate available from litter (lb)	0.00	66.82	96.51
Total available phosphate (lb)	65.00	66.82	96.51
Potash applied as commercial fertilizer (lb)	100.00	50.27	28.17
Potash available from litter (lb)	0.00	49.73	71.83
Total available potash (lb)	100.00	100.00	100.00
Litter applied (ton)		1.64	1.19
Nitrogen cost @ $.25/lb	27.89	0.00	0.00
Phosphate cost @ $.25/lb	16.25	0.00	0.00
Potash cost @ $.15/lb	15.00	7.54	4.23
Application cost ($)	9.00	4.50	4.50
Total commercial fertilizer cost($)	68.14	12.04	8.73
Value of litter ($/ton)		34.15	50.08
Value of litter net of carrying cost ($/ton)		33.88	49.59

= 2.31 lbs per 0.50 acre

wheat = (0.15 x 46 x 0.5 + 0.05 x 17.02 x 0.315 + 0.05 x 22 x 0.185 + 0.03 x 46 x 0.5) x 0.315

= 1.45 lbs per 0.315 acre

barley = (0.15 x 46 x 0.5 + 0.05 x 17.02 x 0.315 + 0.05 x 22 x 0.185 + 0.03 x 46 x 0.5) x 0.185

= 0.85 lbs per 0.185 acre

soybeans = (0.15 x 48 x 0.50 + 0.15 x 17.02 x 0.315 + 0.15 x 22 x 0.185 + 0.05 x 46 x 0.50 + 0.03 x (48 x 0.50 + 17.02 x 0.315 + 22) x 0.185 = 7.17 lbs per 0.50 acre

Soybeans get 74 percent of its nitrogen (or 52.9 lbs per 0.50 acre) by symbiotic nitrogen fixation (Shibles et al., 1975). The amount of crop nitrogen requirement net of nitrogen available from soil organic matter, crop residues, and nitrogen fixation for:

corn grain = 69 - 15 - 2.31 = 51.69 lbs per 0.5 acre,

wheat = 21.10 - 9.45 - 1.46 = 10.19 lbs per 0.315 acre,

barley = 13.69 - 5.55 - 0.85 = 7.29 lbs per 0.185 acre, and

soybeans = 71.5 - 15 - 7.17 - 52.9 = -3.57 lbs per 0.50 acre.

The negative net requirement for soybeans indicates that no external addition of nitrogen is required for soybeans. The total net nitrogen required to be met through external addition of poultry litter or commercial fertilizer is then the sum of net requirements for corn grain, wheat, and barley, and is equal to 69.17 lbs per acre.

With the commercial fertilizer application, a total of 111.56 pounds of nitrogen would have to be applied to meet the 69.17 pound nitrogen requirement assuming 62 percent of commercial nitrogen is taken up by the plant.[7] In addition, 65 pounds of phosphate and 100 pounds of potash

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[7] 60 percent of the commercial fertilizer nitrogen application is available in the year of application and 2

are applied.[8] Total nutrient costs including two custom applications are $68.14 per acre for commercial fertilizer.

A total of 1.64 tons of raw litter is applied to meet crop requirements.[9] This amount of litter contains 38.12 pounds of inorganic and 57.18 pounds of organic nitrogen. Assuming no incorporation, 28.59 pounds (75 percent) of inorganic nitrogen are available, with the remainder being lost to leaching, volatilization, and other factors.[10] Of organic nitrogen contained in the current year's application, 28.59 pounds are available immediately. In addition, 12.01 pounds of nitrogen are available due to the conversion of organic nitrogen from previous years' litter applications to inorganic plant available form.[11]

A total of 69.17 pounds of nitrogen as well as 66.82 pounds of phosphate and 49.73 pounds of potash are available from the litter. Commercial fertilizer is required to satisfy the remainder of the 100-pound per acre potash requirement. The cost of the supplementary commercial fertilizer is $12.04 per acre including application costs. The commercial fertilizer savings are $56.10 per acre or $34.15 per ton of litter applied. These savings provide a basis for calculating what the farmer could afford to pay for poultry litter. However, carrying costs must be deducted from the simple value of litter because some of the nitrogen in litter is not released until two to five years after application.[12] For example, if a ton of litter contains five pounds of nitrogen that are not released until

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percent is immobilized and used the next year (Keeney, 1983). Hence, on a continuous application basis, 62 percent of the commercial fertilizer nitrogen application is available every year.

[8] The nitrogen requirement of 69.17 pounds per acre was obtained by adding the requirements for corn (51.69 lbs/0.5 acre), wheat (10.2 lbs/0.315 acre), and barley (7.28 lbs/0.185 acre). The phosphate requirement of 65 pounds per acre was obtained by adding the requirements for corn (25 lbs/0.5 acre), wheat (12.6 lbs/0.315 acre), barley (7.4 lbs/0.185 acre), and soybeans (20 lbs/0.5 acre). The potash requirement of 100 pounds per acre was obtained by adding the requirements for corn (35 lbs/0.5 acre), wheat (25.2 lbs/0.315 acre), barley (14.8 lbs/0.185 acre), and soybeans (25 lbs/0.5 acre).

[9] This amount is based on the assumption that poultry litter has been applied in previous years. During the transition period when litter is first substituted for commercial fertilizer, there will be no carryover nitrogen available because litter had not been applied before and application rates will have to be higher.

[10] No incorporation was assumed because the value of nitrogen saved by incorporation was found to be less than the cost of incorporation.

[11] The 12.01 pounds of carryover is calculated as follows: carryover = 1.64 x 58.16 x 0.60 x (0.12 + 0.05 + 0.02 + 0.02), where 1.64 is tons of litter applied, 58.16 is pounds of nitrogen per ton, 0.60 is the proportion of total nitrogen that is organic, and 0.12, 0.05, 0.02, and 0.02 are the fractions of organic nitrogen converted to plant available nitrogen in years two, three, four, and five after application.

[12] Using this procedure, nitrogen from the current litter application that is carried over into future years is

year two, if a pound of plant available nitrogen in litter is worth $0.40 (in terms of the value of commercial fertilizer replaced), and if the real annual interest is five percent, then the carrying cost is 0.05 x 0.25 = $0.02 per pound of plant available carryover nitrogen contained in litter. After taking into account the carrying cost of nitrogen available from past litter applications, the savings are $33.88 per ton. Carrying costs per ton of litter are calculated as follows: carrying cost

$$
\begin{aligned}
&= 4.2 \times 0.4032 \times 0.05 + 1.75 \times 0.4032 \times 0.1025 + \\
&\quad 0.7 \times 0.4032 \times 0.1576 + 0.7 \times 0.4032 \times 0.2155 \\
&= \$0.27,
\end{aligned}
$$

where 4.2, 1.75, .7 and .7 are pounds of organic nitrogen converted to plant available nitrogen in years two, three, four, and five after litter application; .05, .1025, .1576, and .2155 are the compound interest factors in years two, three, four and five after application (assuming a five percent annual real rate of interest); and .4032 is the per pound value of plant available carryover nitrogen in litter calculated by dividing $.25 (the cost of commercial fertilizer) by 0.62 to account for 62 percent availability of commercial nitrogen.

The same procedure is followed for composted litter and a a total of 1.19 tons are applied per acre to meet the nitrogen demand. This amount of litter results in excess phosphate applications but a deficit of potash that must be made up with commercial fertilizer. Commercial fertilizer savings are $59.41 per acre or $50.08 per ton of composted litter. After deducting carrying costs for nitrogen available from previous applications, the value is $49.59 per ton. The per-ton value of composted litter is larger than for raw litter because of its higher nitrogen, phosphate, and potash content. However, because two tons of raw litter are used to make one ton of compost, composting reduces the value of raw litter due to the nitrogen lost in the process.

The value of litter in raw as well as composted forms for other crop rotations are summarized in Table IV.2. The rate of litter application is higher for rotations without legume crops than

not valued in the current year. Instead, carryover nitrogen is credited to future litter applications minus a carrying cost.

Table IV.2. Rate of litter application and value of litter net of carrying cost in selected crop rotations[a].

Crop rotation[a]	Rate of litter application (tons/acre): Raw litter	Rate of litter application (tons/acre): Composted litter	Value: raw litter ($/ton)	Value: composted litter ($/ton)
WH-SB	0.53	0.39	39.84	64.10
CS-AH	0.76	0.55	37.37	58.98
TB-WH	0.89	0.64	34.44	50.36
CS-BA & WH-AH	1.03	0.74	43.51	62.92
CS-BA-AH	1.09	0.79	35.54	54.36
CG-SB	1.16	0.83	34.23	53.99
CS-SB	1.18	0.86	34.55	50.52
CG-BA-SB	1.35	0.97	34.76	51.96
CS-WH	1.63	1.18	30.92	49.16
CG-BA & WH-SB	1.64	1.19	33.88	49.59
CONCORNG	2.30	1.66	28.64	42.26
CONCORNS	2.57	1.85	29.34	44.75
CS-BA	3.26	2.35	30.28	44.60
CS-RS	3.51	2.54	31.83	46.66

[a]CG = corn grain, BA = barley, WH = wheat, SB = soybeans, CS = corn silage, AH = alfalfa hay, RS = rye silage, CONCORNG = continuous corn grain, CORCORNS = continuous corn silage, and TB = tobacco.

with legume crops because the legumes meet a significant portion of their nitrogen requirements. For example, the rate of litter application for wheat with corn silage is 1.62 tons per acre compared to 0.53 ton per acre for wheat with soybeans. The rate of application is also affected by the nutrient requirement of crops. For example, the per acre nitrogen requirement for wheat is 67 pounds compared to 138 pounds for corn grain and, as a result, the wheat-soybeans rotation uses less litter than the corn grain-soybeans rotation. In the crop rotations evaluated, the value of litter as a fertilizer is affected by the rate of litter application and the extent to which phosphate and potash in litter have been used to meet the plant requirements. At lower rates of application to these crops, all phosphate and potash as well as nitrogen in litter are more likely to be used by the crop. As a result, the per ton value of litter is higher at lower rates of application because much or all of the litter's phosphate and potash contributes to reducing the commercial fertilizer requirement. In the same manner, the total phosphate and potash requirements for the crop rotation compared to nitrogen requirement affect the per-ton value of litter. For example, the phosphate and potash requirements for continuous corn are lower than for corn silage-barley & wheat-soybeans, but the nitrogen requirement for continuous corn is higher. Consequently, the value of litter for continuous corn is lower because less of phosphate and potash in applied litter are valued than for litter applied to the corn grain-barley & wheat-soybeans rotation.

IV.3. Litter Handling and Processing Alternatives

Litter handling and processing could be done on the farm by the farmer as well as in a central location by a specialized litter handling firm. On-farm handling may be more practical if the farmer plans to use the litter on his own or other nearby land. Centralized handling may have advantages particularly if litter is to be transported in large quantities from surplus to deficit counties. This section is divided into two sub-sections to describe litter handling and processing alternatives and costs at the on-farm and large-scale levels.

IV.3.1.1. On-Farm Raw Litter Handling and Processing Costs

In order to use litter for fertilizer, several operations must be performed. The litter must be removed from the house, stored until ready for use, loaded and transported to the application site, and applied to the crop. Prior to application, litter should be tested to determine nutrient content. Testing should be done close enough to the time of application so the results accurately reflect litter's nutrient content at application yet early enough so that test results can be used to determine application rates. For example, there is a two-week waiting period between the time litter is sent for testing and the time the farmer receives the results of testing from the Water Quality Laboratory at Virginia Polytechnic Institute and State University.

Costs of on-farm handling, storage, and application of raw litter were estimated for a representative poultry grower for Rockingham County. The producer has an assumed annual production of approximately 500 tons of raw poultry litter, the output from two 33,000-bird capacity broiler houses.[13] Estimated per-ton costs of handling and applying raw litter are shown in Table IV.3. Removal from the house is done with a skid steer loader, manure spreader, and tractor. With this equipment, one worker can remove an average of 4.3 tons per hour from the house and move it to the storage shed (Souder, 1989). Variable machinery (fuel, lubrication, and repairs) and labor costs associated with cleaning are $2.81 per ton.

Costs of testing litter for nutrient content were estimated to be $0.72 per ton. This cost is based on the assumption of a $30 charge per sample and one sample per 40 tons, approximately the amount taken from one poultry house cleanout (Collins, 1988). Sampling is done prior to removing the litter from the storage structure and applying it to crops.

Loading, hauling and application are done with a skid steer loader, manure spreader, and tractor. The type of spreader used is capable of applying litter accurately at rates as low as one ton per acre. Average distance from the storage structure to the field is assumed to be one mile.

[13] According to the 1987 Census of Agriculture (Bureau of the Census, 1987) average inventory on those farms reporting broilers in Rockingham County was 52,176 birds or approximately the capacity of 1.6 bird houses (33,000 birds in each house).

Table IV.3. Raw litter handling, storage, testing and application costs.

Item	Unit	Quantity	Cost/unit ($)	Total cost (500 tons) ($)	Average cost per ton ($)
Operating costs[a]					
Cleaning house					
Tractor (65 hp)	hr.	38.76	5.10	197.73	0.40
Skid steer loader (17 hp)	hr.	116.28	3.77	439.34	0.88
Manure spreader	hr.	38.76	1.82	70.54	0.14
Labor @ $ 5/hr	hr.	116.28	6.00	697.67	1.39
Total cleaning					2.81
Manure testing	no.	12.00	30.00	360.00	0.72
Loading and hauling					
Tractor (65 hp)	hr.	50.00	5.10	255.14	0.51
Manure spreader	hr.	50.00	1.80	90.00	0.18
Skid steer loader (17 hp)	hr.	13.33	3.78	50.36	0.10
Labor @ $5/hr	hr.	63.33	6.00	379.98	0.76
Total loading and hauling					1.55
Application					
Tractor (65 hp)	hr.	62.40	5.10	318.33	0.64
Manure spreader	hr.	62.40	1.82	113.82	0.23
Labor @ $ 5/hr	hr.	62.40	6.00	375.00	0.75
Total application cost					1.62
Total operating costs				3347.91	6.70
Ownership costs[b]					
Tractor (65 hp)				507.42	1.01
Skid steer loader (17 hp)				623.29	1.25
Manure spreader				1164.82	2.33
Storage structure				1079.25	2.16
Total ownership costs				3269.78	6.75
Total costs				6620.54	13.45

[a]Machinery operating costs include fuel, lubrication, and repairs. Labor time includes machinery time plus 20 percent overhead.

[b]Machinery ownership costs include depreciation, interest, property taxes, insurance, and housing. Storage ownership costs include depreciation, interest, taxes, insurance, and repairs on the storage structure ($1.95) as well as interest on the stored litter ($0.21). Ownership costs were calculated assuming that 20 percent of 65-hp tractor, 50 percent of skid steer loader, 100 percent of manure spreader, and 100 percent of storage structure are allocated to the poultry litter operation.

One-half hour per five-ton load is required to deliver the litter to the field and return. Application time per five-ton load requires 0.62 hours.[14] Total machinery operating and labor costs are $1.55 per ton for loading and hauling and $1.62 per ton for application.

Machinery ownership costs include depreciation, interest, housing, taxes, and insurance. Based on the hours of machinery used for litter handling operation, 50 percent of the skid loader, 20 percent of the tractor, all of the storage structure, and all of the precision type manure spreader ownership costs are charged to the litter handling operation. The The ownership costs were estimated to be 13.8, 14.66, 15.33, and 14.39 percent of the purchase price of the tractor, skid loader, manure spreader, and storage structure, respectively. Purchase prices were estimated to be $18,200 (65-hp tractor), $8,500 (skid loader), $7,600, (manure spreader) and $7,500 (storage structure). Then, for example, the storage structure annual ownership cost is equal to $1079.25.

Storage takes place in a structure approved by the Soil Conservation Service with an investment cost of $15,000 of which $7500 is subsidized by the Division of Soil and Water Conservation. The storage structure is roofed and permanent and has a dimension of 40 feet wide and 60 feet long. The annual ownership costs of litter storage (depreciation, interest, taxes, insurance, interest on litter in storage, and repairs) per ton stored are $2.16 as shown in Table IV.3.[15]

The total operating and ownership costs of litter storage are $13.45 per ton. However, the added costs of effective management of litter for fertilizer compared to conventional management practice are less than $13.45. Some handling costs will be incurred even for improper litter disposal. For example, a grower may stockpile litter on the ground outside the house and spread it at very high rates on nearby pasture or cropland without accounting for its nutrient value. This grower still incurs costs of cleaning the house and spreading litter. The additional costs for effective, environ-

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[14] Application time was calculated as follows: 14 x 4 x 0.675/8.25 = 4.58 acres/hr., where 14 is the width of application in ft., 4 is the speed of the tractor in mph, 0.675 is the field efficiency for "fertilizer and chemical application" (Boehjle and Eidman, 1984), and 8.25 = 43560 sq. ft. per acre/5280 ft. per mile. Tons of litter applied per acre per application = 3.51 tons per acre/2 = 1.75. Then the application time to apply 500 tons of litter = 500/(4.58 x 1.75) = 62.4 hours or 0.624 hours per five-ton load.

[15] The interest charge on holding litter for four months was $0.21 per ton and was obtained as follows: (4/12)x0.08x$8.0 = $0.21, where 12 is the number of months in a year, 0.08 is interest charge, and $8.00 is amount that could be gained by selling litter off the farm. The ownership cost of storage structure was $1.95 per ton. Hence, $1.95 + $0.21 = $2.16 per ton.

mentally safe use are incurred for: (1) constructing an approved storage structure; (2) testing for nutrient content;[16] (3) using better spreading equipment and more machinery and labor time in order to apply litter accurately at rates required by the crop; and (4) increased cost of hauling litter from the storage to application sites located further distances from the poultry house in order to dispose of litter while applying only the amount required by the crop.

As shown in Table IV.3, costs for safe storage are $2.16 per ton and the testing cost is $0.72 per ton. Additional application costs are estimated to be $2.33-$1.38 = $0.95; this is the difference in ownership costs between a precision spreader required for low application rates and a conventional spreader.[17] Effective application is assumed to increase hauling costs by $0.86 per ton due to increased hauling distances.[18] Hauling costs are three times as high with the improved system compared with the conventional system. Thus, total costs increase $4.69 per ton with improved management. This is substantially less than the average value of $34.15 per ton value estimated for raw litter used in a corn for grain-barley & wheat-soybeans rotation (Table IV.1) as well as for other crop rotations given in Table IV.2, indicating that the grower's returns can be greatly increased by using litter to meet the crop's nutrient requirements.

IV.3.1.2. On-Farm Composting

Poultry litter is processed for use as fertilizer by composting. A budget was constructed for on-farm composting of poultry litter for the representative poultry farm producing 500 tons of litter

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[16] Although at the present time, litter testing is done for free at the Water Quality Laboratory at Virginia Polytechnic Institute and State University, it is unlikely that this free service will be available permanently.

[17] A manure spreader used for the conventional system costs $4,500 compared with $7,600 for a spreader capable of accurately applying rates as low as one ton per acre (Winchel, 1989).

[18] The additional hauling cost is based on 30 tons per hour hauled with the conventional system versus ten tons per hour with the improved management system. Hauling cost is equal to $12.90 per hour for improved management system. It requires 16.67 and 62.4 hours to haul 500 tons of litter for conventional and improved management systems, respectively. Assuming hauling costs (operating costs only) for both systems to be $12.90 per hour, then cost per ton is $12.90/10 = $1.29 for improved system and $0.43 for conventional system, and the difference is $0.86/ton.

annually. A land area of half an acre is required for composting this amount. The on-farm composting process involved forming windrows with a manure spreader pulled by a 65-hp tractor. Based on discussions with a farmer composting litter, an operator using a manure spreader and a tractor was assumed to take about 25 hours to make windrows from 500 tons of litter (Showalter, 1989). A Wildcat FX-400 Compost Turner pulled by a 65-hp tractor was assumed to be used for turning windrows. This composter can turn and aerate 250 tons of litter per hour. Each batch of windrows was assumed to be turned eight times. It takes about eight weeks to complete the composting process. The 65-hp tractor and manure spreader were assumed to be fixed cost because they would be required for poultry litter disposal even if no composting was done. Thus, the ownership costs of tractor and manure spreader were not included in the budget presented in Table IV.4.

Table IV.4 shows that it costs $4.10 per ton of raw litter for on-farm composting of litter. This charge would be in addition to cleaning, hauling, and application costs discussed previously. Almost 75 percent of this cost is ownership cost of the composter. Economies of scale may be obtained by large-scale composting as it will allow the ownership cost to be spread over more tons of litter. Some poultry farms may not have suitable land near the poultry growing operation for environmentally safe composting. Hence, centralized composting may be better than on-farm composting.

IV.3.2. Centralized System of Litter Handling and Processing

A poultry litter-handling industry planning to transfer litter from litter-surplus to deficit counties would be handling and processing a larger volume of litter than at the farm level. The scale of operation may allow costs per ton to be reduced. The following subsections present a potential centralized system of litter handling and processing and the assumptions used to estimate the costs of transferring litter from surplus to deficit counties.

Table IV.4. Costs of on-farm composting of poultry litter[a].

	Unit	Quantity	Cost per Unit	Cost ($)
Operating cost				
Composter	hour	16	2.50	40.00
Tractor (65 hp)	hour	41	5.10	209.10
Manure spreader	hour	25	1.82	45.50
Labor	hour	41	6.00	246.00
Total operating cost				540.60
Ownership cost[b]				
Composter				1446.77
Land tax				5.00
Interest on land investment				60.00
Total ownership cost				1511.77
Total cost				2052.37
Cost/ton of raw litter				4.10

[a]Assumes an annual production of 250 tons of compost which is produced from 500 tons of raw litter. The cost of composting does not include costs of poultry house cleaning, hauling and application.

[b]One hundred percent of the composter was charged to the composting operation; tractor and manure spreader were assumed to be fixed items; land was priced at $1500 per acre; interest rate was set at 8 percent; land area used for composting equalled 0.50 acre; and land tax was $10 per acre. Purchase price and useful life of composter were $9,500 and 10 years, respectively. Tax, insurance, and housing cost was 2.8 percent of average investment cost.

IV.3.2.1. Poultry Litter Collection and Acquisition Costs

In this study, raw litter was assumed to be hauled directly from growers to the demand areas for use as fertilizer. There was no collection cost required to assemble raw litter at a central location. The acquisition cost for raw litter was assumed to be $8.00 per ton of raw litter, assuming that litter was stored on farm and loaded on the truck by the farmer. This rate is what growers in the area are currently receiving (Souder, 1989). Due to the lack of information on the mileage from the poultry houses to the county seat of each supply county, the cost of collecting litter from poultry houses to the central location was included with the cost of delivering the litter to the point of use. The combined collection and delivery distance was assumed to equal the distance between county seats of the surplus and deficit counties.[19]

Raw litter was assembled to a central site for composting. The acquisition cost for raw litter to be used for composting was $5.84 per ton, assuming that litter was not stored on farm and loaded on the truck by the farmer.[20] Costs to transport raw litter to central location are $0.10 per ton per loaded mile (Souder, 1989). The county seat of each of the litter supply counties was designated as the central composting location. The cost of collecting raw litter from growers in each litter surplus county to the central location was estimated by multiplying the cost per ton loaded mile by the weighted average distance from growers to the county seat for each county. The weighted average collection distance for Rockingham County was estimated using a grid map obtained from the Virginia Poultry Federation that displayed locations of poultry producers. This map was divided into six sub-regions. A central location was chosen for each sub-region and the distance from each such location to a central collection site in the county was measured using the highway map. Then the weighted average distance was obtained by taking an average of the distances from each sub-region to the central collection site weighted by litter production in each sub-region. Since the

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[19] Distances between county seats were computed based on highway mileages between the two locations and are shown in Appendix B.

[20] With centralized composting, on-farm storage is not required; consequently, the acquisition cost was reduced by $2.16, the farm storage cost.

information on distribution of litter production in the other four litter surplus counties was not available, the weighted average distance estimate for Rockingham County was used to obtain the weighted average litter collection distance by adjusting the Rockingham estimate in proportion to the geographic area of each of those four surplus counties as shown in Appendix K.

IV.3.2.2. Raw Poultry Litter Storage Cost

It was assumed that raw litter was stored on farm for delivery to deficit areas in raw form. Thus the $8 per ton acquisition cost for raw litter mentioned in section IV.3.2.1 included on-farm storage cost. Raw litter was assumed to be shipped directly from growers to the users in the deficit areas.

For the purpose of transferring litter in composted form to the deficit areas, litter was assumed to be collected from poultry farms immediately after poultry house cleaning with no on-farm storage required. Composted litter is stored in the windrow after composting and does not require storage under a roofed structure (Holden, 1989). During last turning of the windrows, two windrows are pushed together in order to reduce the surface area exposed to rainfall. A four-month period of storage in the windrow was assumed.

IV.3.2.3. Poultry Litter Delivery Cost

The delivery cost was defined as the cost of moving litter from the central storage location to the point of use. A per ton loaded mile cost of $0.10 was used as litter delivery cost (Souder, 1989).[21] Loading is not incurred for the raw litter option as it is loaded directly at the farm and

[21] The $0.10 per ton loaded mile figure was arrived at by dividing the cost of moving a truck load of litter by the capacity of the truck. The truck can carry 20 tons of litter. The cost of moving a truck load of litter is $2 per loaded mile. For example, delivering litter to a distance of 100 miles away costs a total of $10 per ton.

loading is included in the $8 acquisition cost. For composted litter, there is an additional cost incurred for loading litter onto the truck at the compost storage site for delivery to the place of use. Two elevators per truck were used for loading composted litter onto trucks and two skid loaders were used for pushing litter onto the elevators.[22] The ownership and operating costs of loading composted litter at the compost storage site for delivery to demand areas is presented in Table IV.5. From Table IV.5, the total operating cost of loading equals $27,221.71 and the total ownership cost equals $7,190.92. The average cost of loading composted litter at the composting site for delivery to deficit areas equals $0.24 per ton of raw litter equivalent.

The cost of transportation may be reduced by backhauling litter in trucks used for transporting grains from the Northern Neck to litter surplus counties. The effect of backhauling on the profit potential for the litter handling firm was not considered in this study.

IV.3.2.4. Cost of Litter Application

It was asumed that the poultry litter handling firm provides the service of litter application to the farmers. The cost of litter application on a large scale was estimated based on a volume of 145,627 tons of raw litter, which, as will be described in Chapter V, is the total amount of raw litter available for export to deficit counties. Litter is hauled by truck from the on-farm or central storage site and unloaded at the field where it is to be applied. There it is to be reloaded onto spreaders using elevators and skid loaders. The budget on the cost of litter application is shown in Table IV.6. The purchase price of each skid loader is $8,500 and has a useful life of 2500 hours of operation. Each elevator takes about 31.5 minutes to load 14 tons of litter into spreaders (Souder, 1989). Each elevator costs about $2800 and has a useful life of 2500 hours of operation. The 2100 series Shamrock spreaders and 2-ton 300-hp DT-466 International Engine trucks were assumed to be used for applying litter. The spreader (14-ton capacity) is carried by the truck and is operated

[22] Two elevators and two skid loaders were used to reduce loading time.

Table IV.5. Cost of loading composted litter for delivery to demand areas.

	Unit	Quantity	Cost per unit	Cost ($)
Operating cost				
Skid loaders	hour	2730.50	3.30	9003.82
Elevators	hour	2730.5	0.67	1834.89
Labor	hour	2730.5	6.00	16383.00
Total operating cost				27221.71
Ownership cost[b]				
Skid loaders				5200.68
Elevators				1990.24
Total ownership cost				7190.92
Total cost				34412.63
Cost/ton of raw litter equivalent[c]				0.24

[a]Cost per ton of raw litter based on loading 145,627 tons of raw litter equivalent of composted litter.

[b]One hundred percent of the skid loader and elevator was charged to the loading operation. Interest rate was set at 8 percent. Purchase price and useful life of elevator were $2,800 and 2500 hours, respectively. Likewise, the purchase price and useful life of skid loader were $8,500 and 2000 hours, respectively. Tax, insurance, and housing cost was 2.8 percent of average investment cost.

[c]One ton of compost equals to two tons of raw litter.

Table IV.6. Cost of large scale application of litter.

	Unit	Quantity	Cost per unit	Cost ($)
Operating cost[a]				
Truck (300 hp)	hour	2851.20	29.206	83272.15
Spreader	hour	2851.20	3.15	8981.28
Elevator	hour	5461.00	0.672	3669.79
Skid loader	hour	5461.00	3.297	18004.92
Labor[b]	hour	8312.20	6.00	49873.20
Total operating cost				163801.34
Ownership cost[c]				
Truck (300 hp)				155109.60
Spreader				53418.96
Elevator				9869.04
Skid loader				31187.76
Total ownership cost				249585.36
Total cost				413386.70
Cost/ton				2.84

[a]The operating costs of trucks and skid loaders include expenditures on fuel, lubrication, repair and maintenance whereas the operating costs for spreader and elevators include only the repair and maintenance costs.

[b]Includes application time (2592 hours), time spent in going from one customer to another (10 percent of application time = 259.2 hours), and loading time (5461 hours).

[c]The ownership costs include depreciation, interest, tax, insurance, and housing. About 3.96, 8.33, 11.37 and 9.01 percent of useful life of truck, spreader, skid loader, and elevator, respectively, were used for litter application operation. These figures are based on spreading 145627 tons of raw litter.

by power-take-off (PTO) from the truck. The price of the spreader and the truck were $10,500 and $40,000 respectively. The spreader takes 15 minutes to empty at the application rate of 2 tons per acre (Winchel, 1989). The life of manure spreader and truck was assumed to be 2,500 and 2,000 hours of operation, respectively. The ownership cost includes depreciation, interest, tax, insurance, and housing. It costs about $2.84 to apply a ton of litter. This figure is quite close to the rate charged by an established litter distributor in Minnesota.[23]

The number of elevators, spreaders and trucks required for application of litter was determined based on the number of fieldwork days during the application period. The litter application period for corn was assumed to be March 15 through April 15; and for wheat and barley, it was assumed to be August 27 through September 24 (Reneau, 1990). The five-year average (1983-1987) number of fieldwork days for the periods of March 15 through April 15 and August 27 through September 24 was 14.2 and 25.8 days, respectively (VAS, 1988). It was assumed that litter can be applied 12 hours in a fieldwork day. Based on these assumptions, the number of elevators, skid loaders, spreader beds and trucks required to spread 145,627 tons of litter was found out to be 24, 24, 35, and 35, respectively.[24]

IV.3.2.5. Cost of Brokering

A poultry litter-handling firm would have expenditures on telephone time, taking orders and maintaining records of all transactions, and scheduling litter pick-ups from sellers and delivery to buyers. All of these costs are together lumped into one cost component called a brokerage fee. In this study, the brokerage fee is assumed to be $1.00 per ton.[25]

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[23] Holden (1989) reports charging $3.00 per ton for the services of delivering within 10 miles radius and applying litter.

[24] The calculations involved in the estimation of the number of elevators, spreaders, and trucks are given in Appendix C.

[25] A broker in the Shenandoah Valley (Gilbert Souder, Valley Resource Exchange, Rt. 2, Box 94A, Dayton, VA) charges the litter buyer a fee of $1.00 per ton of litter handled.

IV.3.2.6. Large Scale Composting of Litter

As mentioned in Chapter One, there are five litter-surplus counties. The litter in these counties could be composted at one or more sites. In order to determine whether composting at a centralized location would be cheaper than composting in each of the litter surplus counties, the reductions in the costs of composting as volume increased was compared with the increase in the costs of collecting litter from growers to a central location. An enterprise budget was constructed for composting each volume of surplus litter for each county. A budget was also constructed for the cost of composting litter from three adjoining counties in the Shenandoah Valley (Rockingham, Page, and Shenandoah Counties) at a central location in Rockingham County.[26] Likewise, a centralized location for composting surplus litter collected from Amelia and Cumberland Counties was designated at the boundary between these two counties. The costs of composting litter for each individual county, and centralized composting of litter collected from Amelia and Cumberland Counties are presented in Appendix D.

The budget on the cost of large scale composting in the Rockingham County is presented in Table IV.7. For the large scale composting of litter in Rockingham County, a land area requirement of about 16 acres was estimated as described in Appendix E. Site development includes (1) building an embankment around the composting site which keeps water from running through the site, (2) scraping off top soil and covering with 6 to 12 inches of clay to impede leaching, (3) creating some slope at the site and digging a pond at the end of the slope to catch runoff, and (4) seeding banks with grass to act as filters (Holden, 1989). The equipment used for large-scale composting were a dump truck used to form windrows, a CX-700-M Wildcat Composter used to turn windrows, and a 105-hp tractor used to pull the composter. The ownership costs of the composter, dump truck, tractor, land tax, interest on land investment, and annual recovery charge on composting site development were included as ownership costs.[27] The dump truck is able to

[26] Rockingham County was chosen as the composting site for central location because of the relatively large volume of surplus litter in this county compared to Page and Shenandoah Counties.

[27] Site development was assumed to be similar to land terracing (Hoag, 1990). Investment cost on site de-

dump litter at the rate of 100 tons per hour to make windrows (Winchel, 1989). The CX-700-M Wildcat Composter can turn 800 tons of litter per hour. The windrows were assumed to be turned 8 times during the composting period. The composter is tractor driven and powered by PTO and costs $25,000.

The alternatives available to a potential litter handling firm are: (1) to compost litter in each litter-surplus county, or (2) to compost litter collected from the three surplus counties in Shenandoah Valley counties at a central location and to compost litter collected from Amelia and Cumberland counties at a central location at the boundary between these two counties. Assembling litter from more than one county would reduce the per ton composting cost but increase collection distances and costs. multiple counties over the costs of composting litter in the individual

From Table IV.7 the cost per ton is $0.85 for large scale composting of litter in Rockingham County. From Appendix D, the cost of composting litter in Amelia, Cumberland, Shenandoah, and Page Counties are $1.63, $1.38, $1.38, and $1.22 per ton of raw litter. Also, from Appendix D, the cost of centralized composting of litter collected from Rockingham, Shenandoah, and Page Counties at the county seat of Rockingham County was equal to $0.78 per ton of raw litter. There is a saving of $0.60 and $0.44 per ton of raw litter by centralizing composting of litter from Shenandoah and Page Counties, respectively, to a central location in Rockingham County. These economies of scale are due to spreading of ownership costs of the composter over a larger volume of litter than is possible with the volume of litter in each individual county. The increase in litter collection cost for collecting litter from Shenandoah and Page Counties to the county seat of Rockingham County are $3.70 and $2.50, respectively, per ton of raw litter.[28] Although there are some economies of scale in composting, the decrease in the cost of composting is not enough to justify collecting litter from these counties to a central location. Likewise, the increase in collection

velopment was assumed to be $1000 per acre (Holden, 1989). A capital recovery factor of 0.0937 was used based on an interest rate of 8 percent and a useful life of 25 years. Maintenance cost was assumed to be 2 percent of the initial investment as that is the rate assumed for terracing (Hoag, 1990).

[28] The additional collection cost of $3.70 per ton was obtained by multiplying the estimated collection distance from Shenandoah County to the county seat of Rockingham County (37 miles) by the cost per loaded ton mile ($0.10). The additional collection cost of $2.50 per ton of litter collected from Page County to the county seat of Rockingham County was obtained in the same manner.

cost for collecting litter from Amelia and Cumberland Counties to a central location at the boundary between the two counties are $2.79 and $1.53, respectively per ton of raw litter. The savings in the cost of composting obtained by collecting litter from the two counties to a central location were much less than the increase in the cost of litter collection to a central location. Therefore, composting was assumed to be done individually in each litter-surplus county in the study.

IV.4. Use of Litter as Livestock Feed

This section presents the empirical procedures used to determine the value of litter and quantities used in rations. This section is divided into four sub-sections. Sub-section IV.4.1 presents nutrients requirements for cow-calf and backgrounding rations; IV.4.2 presents the handling and storage costs for stocker and beef cow feeding; IV.4.3 presents the amount and value of litter in cow-calf rations; and IV.4.4 presents the results on the amount and value of litter in stocker rations.

IV.4.1. Stocker and Cow-Calf Nutrient Requirements

Linear programming feed-cost minimization models were developed to evaluate litter use in stocker (growing cattle) and breeding cattle rations. The objective of the model was to provide the animal with nutrients at least cost where costs included feed acquisition and handling costs for both cow-calf and stocker rations. The only difference between the cow-calf and the stocker feed-cost minimization models is in the right-hand side values reflecting the varying nutrient requirements by animal age, body weight, milking ability, and the rate of gain in body weight. The cow-calf operation in the analysis was assumed to consist of cows nursing calves in their first 3-4 months postpartum with a milking ability of 10 lb/day. The body weight and the rate of gain in body

Table IV.7. Costs of composting in Rockingham County[a].

	Unit	Quantity	Cost per unit	Cost ($)
Operating cost				
Tractor (105 hp)	hour	1056.44	9.32	9846.02
Composter	hour	1056.44	6.00	6338.64
Dump truck	hour	1056.44	22.12	23368.45
Site maintenance	acre	16.00	30.00	480.00
Labor[b]	hour	2535.45	5.00	12677.28
Total operating cost				52710.39
Ownership cost[c]				
Composter				14370.00
Tractor (105 hp)				5882.28
Dump truck				16381.80
Land tax				160.00
Interest on land investment				1920.00
Site development investment cost				2248.80
Total ownership cost				40962.88
Total cost				93673.27
Cost/ton of raw litter				0.89

[a]Assumes an annual production of 52,822 tons of compost from 105,644 tons of raw litter.
[b]Labor hours include a 20 percent overhead for for lubricating and servicing machines, and for getting to and from the composting site.
[c]One hundred percent of the composter, tractor and dump truck were charged to the composting operation; land was priced at $1500 per acre; interest rate was set at 8 percent; land area used for composting was 16 acres; and land tax used was equal to $10 per acre. Tractor: useful life = 12 years, purchase price = $47,046. Composter: useful life = 2 years, purchase price = $25,000, and tax, insurance, and housing cost = 2.8 percent of average investment cost.

weight for cows nursing calves were assumed to be 1100 lb and zero lb/day, respectively. For stockers, body weight categories of 400, 500, 600, and 700 pounds, and the rates of gain in body weight of one-pound-a-day and two-pounds-a-day were considered in this study.

The alternative feeds considered in this study, as well as their prices and nutrient contents, are shown in Table IV.8. The price of each feed is expressed in dollars per hundredweight. The dry matter, protein, calcium, and phosphorus are expressed in pounds per hundredweight of feed. Net energy for maintenance and growth are expressed in MCal per hundredweight of feed.[29]

Daily nutrient requirements per head were estimated by size of animal and by rate of gain. The nutrient requirements for breeding cattle depend on the body weight, rate of gain, stage of pregnancy, age of animal, and the milk production level. The nutrient requirements and underlying assumptions for breeding cattle are shown in Table IV.9[30] and for medium-frame steer calves in Table IV.10. Daily nutritional requirements for each size-gain combination were generally based on National Research Council (1984) estimates. The constraints of feed cost minimization models included daily minimum requirements for protein, net energy for gain (NEG), net energy for maintenance (NEM), dry matter (DM), phosphorus, and calcium. In addition, dry matter intake was set at a maximum of 12 percent above the minimum requirement. The maximum amount of feed consumed per day on an "as-fed" basis was set at 6 pounds per 100 lb body weight and was imposed to prevent the ration from including more feed than the animal could eat.[31] A maximum limit on poultry litter consumption was set at 70 percent of the breeding cattle ration's dry matter content. For growing cattle the maximum limit on poultry litter consumption was set at 40 percent of the ration's dry matter content. For breeding cattle a palatability constraint was used to insure adequate consumption of litter because cattle tend to reject litter if it is fed alone. Therefore, the model was constrained to choose corn grain or barley grain and poultry litter at the ratio of

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[29] Mixed hay refers to a mixture of 70 parts orchard grass hay plus 30 parts clover hay.

[30] For cows nursing calves (in their first 3-4 months postpartum) average milking ability = 10 lb per day, body weight = 1100, and the rate of gain in body weight = 0 lb per day.

[31] In the absence of such a constraint, there is a tendency for the model to select rations with more roughage than the animal could realistically eat in a day. This constraint was imposed on the advice of John Gerken, Professor, Department of Animal Science, Virginia Polytechnic Institute and State University.

15:85.[32] No palatability constraint was used in the growing cattle ration because the poultry litter intake is limited to a maximum of 40 percent of dry matter in the ration. The calcium content in the ration was required to be at least as great as the phosphorus requirement as suggested by Fox and Black.

IV.4.2. Handling and Storage Costs for Stocker and Cow-Calf Feeding

Potential utilization of poultry litter as animal feed depends on the cost of acquiring, storing, handling, and feeding it relative to its value as feed and relative to the cost of other feeds. In order to use litter for feed, several operations must be performed. The litter must be acquired, stored until ready for use, removed from storage on a daily basis to feed animals, mixed with corn grain or barley grain or soybean meal, hauled to the feeding place, and distributed in feed bunks. Therefore, the costs of acquisition, storage, and feeding of litter as well as alternative feeds were included in the evaluation of poultry litter as feed. These costs were estimated for a representative cow-calf operation and a representative stocker (backgrounding) operation. The same feed acquisition, handling, and storage costs were used for both the cow-calf and the stocker operations. Each operation was assumed to have a herd size of 50 head for purposes of estimating feeding costs (McKinnon, 1989). According to Census data, the average Virginia farm had 26 beef cows, 20 heifers and heifer calves, and 16 steers, steer calves, bulls, and bull calves (U. S. Dept. of Commerce, 1989).

For the cow-calf system, it was assumed that the herd is wintered on litter plus grain or some alternative ration for a period of 120 days (January through April) (Gerken, 1989). For the backgrounding system, it was assumed that stockers were wintered on litter plus grain or some alternative ration for a period of 120 days to put on 120 pounds for the one-pound-a-day gain in body weight category and 240 pounds for the two-pounds-a-day gain in body weight category. The alternative feed rations containing feeds in Table IV.8 can be classified into silage-based, litter-based,

[32] This ratio as well as maximum limits on poultry litter in the ration were suggested by John Gerken, Professor, Department of Animal Science, Virginia Polytechnic Institute and State University.

Table IV.8. Feed composition values and prices[a].

	Corn Grain	Corn Silage	Poultry Litter	Soybean Meal	Alfalfa Hay	Clover Hay	Fescue Hay	Orchard Grass Hay	Rye Silage	Mixed Hay	Barley Grain
Price ($/cwt)[b]	5.80	1.00	0.75	13.75	5.00	3.75	2.50	3.00	1.25	3.22	5.42
Dry Matter[c]	85.00	32.00	70.00	90.00	90.00	90.00	90.00	90.00	40.00	90.00	89.00
NEM[d]	86.70	22.72	42.00	79.20	45.90	50.40	54.00	51.30	22.40	52.90	86.33
NEG[e]	56.95	14.40	24.50	53.10	16.20	24.30	29.70	22.50	7.20	28.08	56.96
Protein	8.50	2.56	20.80	45.70	15.39	13.32	9.45	9.90	5.60	10.61	11.57
Calcium	0.03	0.09	1.61	0.32	1.13	1.45	0.45	0.40	0.16	0.75	0.08
Phosphorus	0.34	0.07	1.27	0.67	0.198	0.07	0.32	0.33	0.09	0.245	0.42

[a]Feed composition values were obtained from Fox et al.
[b]Information on feed prices was obtained from West Central Farm Management Extension Staff (1989). Feed prices are expressed in 1989 dollars. An initial value of $0.75 per cwt of litter was used; however, further analysis was done to determine the maximum that farmers would afford to pay for litter given other feed prices. [c]Dry matter, protein, calcium, and phosphorus are expressed in lbs/cwt.
[d]NEM = net energy for maintenance (expressed in MCal/cwt).
[e]NEG = net energy for gain (expressed in MCal/cwt).

Table IV.9. Nutrient requirements per day per animal for breeding cattle[a].

Nutrient	Cows nursing calves 1st 3-4 months postpartum
Dry Matter	21.60
NEM	11.54
NEG	0.00
Protein	2.00
Calcium	0.059
Phophorus	0.048

[a]National Research Council,1984. Dry matter, protein, calcium, and phosphorus are expressed in pounds. NEM = net energy for maintenance (expressed in MCal). NEG = net energy for gain (expressed in MCal).

Table IV.10. Nutrient requirements per day per animal for growing cattle (medium-frame steer calves)[a].

	Body Weight (lbs)							
	Four Hundred		Five Hundred		Six Hundred		Seven Hundred	
	Rate of Gain in Body Weight (lbs/Day)							
	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0
Dry Matter	10.40	11.00	12.30	13.10	14.10	15.00	15.80	16.80
NEM[b]	5.92	7.70	7.01	9.17	8.04	10.50	9.01	11.76
NEG[c]	3.22	4.84	3.81	5.76	4.37	6.60	4.89	7.39
Protein[d]	1.06	1.41	1.16	1.49	1.26	1.57	1.35	1.65
Calcium	0.039	0.062	0.039	0.062	0.039	0.060	0.043	0.057
Phophorus	0.022	0.029	0.025	0.031	0.027	0.033	0.028	0.035

[a]All information in the table was obtained from National Research Council, 1984.

[b]NEM = net energy for maintenance (expressed in MCal).

[c]NEG = net energy for gain (expressed in MCal).

[d]Dry matter, protein, calcium, and phosphorus are expressed in pounds.

and hay-based types depending on the predominant feed in the ration. A litter-based ration can be fed using the "mixer wagon system" which involves unloading litter from the storage shed into a mixer wagon with a front-end loader and 65-hp tractor, loading corn or barley grain from a storage bin into the mixer wagon, mixing grain and litter, and hauling and pouring the mixture into feed bunks. An alternative system would be to use a front-end loader to haul litter and grain from the storage shed and feed it in used tractor tires. The tractor tires are turned inside out, and placed at several locations depending on the number of animals to be fed. This system will be identified as the Auburn system of feeding litter grain mixture in this study (Donald, 1989). For a hay feeding system, the feeding activity includes loading bales of hay into a bale mover attached to a 65 hp tractor, hauling it to the field, and unrolling the bale of hay on the ground for consumption by animals. For a silage feeding system, the feeding activity is similar to the litter feeding system in that silage is fed mixed with corn or barley grain using a mixer wagon.

In order to estimate the cost per ton of handling and storing different feeds, an initial estimate of the total amount of each feed to be handled was required. This estimate was obtained from the initial run of the feed-cost minimization model for breeding cows where only the acquisition cost of each feed was included. The feed cost minimization model used is presented in Appendix F. For a poultry litter ration this amount was equal to 24 pounds per head per day out of which about 4 lb was barley grain and about 20 lb was poultry litter. The ownership costs of necessary machinery, equipment, and storage were estimated and allocated per ton of feed or litter based on a daily grain plus litter mixture requirement of 24 pounds. Ownership and operating costs of other feeds were allocated in a similar manner.

The ownership and operating costs of storing alternative feed types are shown in Table IV.11. The costs of a litter storage shed were estimated to be \$3.70 per ton out of which the ownership cost (capital recovery charge, tax, and insurance) was \$3.14 per ton and operating costs (for repairs to the structure) were \$0.56 per ton.[33] For the hay feeding system the storage cost per

[33] This figure is different from the litter storage cost for litter used as fertilizer (Table IV.3) because 50 percent subsidy is assumed to be available for storing litter on the farm where it is produced until it can be used for fertilizer. Such a subsidy would not be available for a cattle feeder who purchases litter from another producer.

ton is based on an investment cost of $35.00 per ton of capacity for the construction of a storage structure. The ownership and operating costs of a storage shed for all kinds of hay were estimated to be $4.62 per ton. For the silage feeding system, it is assumed that corn silage or rye silage is stored in a horizontal bunker silo, 10 feet high, 30 feet wide, and 80 feet long. Corn grain or barley grain for feed is assumed to be stored in hopper bins. An agitator (also called bridge beater) is required in addition to a hopper bin for storage of soybean meal to facilitate free flow while unloading.

Machinery ownership costs for each feeding system included annual capital recovery charge, housing, taxes, and insurance. Because the tractor and front-end loader were assumed to have alternative uses on the farm, the percent of their ownership costs that were charged to the feeding operation were based on the number of hours used. Eight percent of the tractor's useful life and 38.4 percent of the front-end loader's useful life were utilized for the purpose of litter and grain mixture feeding. These figures were calculated assuming the front-end loader and the tractor's useful life are 2,500 hours (over a period of 12 years) and 12,000 hours (over a period of 12 years), respectively. The tractor and loader were used for feeding 80 hours during a wintering period of 120 days. The mixer and feed bunks were assumed to be exclusively for the purpose of feeding litter and grain mixture; thus, 100 percent of their ownership costs were charged to feeding. The ownership costs of the tractor, front-end loader attachment, mixer wagon and feed bunks used for litter plus grain mixture feeding were estimated to be $29.02 per ton.

For the mixer wagon system of litter feeding, the operating costs include the costs of fuel, lubrication, and repair and maintenance for the tractor, whereas the operating costs for the loader attachment and mixer wagon include only the repair and maintenance costs. Labor is priced at $5 per hour and labor hours equal machine hours plus 20 percent to account for labor overhead. The operating cost of litter feeding is $17.94 per ton. The machinery and labor needed for feeding rye silage and corn silage were assumed to be the same as for poultry litter. Hence, the variable machinery and labor costs for silage feeding were also equal to $17.94 per ton. The feeding budget for the mixer-wagon system of litter-grain mixture feeding is shown in Table IV.12.

Table IV.11. Cost of feed storage per ton[a].

	Cost/ton ($/ton)
Ownership cost[b]	
Corn silage silo	3.72
Rye silage silo	4.66
Hopper bin	11.69
Agitator	3.11
Litter storage shed	3.14
Hay storage shed	3.92
Operating cost	
Repair & maintenance	
Corn silage silo	0.75
Rye silage silo	0.94
Hopper bin	2.37
Agitator	0.41
Litter storage shed	0.56
Hay storage shed	0.70

[a]The ownership costs for corn silage and rye silage were estimated from the same cost per ton of dry matter. So the differences in the costs for rye silage and corn silage reflect the adjustment made for the differences in the moisture contents of the rye silage and corn silage.

[b]The ownership costs include depreciation, interest, insurance, and tax. Length of life in years for each structure were: horizontal bunker silo, 30, hopper bin, 30, agitator, 10, litter storage shed, 20, and hay storage shed, 20. An interest rate of 8 percent was used. Investment cost per ton: hay storage, $35, corn silage silo, $37.67, rye silage silo, $47.09, litter storage, $28.08, hopper bin, $118.39, and agitator, $20.69. Tax and insurance costs were 2 percent of average investment cost.

Table IV.12. On-farm storing and handling costs for litter-grain feeding system for 50-cow enterprise using a mixer wagon system.

	Unit	Quantity	Cost per Unit	Cost ($)
Operating cost				
Tractor (65 hp)	hour	80	5.10	408.00
Loader attachment	hour	80	1.32	105.60
Mixer wagon	hour	80	3.73	298.40
Labor	hour	96	5.00	480.00
Total operating cost				1292.00
Ownership cost[a]				
Tractor (65 hp)				245.71
Loader attachment				298.47
Mixer wagon				1430.42
Feed bunks				115.15
Storage costs[b]				378.29
Total ownership cost				2468.04
Total cost				3760.04
Cost/ton of mixture fed[c]				52.22

[a]Ownership costs were based on percent of useful life of the equipment that is used for feeding. Purchase price: tractor = $22,415, loader = $5,500 and mixer wagon = $9333.00.

[b]The storage cost is the weighted average of litter and grain storage costs and is equal to [0.85x($3.14 + $0.56) + 0.15x($11.69 + $2.37)]x72 tons = $378.29, where 0.85 is the proportion of litter in the mixture, 0.15 is the proportion of grain in the mixture, $3.14 and $11.69 are the storage ownership costs for a ton of litter and grain, respectively, and $0.56 and $2.37 are the repair costs per ton for litter storage shed and hopper bin.

[c]A total of 72 tons of litter-grain mixture is fed in a wintering period of 120 days to 50 cows.

The cost of feeding litter and grain mixture using the Auburn System was also estimated. This system differed from the mixer wagon system in that it did not need feed bunks and a mixer wagon and it has additional cost for tires used as feed bunks. The investment cost of tires was estimated as follows: 3 tires were required to feed 50 animals; the tire life equals 5 years; interest rate equals 8 percent; and tires are assumed to be available for free but there is a fee of $10.00 per tire to turn it inside out. The annual capital recovery charge is equal to $10x3x.2505 = $7.51. The cost of feeding litter-grain mixture using the Auburn System is presented in Table IV.13.

For the hay feeding system, 3 percent of the tractor and 100 percent of the bale mover ownership costs were charged to the hay feeding operation. The ownership and operating costs of hay feeding were based on the assumption that it takes about 15 minutes for a farmer to feed hay to a cow-calf herd of 50 cattle using a bale mover and a 65 hp tractor.[34] The ownership costs of the bale mover and the tractor used for hay feeding were estimated to be $2.06 per ton. The variable machinery and labor costs for hay feeding were estimated to be $4.67 per ton. The feeding budget for the hay system is shown in Table IV.14.

The feeding budgets indicate that the costs per ton of feeding are $11.35 per ton of hay for the hay feeding system, $26.72 per ton of litter plus grain mixture for the Auburn system of litter feeding, and $52.22 per ton of litter plus grain mixture for the mixer wagon system of litter feeding. The much higher cost per ton for the mixer wagon system is mainly due to the higher ownership costs of the mixer wagon and feed bunks. The feeding cost per ton for the hay feeding system is significantly less than for both mixer wagon system and for the Auburn system because of the lower capital requirement for this system and the lesser amount of time required for feeding.

[34] The useful life of the tractor was assumed to be equal to 12,000 hours over 12 years, implying 1000 hours per year. Time required to feed hay to a 50-herd cow over a feeding period of 120 days at the rate of 0.25 hours per day is equal to 30 hours. Therefore, the percent of the ownership cost of the tractor charged to the hay feeding operation was equal to 30/1000 = 3 percent.

Table IV.13. On-farm storing and handling costs for Auburn litter-grain feeding system for 50-cow enterprise.

	Unit	Quantity	Cost per unit	Cost ($)
Operating cost				
Tractor (65 hp)	hour	80	5.10	408.00
Loader attachment	hour	80	1.32	105.60
Labor	hour	96	5.00	480.00
Total operating cost				993.60
Ownership cost[a]				
Tractor (65 hp)				245.71
Loader attachment				298.47
Tire[b]				7.51
Storage costs[c]				378.29
Total ownership cost				929.98
Total cost				1923.58
Cost/ton of mixture fed				26.72

[a]The ownership costs were based on percent of useful life used in feeding.

[b]The annual cost of tires is based on the assumptions that one tire can serve about 15 cows; each tire costs $10.00 to turn it inside out; the useful life of a tire is 5 years, and the interest rate used to calculate the annual capital recovery charge was 8 percent.

[c]The storage cost is the weighted average of the storage costs for litter and grain = [0.85x($3.14 + $0.56) + 0.15x($11.69 + $2.37)]x72 = $378.29, where 0.85 is the proportion of litter in the mixture, $3.14 is the ownership cost of the storage of a ton of litter, 0.15 is the proportion of grain in the mixture, and $11.69 is the ownership cost per ton of grain storage, and $0.56 and $2.37 are repair costs per ton of litter storage and grain storage in a hopper bin, respectively.

Table IV.14. On-farm storing and handling costs for hay feeding system for 50-cow enterprise.

	Unit	Quantity	Cost per unit	Cost ($)
Operating cost				
Tractor (65 hp)	hour	30	5.10	153.00
Bale mover	hour	30	0.12	3.60
Labor	hour	36	5.00	180.00
Total operating cost				336.60
Ownership cost[a]				
Tractor (65 hp)				92.14
Bale mover				56.25
Storage cost[b]				332.64
Total ownership cost				481.03
Total cost				817.63
Cost/ton fed[c]				11.35

[a]Ownership costs are based on percent of useful life used for feeding. Purchase price: equals $400 for bale mover and $22,415 for the tractor. The investment cost for the litter storage shed equals $35 per ton.

[b]Storage cost includes ownership and repair and maintenance costs and is equal to ($3.92 + $0.70)x72 tons = $332.64.

[c]A total of 72 tons of hay is fed in a 120-day feeding period.

IV.4.3. Amount and Value of Litter in a Cow-Calf Ration

The amount and the value of litter in a cow-calf ration depends on the costs of litter acquisition, storage and handling relative to these costs for the competing feeds. This section presents the results of feed cost minimization model solutions showing the amount and value of litter in a wintering beef ration.

For the cow-calf operation, the feed-cost minimization models were run initially assuming that litter would be fed with a mixer wagon. The results indicated that the minimum-cost ration did not include poultry litter nor any concentrate. Instead, all the nutrient requirements were met through fescue hay (24 lb/day/cow). Litter was not fed under this scenario because of the high operating and ownership costs of litter feeding equipment relative to hay feeding.

The second scenario involved running the model with the handling and storage costs based on the Auburn system of feeding litter and grain mixture as shown in Table IV.13. Under this scenario, the minimum-cost ration consisted of 21.59 pounds of poultry litter, 4 pounds of fescue hay, and 3.24 pounds of barley grain. Under this scenario, the model solution indicated that farmers would be willing to pay a maximum of $17.40 to acquire a ton of poultry litter. The analysis shows that if litter is to be economically feasible for feeding to cow-calf herds on farms with the relatively small herd sizes typical of Virginia, then a feeding system requiring a low capital investment such as the Auburn system will be needed.

IV.4.4. Amount and Value of Litter in Backgrounding Cattle Ration

For backgrounding cattle, the feed cost minimization model was run initially by including all the ownership and operating costs of feed handling, storage, and feeding and the feed acquisition (for mixer-wagon system) in the objective function coefficient for each feed. The results under this scenario (scenario one) indicated that the minimium-cost ration composition for backgrounding cattle included a mixture of fescue hay and barley grain for 2-lb-a-day gain in body weight category for all body weights considered. For the one-lb-a-day gain in body weight category, the minimum-cost ration consisted of fescue hay only. The minimum-cost ration composition by body weight and by rate of gain is given in Table IV.15. Under this scenario, no poultry litter was chosen in the minimum cost ration except for a body weight category of 400 lbs and a rate of gain of 2 lbs per day for which 0.19 pound of litter, 12.79 pounds of fescue hay and 1.74 pounds of barley grain per day were included. As shown in the previous section, the high capital cost of equipment used in feeding litter made litter noncompetitive with hay feeding. Under this scenario, the delivered price of litter (before feeding costs) would have to be less than $15.00 per ton before litter is included in the ration.

Next, the feed-cost minimization model was solved using only the costs of feed acquisition for each feed (scenario number two) in order to compare litter with other feeds without feeding and storage costs. This analysis was done to determine how much the labor and capital requirements of litter feeding reduced the amount the farmer could afford to pay for litter. The minimum-cost ration composition under this scenario by body weight and rate of gain is shown in Table IV.16. The minimum-cost ration consisted of a combination of poultry litter and fescue hay for 1-lb-a-day gain in body weight category for all body weights under consideration. For the 2-lb-a-day gain in body weight category, the minimum-cost ration consisted of a combination of poultry litter, fescue hay, and barley grain for all body weight categories. For both categories of rate of gain in body weight, the litter use increased with the increase in body weight. Litter use is higher for the 2-lb-a-day rate of gain in body weight than for 1-lb-a-day rate. For the 1-lb-a-day rate, farmers would be willing to pay a maximum of $38.80 to acquire a ton of poultry litter. On the other hand, for the 2-lb-a-day rate of gain in body weight, farmers would be willing to pay a maximum of $39.80 to acquire a ton of poultry litter.

Lastly, the feed-cost minimization model was run using all costs based on the Auburn System feeding budget. Under this scenario, the minimum-cost feed ration included poultry litter for all weight groups and all rates of gain in body weight. The minimum-cost ration composition is presented by body weight and rate of gain in body weight in Table IV.17. The labor and capital

Table IV.15. Minimum-cost ration composition for medium-frame steer calves with feed acquisition and feeding costs included for the mixer wagon system of feeding[a].

	Body Weight (lbs)							
	Four hundred lb steer		Five hundred lb steer		Six hundred lb steer		Seven hundred lb steer	
	Rate of gain in body weight (lbs/day)							
	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0
Poultry litter		0.19						
Fescue hay	11.55	12.79	13.67	13.20	15.67	12.82	17.56	14.35
Barley grain		1.74		3.23		4.90		5.49

[a]The results were derived including all ownership and operating costs of feed acquisition, storage, handling and feeding. Results are expressed in lbs/animal/day on an as-fed basis.

Table IV.16 Minimum-cost ration composition for medium-frame steer calves with only the acquisition cost of feeds included[a].

	Body Weight (lbs)							
	Four hundred lb steer		Five hundred lb steer		Six hundred lb steer		Seven hundred lb steer	
	Rate of Gain in Body Weight (lbs/Day)							
	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0
Poultry Litter	5.94	7.37	7.03	8.59	8.06	9.63	9.03	10.57
Fescue Hay	6.93	4.18	8.20	3.74	9.40	2.89	10.53	1.79
Corn Silage		12.44		17.67		23.47		29.64

[a]The results are based on only the acquisition cost of feeds and do not include the costs of feed storage, handling and feeding. Results are expressed in lbs/animal/day on an as-fed basis.

requirements of Auburn system of litter feeding compared to hay feeding reduced the amount farmers could afford to pay for litter from $38.80 to $25.80 and from $39.80 to $29.00 per ton for the 1-lb-a-day and 2-lbs-a-day gain in body weight, respectively, compared to the case where only acquisition costs were included. However, the results indicate that a less capital intensive method of feeding like Auburn System makes litter relatively more competitive with hay feeding. For the 1-lb-a-day rate of gain in body weight, the minimum-cost ration composition under this scenario is the same as under scenario two. However, the ration composition for the 2-lb-a-day rate of gain in body weight consisted of a slightly higher level of litter and a much higher level of fescue hay under this scenario than under scenario two.

For the mixer wagon system of litter feeding, the feeding and storage costs of litter make litter very noncompetitive with hay feeding. For the Auburn system of litter feeding, litter seems to be competitive with hay feeding and, therefore, some litter is included in the ration. On the other hand, if it is assumed that the cost of feeding is zero, then litter has a higher imputed value and is included in the ration at higher amounts than for Auburn system of feeding. Farmers would be willing to pay the highest price per ton if the assumption of no feeding cost holds true.

This chapter focused on the procedures used to value litter for feed and fertilizer and to estimate the costs of providing services to facilitate litter use as well as results from applying the procedures. These procedures and results were used to evaluate the aggregate potential to export litter from surplus to deficit counties for use as fertilizer as well as to surrounding counties for use as livestock feed. Chapter five presents the results of that analysis.

Table IV.17 Minimum-cost ration composition for medium-frame steer calves for Auburn system[a].

	Body Weight (lbs)							
	Four hundred lb steer		Five hundred lb steer		Six hundred lb steer		Seven hundred lb steer	
	Rate of Gain in Body Weight (lbs/day)							
	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0
Poultry litter	5.94	7.54	7.03	8.98	8.06	10.28	9.03	11.52
Fescue hay	6.93	7.44	8.20	8.88	9.40	10.15	10.53	11.37
Barley grain		1.37		1.62		1.87		2.09

[a]The results are based on the ownership and operating costs of litter feeding, storage, and handling for Auburn system. The Auburn System of litter feeding includes the material cost of litter, labor cost of feeding, ownership cost of 3 tires and the operating and ownership costs of a 65-hp tractor, a front-end loader attachment, and feed storage. Results are expressed in lbs/animal/day on an as-fed basis.

Chapter V: The Economic Feasibility of Transporting Poultry Litter from Surplus to Deficit Areas

V.1. Introduction

This chapter discusses the opportunities to export litter for feed and for fertilizer from litter-surplus to selected litter-deficit counties in Virginia. The section on the export of litter for feed presents the estimation of maximum distances litter can be transferred from the designated litter supply point to livestock farmers in neighboring counties as well as the aggregate potential utilization of litter for feed.[35] Next, the opportunity to export litter to litter-deficit areas for use as fertilizer is presented. Counties in the Northern Neck and Middle Peninsula were chosen as the demand area because they are relatively homogeneous in terms of crop production, have a relatively large amount of crop production and have a small local supplies of animal manure. The homogeneity of the area would make marketing of litter for fertilizer easier. Research has indicated that the

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[35] Since Rockingham County was the major litter-surplus county, the county seat of this county was chosen to be the litter supply point from which litter is transferred to the county seats of neighboring counties.

widespread use of commercial fertilizer in areas near the Chesapeake Bay has contributed to the pollution of the Chesapeake Bay (U.S. Environmental Protection Agency, 1983). Poultry litter, if applied at rates that meet the crop nutrient requirements and no more, may be less of a threat to groundwater pollution than commercial fertilizer due to the organic matter content of litter and the organic form of nitrogen in litter. Therefore, substituting poultry litter for commercial litter may be an effective method of decreasing nitrate loadings into the Chesapeake Bay, thereby contributing to a sustainable agriculture in areas such as the Northern Neck and Middle Peninsula.

V.2. Opportunities to Export Litter for Animal Feed

The value[36] net of feeding and storage costs of a ton of poultry litter in the ration of cows nursing calves for the weight group of 1100 pounds was found to be $17.40 per ton of litter fed using the Auburn System. At this price, 21.59 pounds of litter could be fed per animal per day. Assuming a $1 per ton brokerage fee and an $8 per ton cost of acquiring poultry litter from the grower, then a residual of $8.40 per ton is available to cover transportation costs and provide a return to the litter handler's management and investment. Assuming a per ton loaded mile cost of litter of $0.10, then the economically feasible distance that litter can be distributed is 84 miles or less from the litter production point to the point of use.

The number of beef cows in Virginia counties whose county seat lies within 84 miles from the county seat of Rockingham County was estimated to be 193,917 (Bureau of the Census, 1989a). Based on a 120-day feeding period, approximately 251,200 tons of poultry litter could potentially be utilized as feed supplement for wintering cows in a cow-calf operation. This estimate is obtained by multiplying litter requirement per day per animal (21.59 pounds) by the number of days litter is fed (120) and by the number of animals fed. This amount is greater than the total production in Rockingham County (170,281 tons) as shown in Table V.1 indicating that there is a potential

[36] As explained in Chapter IV, the value of litter was calculated by determining the reduction in expenditures on other feeds per pound of litter substituted into the ration while holding animal performances constant.

to use animal feed as a way of disposing of litter surpluses. However, it is unlikely that this amount of use will occur for several reasons. First, after deducting transportation costs, the level of profits to the handling firm is likely to be low; thus, there are limited incentives for a firm to enter the industry. Second, even a low-capital system such as the Auburn system will require changes by farmers in how they store and handle feed. It is questionable whether adequate numbers of farmers would be willing to change their feeding practices in order to utilize this amount of litter.

By contrast, when litter is used for fertilizer, the litter handling firm can provide farmers with all services required including poultry litter testing and certification, delivery, and application; thus the farmer will not have to greatly change production practices. Also by having a centralized firm handle all services, benefits of scale and specialization can be obtained. As a result, there may be more potential to use litter as fertilizer. The following section describes the analysis of the opportunities to export litter to the Northern Neck for use as fertilizer.

V.3. Opportunities to Export Litter to Deficit Areas as Fertilizer

In order to estimate the net amount of poultry litter and its nutrients that can be exported from surplus to deficit counties, it was necessary to first estimate the amount of litter produced in potential surplus counties. Then the crop requirements for litter (based on its nitrogen content) within the litter producing county were deducted. Next, the amount of nitrogen available from dairy manure in the supply counties was estimated. Finally, the amount of surplus nitrogen in the form of litter that is available for export to the deficit counties was estimated.

V.3.1. Aggregate Potential to Export Litter from Surplus Counties

Litter production for the major litter producing counties in Virginia was estimated based on the census data on the number of poultry birds in each county. According to the 1987 Census of Agriculture, the major poultry-producing counties in Virginia are Accomack, Amelia, Augusta, Buckingham, Cumberland, Isle of Wight, Nottoway, Page, Rockingham, and Shenandoah. The poultry litter production and dairy manure production for each of the poultry-producing counties are shown in Table V.1. From Table V.1, Rockingham, Page, Augusta, and Shenandoah counties are the leading poultry litter producing counties. Likewise, Rockingham, Augusta, and Shenandoah counties are the leading dairy manure producing counties. Because dairy cows are usually kept confined, much of the dairy manure can be recovered and applied to crops. Thus, dairy manure competes with poultry litter for use as fertilizer and nutrients in dairy manure are deducted from total crop nutrient requirements in the surplus counties. Procedures used to calculate poultry litter and dairy manure production are shown in Appendix G.

The crop nitrogen requirement and litter nitrogen content were used to determine how much litter could be applied. This procedure may have caused phosphate and potash to be applied in excess of crop requirements. Over-application of phosphate and potash is not as environmentally damaging as nitrogen application over and above crop requirement because the former two are relatively less likely to be leached to the ground water acquifer than nitrogen which is known to be very mobile in the presence of water (Beegle, 1988). Nitrogen requirements were determined for crop rotations prevalent in each county. The number of acres accounted for by each crop and the total harvested cropland by county were obtained from the 1987 Census of Agriculture. The crop rotations used were based on personal communications with county extension agents in the corresponding counties. The crop rotations suggested by extension agents in each surplus county were then allocated a number of acres based on crop acreage figures from 1987 Census. The number of acres under each crop rotation, crop rotations, total cropland, and hay acreage by county are given in Table V.2. The "total rotation acres" in Table V.2 is the total acres accounted for by the crop rotations considered in this study for each surplus county. Likewise, Cropland in Table V.2 refers to land devoted to hay and all row crops as indicated by the 1987 Census. The cropland rotations account for differing amounts of cropland from a low of 24 percent in Buckingham County to a high of 63 percent in Amelia County. Most of the remainder was hay

Table V.1. Poultry litter and dairy manure production by county[a].

County name	Tons of poultry litter	Tons of dairy manure
Amelia	15750.56	26539.00
Augusta	26311.22	135267.00
Buckingham	6143.33	2842.00
Cumberland	11018.50	12640.00
Isle of Wight	4464.54	151.00
Nottoway	5751.26	18206.00
Page	34559.40	9830.00
Rockingham	170281.60	265814.00
Shenandoah	25090.62	36792.00

[a]Manure production figures calculated based on the poultry and dairy cow numbers as reported in the Census of Agriculture, 1987 using procedures described in Appendix G.

which does not require external addition of nitrogen. As shown in the table, hay plus rotational crops account for over 95 percent of the cropland acres in the counties shown.

Total nitrogen requirements by county and crop rotation are given in Table V.3. The nitrogen requirement for each crop rotation was estimated for a given yield level of the crop. The yield level was selected based on the ten year (1977 to 1986) average for each crop reporting district in which the county belongs. For each crop rotation, net nitrogen requirement was calculated as equal to crop nitrogen requirement less nitrogen available from soil organic matter less nitrogen available from symbiotic nitrogen fixation less nitrogen available from previous crop residues.[37] It is assumed that approximately 30 pounds of nitrogen per acre is available to plants from soil organic matter in one crop season (Norris, 1988). Crop residue nitrogen is assumed to be available at the rate of 15, 5, and 3 percent of the total nitrogen in crop residue in the first, second, and the third year after crop harvest (Gilbertson et al., 1979).

Since the procedure used to calculate nitrogen requirement for each crop rotation is similar, only one example is shown here to illustrate the procedure. The example considered is corn silage-alfalfa hay. Corn is assumed to be in the field for two years followed by four years of alfalfa. In any given year, 2/3 of the land will be in alfalfa and 1/3 will be in corn. If we consider a representative acre of the rotation, then 1/6th will be in year 1 corn, 1/6th will be in year 2 corn, and 1/6th each will be in year 1 through year 4 alfalfa. Alfalfa producing 3 tons of hay requires 180 pounds of nitrogen per acre (White, 1980). Corn silage requires 138 pounds of plant available nitrogen per acre (Norris, 1988).

Nitrogen requirements for corn and alfalfa at different stages in the rotation are as shown in Table V.4. In the analysis it is assumed that alfalfa harvested for hay fixes approximately 224 lbs of nitrogen out of which 144 lb is available to alfalfa and 80 lbs is left in the root nodules and is available to the following crop (White, 1980). This eighty pounds will decompose to release nitrogen at the rate of 15, 5, and 3 percent in the first, second, and third year after harvest (Keeney, 1983). Soil organic matter is assumed to provide 30 lbs of nitrogen per acre. The distribution of

[37] Symbiotic nitrogen fixation is the process whereby mutually beneficial association between certain microorganisms (e.g., *Rhizobium* species) and higher plants (e.g., leguminous crop plants) result in the reduction of atmospheric nitrogen to ammonia (Phillips and DeJong, 1984).

Table V.2. Number of harvested acres accounted for by different crop rotations and total harvested cropland by county.[a]

Crop rotation	Amelia county	Augusta county	Buckingham county	Cumberland county	Nottoway county	Page county	Rockingham county	Shenandoah county
CG-BA-SB	5648							
CS-AH	2154	14784		1369	831		17808	
WH-SB	464		878	386				
CS-SB	5648							
TB-WH	353							
CS-RS							19733	
CONCORNG		8002	2345	808		1551	5008	2046
CONCORNS		7489		572		2149		3427
CS-WH		3225		469	689		1641	
CS-BA-AH		3952	1002					
CG-SB					1562			
CS-BA & WH-AH						3768		8262
CS-BA					910		1102	
Total rotation acres	14267	37452	4225	3604	3992	7468	45292	13735
Hay[b]	6436	37876	12162	7515	7072	10492	43804	19871
Cropland	22747	78974	17840	12243	13373	19405	84661	39622

[a]CG = corn for grain; SB = soybeans for beans; CS = corn for silage; WH = wheat for grain; BA = barley for grain; AH = alfalfa for hay; RS = rye silage; TB = tobacco; CONCORNG = continuous corn for grain; and CONCORNS = continuous corn for silage.

[b]Includes other tame, small grain, wild, grass silage, and grass chop (Bureau of the Census, 1989a).

Table V.3. Tons of nitrogen requirement by county and by crop rotation[a]

Crop rotation	Amelia county	Augusta county	Buckingham county	Cumberland county	Nottoway county	Page county	Rockingham county	Shenandoah county
CG-BA-SB	155							
CS-AH	34	235		22	13		283	
WH-SB	5		10	4				
CS-SB	141							
TB-WH	13							
CS-RS							1460	
CONCORNG		388	114	39		75	243	99
CONCORNS		404		31		116		36
CS-WH		221		32	47		112	
CS-BA-AH		91	23					
CG-SB					38			
CS-BA & WH-AH						81		357
CS-BA					62		76	
Total	348	1339	147	128	160	272	2174	492

[a]CG = corn for grain; SB = soybeans for beans; CS = corn for silage; WH = wheat for grain; BA = barley for grain; AH = alfalfa for hay; RS = rye silage; TB = tobacco; CONCORNG = continuos corn for grain; and CONCORNS = continuous corn for silage. Tons of nitrogen requirement were calculated as described in the text.

this nitrogen among crops at different stages of rotation is shown in Table V.4. Because alfalfa crop residues (mainly root nodules) are assumed to contain 80 lbs of nitrogen per acre, the amount of nitrogen available to the following crops in years 1, 2, and 3 after harvesting alfalfa for hay are 0.15 x 80 = 12, 0.05 x 80 = 4, and 0.03 x 80 = 2.4 lbs per acre respectively. Corn harvested for silage is assumed to contribute no residual nitrogen to the following crops because it leaves very little stover on the field. Therefore, the amounts of nitrogen available to corn and alfalfa in each one-sixth portion of the representative acre at different stages of the crop rotation from crop residues are obtained as follows:[38]

Ccaaaa = (0.15 + 0.05 + 0.03) x 80/6 = 3.07

cCaaaa = (0.05 x 80 + 0.03 x 80)/6 = 1.07

ccAaaa = (0.03 x 80)/6 = 0.40

ccaAaa = (0.15 x 80)/6 = 2.00

ccaaAa = (0.15 x 80 + 0.05 x 80)/6 = 2.67

ccaaaA = (0.15 + 0.05 + 0.03) x 80/6 = 3.07

Since alfalfa harvested for hay is assumed to receive 144 pounds of nitrogen from symbiotic fixation, each alfalfa crop at each stage of the rotation gets about 24 pounds of nitrogen from fixation. Net nitrogen requirement at each stage of the rotation is estimated as follows:

Ccaaaa = 23 - 5 - 0 - 3.07 = 14.93

cCaaaa = 23 - 5 - 0 - 1.07 = 16.93

ccAaaa = 30 - 5 - 24 - 0.4 = 0.60

ccaAaa = 30 - 5 - 24 - 2.0 = - 1.0

ccaaAa = 30 - 5 - 24 - 2.67 = - 1.67

[38] The stage of the crop in the rotation is indicated by the upper case letter for the corresponding crop. For example, corn in year 1 is represented by Ccaaaa. Likewise, second year corn in the rotation is represented by cCaaaa.

Table V.4. Nitrogen requirement for corn silage-alfalfa hay rotation[a].

Stage	Nitrogen required in rotation	Nitrogen from soil organic matter	Nitrogen from symbiotic fixation	Nitrogen from crop residues	Net nitrogen required
Ccaaaa	23	5	0	3.07	14.93
cCaaaa	23	5	0	1.07	16.93
ccAaaa	30	5	24	0.40	0.60
ccaAaa	30	5	24	2.00	-1.00
ccaaAa	30	5	24	2.67	-1.67
ccaaaA	30	5	24	3.07	-2.07

[a]Ccaaaa represents corn in the year 1 of rotation. cCaaaa represents corn in the year 2 of rotation; ccAaaa represents alfalfa in the year 3 of rotation; and so on.

ccaaaA = 30 - 5 - 24 - 3.07 = - 2.07

Alfalfa meets practically all its nitrogen requirement internally, and disregarding the small nitrogen requirement for first-year alfalfa, does not require nitrogen additions. The total requirement for an acre of corn silage produced in this rotation is given by (14.93 + 16.93) x 3 = 95.58 lbs nitrogen per acre. According to the census data and crop rotation information obtained from county extension agents, 5,936 acres of corn was harvested for silage in corn silage-alfalfa hay rotation in Rockingham County in 1987. Therefore, total nitrogen required for corn grown for silage on 5,936 acres was equal to (95.58 lb nitrogen/acre) x 5,936 acres = 283.7 tons. Similar procedures were used to determine the nitrogen requirements for other crops. The assumptions used in the calculations of nitrogen for other crops in other rotations are given in Appendix H.

The total plant available nitrogen required from external sources (fertilizer or animal manure) for each county was obtained by adding the net nitrogen requirements for the crop rotations prevalent in each county. For example, as shown in Table V.3, the total plant available nitrogen required from external sources for Amelia County is obtained by adding nitrogen requirements for five crop rotations; the total requirement is 348 tons. The amount of plant available nitrogen to be met through poultry litter was obtained by subtracting the amount of plant available nitrogen in dairy manure from crop external nitrogen requirements for each county. This procedure assumes that poultry litter and dairy manure were applied up to each crop's nitrogen requirement. Table V.5 shows the amount of nitrogen available from dairy manure, poultry litter, crop nitrogen requirement, and surplus litter available for export to the litter-deficit counties. Assuming that 75 percent of inorganic nitrogen and 50 percent of organic nitrogen in poultry litter are available in the year of application, and that 12, 5, 2, and 2 percent of organic nitrogen are available in the years 2, 3, 4, and 5 of litter application, the amount of nitrogen available to plants in the current year (assuming continuous application of litter) is equal to 42.10 pounds per ton of raw litter. Tons of nitrogen from poultry litter are obtained by multiplying tons of litter by 42.10 and dividing by 2,000. Likewise, assuming that (1) dairy manure has 3.88 pounds of organic and 7.07 pounds of inorganic nitrogen per ton, (2) 25 percent of inorganic and 50 percent of organic nitrogen in dairy manure are available in the year of application, and (3) 15, 5, and 3 percent of organic nitrogen are available in years 2, 3, and 4, respectively of litter application, the amount of nitrogen available from a ton of dairy manure to the current crop is equal to 6.12 pounds. Thus, tons of nitrogen available from dairy manure in Table V.5 are obtained by multiplying tons of dairy manure by 6.12 and dividing by 2,000. For example, the amount of plant available nitrogen to be met through poultry litter is equal to (272.0 - 30.10) = 241.90 tons for Page County. The amount of surplus plant available nitrogen in poultry litter available for export was obtained by subtracting the crop nitrogen requirement net of dairy manure nitrogen from total plant available nitrogen in litter for each county. For example, as shown in Table V.5, the amount of surplus plant available nitrogen available for export is equal to (727.0-272.0-30.10) = 485.58 tons for Page County. Finally, the tons of surplus litter available for export as shown in Table V.5 were obtained by converting tons of surplus nitrogen available for export into tons of litter by assuming that a ton of raw litter, on a continuous application basis, provides 42.10 pounds of nitrogen each year. For example, the amount of litter available for export was equal to 64.76 x 2000/42.10 = 3,076 tons for Amelia County. Rockingham County is the major litter-surplus county with a surplus of 105,644 tons of raw litter available for export. Total litter surpluses from the surplus counties equal 145,627 tons of raw litter.

V.3.2. Aggregate Potential to Import Litter by Deficit Counties

In order to determine the aggregate potential of the demand counties to import litter for use as fertilizer, the nitrogen requirements were evaluated for the major crop rotations prevalent in the demand counties identified in chapter one. The crop acreage figures were obtained from the 1987 Census (Table V.6) and the information on crop rotations was obtained from personal communication with extension agents in deficit counties. One major crop rotation common to all of these demand counties was identified to be corn grain-barley and wheat-soybeans rotation (rotation1) (Norris, 1988). The other crop rotation common to most of these counties is corn grain-soybeans.

Table V.5. Amount of nitrogen in litter available for export to other counties.[a]

County name	Tons of nitrogen from poultry litter	Tons of crop nitrogen required	Tons of nitrogen from dairy manure	Tons of surplus nitrogen for export	Tons of surplus litter for export[b]
Accomack	403.21	602.00	00.00	-198.79	
Amelia	331.55	348.00	81.20	64.76	3076.00
Augusta	553.85	1339.00	413.90	-371.23	
Buckingham	129.32	146.00	8.70	-7.98	
Cumberland	231.94	128.00	38.70	142.62	6775.00
Isle of Wight	93.98	657.00	0.46	-562.56	
Nottoway	121.06	160.00	55.70	16.77	796.19
Page	727.48	272.00	30.10	485.56	23066.00
Rockingham	3584.43	2174.00	813.40	2223.82	105644.00
Shenandoah	528.16	492.00	112.60	148.74	7066.00

[a]Counties with negative excess nitrogen available for export were not considered as litter-surplus counties for the litter transfer cost minimization model. Nottoway County was also not considered as a litter-surplus county because of the very low surplus.

[b]Tons of litter available for export was obtained by multiplying tons of nitrogen available for export by 2000 and then by dividing by 42.10, where 2,000 is the pounds per ton and 42.10 is the pounds of plant available nitrogen available from a ton of poultry litter on a continuous application basis.

Table V.6. Harvested acres of corn, wheat, barley, and soybeans in the selected litter-deficit counties in 1987[a].

County name	Corn grain	Wheat	Barley	Soybeans
Essex	11167	6979	4563	21872
Gloucester	4754	733	688	8424
King & Queen	10185	4975	2996	16612
King George	3452	1786	450	6692
King William	10031	4805	2955	16999
Lancaster	3150	2203	923	6855
Mathews	1235	547	---	2508
Middlesex	2918	2853	770	6282
Northumberland	9413	8132	2661	17272
Richmond	6303	5021	2208	11593
Westmoreland	10300	5590	4621	15701
Total	95600	40500	22835	135200

[a]Source : Bureau of the Census, 1989a.

The total nitrogen requirement for each county in Table V.7 is obtained by adding the nitrogen requirements for rotation1 and rotation2. Likewise, total acres accounted for by crop rotations for each county in Table V.7 are obtained by adding acres accounted for by rotation1 and rotation2. Rotations 1 and 2 shown in Table V.7 account for over 60 percent of total harvested cropland in most counties except Lancaster, Mathews, and King George Counties where they account for between 50 to 60 percent of total harvested cropland. Some of the discrepancy between the acres accounted for by crop rotations and the harvested cropland is accounted for by hay which does not require nitrogen additions. The nitrogen requirement from external sources for corn grain-barley and wheat-soybeans rotation was estimated to be 69.17 pounds per acre as shown in chapter four. For corn grain-soybeans, the nitrogen requirement from external sources was estimated to be 48.66 pounds per acre. Multiplying these nitrogen requirements by the acreages in rotation1 and rotation2 yield the total nitrogen requirement for each rotationas shown in Table V.7.[39]

V.3.3. Litter Marketing Cost Minimization Model

A linear programming cost minimization model was used to determine the total cost of supplying different levels of crop nitrogen requirements in 11 litter-deficit counties from poultry litter obtained from the five litter-surplus counties shown in Table V.5.[40] Separate versions of the model were solved to find the total costs of supplying raw litter and composted litter from the surplus to the deficit counties at varying levels of demand. For each model, there were 55 activities involving movements of litter corresponding to the 55 possible combinations of 5 surplus and 11

[39] About one-third of the cropland is still not accounted for. However, this discrepancy should not affect the results from this study because as will be shown, there is much less poultry litter than the crops in rotations 1 and 2 can absorb in the deficit counties.

[40] The linear programming litter marketing cost minimization model is presented in Appendix I. Assuming continuous application, a ton of raw litter was assumed to provide 42.10 pounds of plant available nitrogen (including previous years' carryover nitrogen) to the current crop whereas a ton of composted litter was assumed to provide 58.3 pounds of plant available nitrogen.

Table V.7. Nitrogen requirement and number of acres accounted for by different crop rotations and total harvested cropland by county.[a]

County	Nitrogen[b] requirement (tons)		Acres accounted for		Harvested cropland (acres)
	rotation1	rotation2	rotation1	rotation2	
Essex	799.38		23,084		37,017
Gloucester	98.86	162.18	2,842	6,666	14,991
King & Queen	551.51	107.73	15,942	4,428	30,147
King George	153.33	59.17	4,472	2,432	14,479
King William	537.05	110.51	15,520	4,542	33,991
Lancaster	215.40	1.17	6,252	48	11,715
Mathews	37.12	33.48	1,094	1,376	4,372
Middlesex	248.59		7,246		11,487
Northumberland	741.85		21,586		30,405
Richmond	498.38		14,458		22,027
Westmoreland	709.26	4.33	20,422	178	33,604
Total	4590.73	478.57	132,918	19,670	244,235

[a]Rotation1 is corn grain followed by barley and wheat in the winter and by soybeans in the following year; and rotation2 is corn grain followed by soybeans in the following year. Hay accounts for some of the difference between harvested cropland and acres accounted for by rotations. Total acreage under hay for the above 11 counties was equal to 10,925.

[b]Nitrogen requirement refers to tons of externally applied nitrogen required by the crop.

deficit counties. Each model contained 5 supply constraints expressed in tons of raw or composted litter and 12 demand constraints expressed in pounds of plant available nitrogen including 11 county demand constraints and one regional total demand constraint. The county demand constraints put upper limits on the amount of litter that can be absorbed for crop production. The regional total demand refers to the sum of all the deficit counties' demand for nitrogen. The regional total demand constraint requires a minimum amount of litter to be moved into the region as a whole. The minimum requirement was varied in order to derive a total cost curve corresponding to alternative levels of shipments from surplus to deficit counties. This total cost curve was then used to estimate a marginal cost curve of moving litter from surplus to deficit counties.

The objective function coefficients for the activities involving the movements of raw litter were obtained by adding the per ton costs of litter acquisition, brokerage fee, testing, delivery, and application.[41] The objective function coefficients for activities involving movements of composted litter were obtained by adding the per ton costs of litter acquisition, collection from growers to the composting site, composting, brokerage fee, loading at the composting site for delivery, delivery, and application.[42]

The litter marketing cost minimization model was run at varying levels of total demand for plant available nitrogen in litter in order to trace out a total cost curve. The regional total demand for nitrogen constraint was varied for each model starting from 20 percent of the total regional demand up to 61.14 percent for the shipments of raw litter and from 20 percent up to 42.33 percent for the shipments of composted litter. The upper bound of 61.14 percent of total demand for shipments of raw litter and 42.33 percent of total demand for shipments of composted litter were chosen because these amounts accounted for 100 percent of total surplus raw litter available for export to the deficit counties.

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[41] The litter acquisition cost of raw litter ($8/ton) includes the cost of on-farm storage of litter ($2.16/ton of raw litter).

[42] Raw litter to be composted was assumed to be collected from poultry growers immediately upon poultry house cleaning. Hence, the poultry grower did not incur litter storage cost. Therefore, the acquisition cost of raw litter collected for composting was $5.84 or the $8.00 acquisition cost minus $2.16 storage cost.

The use of the regional total demand constraint allows the cost minimization model to ship litter to the nearest counties up to their potential to use litter. It may be that the firm would not be able to get rid of all litter in the closest counties due to unwillingness of many farmers to purchase litter. Thus, another scenario was evaluated in which each county was assumed to purchase litter in the same relative proportion. For example, if 20 percent of the region's nitrogen requirements were obtained from litter, then each county also obtained 20 percent of its requirement from litter. In this case, the individual county demand constraints were specified as greater than or equal to constraints. The demand constraints were varied by a fixed percentage in each run of the model to determine the relationship between total cost and the amount of litter moved.

V.3.4. Results on Potential to Move Litter

The results of the linear programming cost minimization model for a base case are presented in this section. The base case is based on the assumptions that: (1) a 50 percent subsidy is available for construction of on-farm raw litter storage; (2) the imputed value of poultry litter will be based on a single application of commercial fertilizer; and (3) a regional total demand constraint is imposed but the distribution of litter within the region is not constrained other than an upper limit on the amount of litter that the county can absorb.

Tons of litter moved to the Northern Neck and Middle Peninsula from litter-surplus counties as well as total and marginal costs of moving these amounts are given in Table V.8 for both raw and composted litter.[43] The distribution of the amounts of litter moved from each litter-surplus to litter-deficit counties are shown in Appendix J for the base case. The composted litter amounts are presented in raw litter units (one ton of compost equals two tons of raw litter) for ease of comparision with the raw litter option. Table V.8 indicates that total costs increase with in-

[43] Marginal cost is calculated by dividing the difference in total costs by the difference in total amounts of litter made available to the users. For example, in Table V.8, the marginal cost of an additional ton of raw litter as litter expands from 142,913.75 to 145,627 is equal to (\$3,927,899.89 - \$3,846,551.89)/(145,627 - 142,913.75) = \$29.98.

creasing amounts of litter marketed to the demand areas. Average cost is below marginal cost at all levels of litter marketed implying that the portion of the marginal cost curve shown in Figure V.1 is the supply curve for litter. The marginal costs are increasing with the increase in the amount of litter marketed meaning that the estimated litter supply curve has a positive slope. As is clear from Figure V.1, the marginal costs of moving raw litter from surplus to deficit counties rise slowly with the increase in the amounts of litter moved.

The profit potential of moving litter from litter-surplus counties to the litter-deficit counties was assessed by comparing total costs of marketing litter with total revenues that could be generated from the sales of litter. The total revenues were based on the maximum farmers could afford to pay for litter as fertilizer for a corn grain-barley and wheat- soybeans rotation as shown in Table IV.1. The value of a ton of raw litter net of carrying cost in a corn grain-barley and wheat-soybeans rotation is equal to $33.88. The litter-handling firm that attempts to maximize profits will expand output as long as marginal cost of moving litter is less than $33.88 assuming that is the amount farmers are willing to pay. From Figure V.1, the profit-maximizing level of raw litter moved is equal to 145,627 tons. Here the upper limit on the available amount of litter constrains total sales. Total revenue at this level of output is $33.88 x 145,627 = $4,933,843 and total cost is $3,927,900. Profits to the firm (total revenue - total cost) are $1,005,943.[44]

The litter handling firm would choose to move that level of composted litter at which marginal revenue is equal to marginal cost or where total supplies are exhausted. The value of a ton of composted litter net of carrying cost for a corn grain-barley and wheat-soybeans rotation was found to be $49.59 per ton or $24.80 per ton of raw litter equivalent (Table IV.1). From Table V.8, the litter handling firm will choose to transfer 145,627 tons of raw litter equivalent at a total cost of $2,708,699. Total revenues at this level of output are $24.795 x 145,627 = $3,610,821. Profits to the firm (total revenue - total cost) are $902,122 indicating that it is more profitable to transfer litter in raw form than in composted form.

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[44] This is a maximum profit level; if farmers are not willing to pay the full $33.88 per ton, profits will be lower. Also the cost per loaded mile may exceed the $0.10 per ton mile assumed here due to the volume of litter to be moved in short period (about 145,627 tons in two months). Assuming 20 tons per load, 7,281 loads would have to be moved in two months. This increased demand for trucking services might cause the price charged to increase as well.

Table V.8. Amounts, marginal and total costs of moving litter for the base case with the regional demand.

Percent of total nitrogen requirement met[a]	Tons of raw litter moved	Total cost of moving raw litter[b] ($)	Marginal cost of moving raw litter ($/ton)	Percent of total nitrogen requirement met	Tons of composted litter moved[c]	Total cost of moving composted litter[d] ($)	Marginal cost of moving composted litter ($/ton)
20	47637.90	1116538.92		20	68801.25	1206114.38	
			27.72				19.41
30	71456.77	1776829.11		30	103201.89	1873943.90	
			28.19				19.58
40	95275.82	2448207.17		40	137602.47	2547457.53	
			29.22				20.09
50	119094.80	3144299.39		42.33	145627.00	2708698.82	
			29.48				
60	142913.75	3846551.89					
			29.98				
61.14	145627.00	3927899.89					

[a]Numbers in the column refer to percentages of total nitrogen requirements in the selected deficit counties.

[b]Total cost for raw litter movements includes costs of litter acquisition ($8/ton of raw litter acquired for shipments in raw form, assuming litter is stored on the poultry farm), testing, brokerage fee, delivery and application.

[c]Amount and total cost of composted litter moved are expressed in raw litter equivalent for ease of comparision with the raw litter option. The results for the composted litter are based on the assumption of 50 percent reduction in litter weight due to composting.

[d]Total cost for composted litter movements includes costs of litter acquisition ($5.84/ton of raw litter collected for shipments in composted form, assuming litter is not stored on the poultry farm), collection, brokerage, processing, delivery, and application.

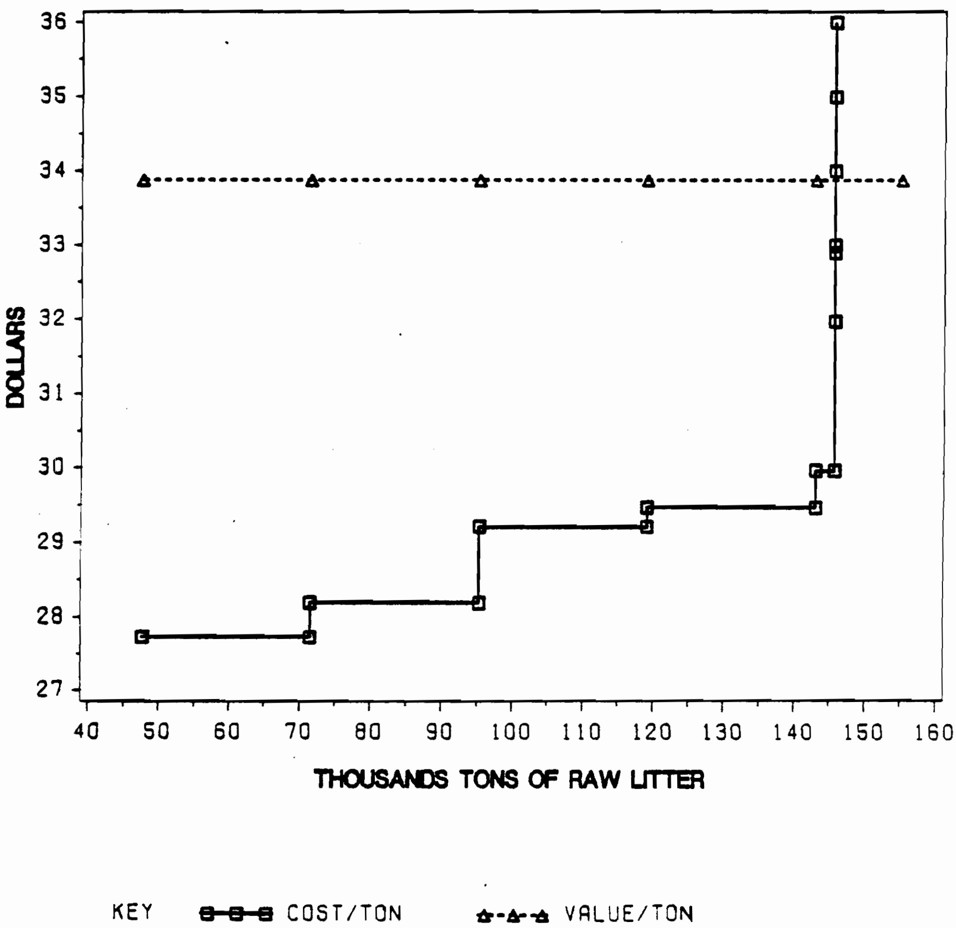

Figure V.1. Estimated marginal cost curve and value of raw litter.

Results were also obtained with the additional assumption that litter would be distributed in each county in the same relative proportion. The tons of litter moved, and average and marginal costs of moving raw and composted litter from deficit counties to surplus counties based on this model are presented in Table V.9. Comparing Table V.8 with Table V.9, it is clear that forcing the model to meet a specified level of demand in each litter-deficit county increases the total cost of moving litter in raw as well as composted form from between 4 to 9 percent over the base case. These increases in total costs are due to the additional distance litter has to be moved to farther away counties compared to the base case where the model chose to meet the nitrogen requirements of the nearest counties first before hauling litter to counties located farther away. Since the amount of litter moved remained the same in both cases, the average costs of moving litter also increased compared to the base case. However, the marginal cost of moving litter from surplus counties to the deficit counties increased more slowly compared to the base case. The very slow increase in marginal cost is due to the fact that average transportation distances increased little if at all as the amount of litter to be moved increased. Transportation distances do not increase because of the requirement that each deficit county receive the same relative share of litter.

From Table V.9, the profit-maximizing litter handling firm would move a total of 145,627 tons of raw litter from litter-surplus to litter-deficit counties at a total cost of $4,073,135 for the base case without the regional demand contraint. At this level of output, total revenues are $33.88 x 145,627 = $4,933,843. The profits to the firm are $860,708 compared to $1,005,943 for base case with the regional demand contraint. Likewise, from Table V.9, the litter handling firm would move a total of 145,627 tons of raw litter equivalent of compost at a total cost of $2,828,517. The profits to the firm from moving composted litter are $782,304 which is less than the profits ($902,122) for the base case model.

Effects of Changes in Delivery Distances

Since poultry litter is a bulky product, the transportation cost becomes the major component of the total cost of transferring litter from litter surplus to deficit areas and the distance that

Table V.9. Amounts, marginal and total costs of moving litter for the base case without the regional demand.

Percent of total nitrogen requirement met[a]	Tons of raw litter moved	Total cost of moving raw litter[b] ($)	Marginal cost of moving raw litter ($/ton)	Percent of total nitrogen requirement met	Tons of composted litter moved[c]	Total cost of moving composted litter[d] ($)	Marginal cost of moving composted litter ($/ton)
20	47637.90	1231532.00		20	68801.25	1292493.73	
			28.93				19.98
30	71456.77	1920531.87		30	103201.89	1979808.51	
			29.01				19.98
40	95275.82	2611637.86		40	137602.47	2667181.65	
			29.01				20.11
50	119094.80	3302740.32		42.33	145627.00	2828516.97	
			29.03				
60	142913.75	3994243.11					
			29.08				
61.14	145627.00	4073135.04					

[a]Numbers in the column refer to percentages of total nitrogen requirements in the selected deficit counties.

[b]Total cost for raw litter movements includes costs of litter acquisition ($8/ton of raw litter acquired for shipments in raw form, assuming litter is stored on the poultry farm), testing, brokerage fee, delivery and application.

[c]Amount and total cost of composted litter moved are expressed in raw litter equivalent for ease of comparision with the raw litter option. The results for the composted litter are based on the assumption of 50 percent reduction in litter weight due to composting.

[d]Total cost for composted litter movements includes costs of litter acquisition ($5.84/ton of raw litter collected for shipments in composted form, assuming litter is not stored on the poultry farm), collection, brokerage, processing, delivery, and application.

litter has to travel from its origin to its place of use will affect the profitability of a litter handling business. For example, for the base case the transportation cost of moving 145,627 tons of composted litter equals 74 percent of the total cost of making composted litter available to farmers in the deficit areas. Also, the distance from the origin to the destination of litter for use as fertilizer is likely to affect the firm's decision on whether to ship litter in raw or composted form because composting reduces litter weight and volume. Therefore, it is necessary to look at the effects of changes in distance litter has to be transported.

The effects of an increase in hauling distance on the amounts and costs of moving litter were evaluated by parametrically increasing the county seat to county seat distance until the profits from transfer of raw litter from surplus to deficit areas was driven to zero. The results indicated that there were profits for some level of output up to a 40 percent increase in delivery distances but that profits started to become negative once the delivery distances were increased by more than 40 percent.[45] The total amounts, total and marginal costs of moving litter for the 40 percent increase in delivery distances are presented in Tables V.10. A profit maximizing litter handling firm will move only 71,456.77 tons of raw litter at a total cost of $2,128,614.25. The profits to the litter handling firm are $33.88 x 71,456.77 - $2,128,614.25 = $292,341. For the 41 percent increase in distance, the profits to the litter handling firm approached close to zero for movements of litter enough to meet 20 percent or more of the nitrogen requirement in each deficit county. The results indicated that the profit potential of moving raw litter from surplus to the deficit areas is sensitive to the distance litter has to be transported.

V.4.1. Effects of Policy Changes on Litter Use

The results of the analyses may be sensitive to policy changes affecting the value and cost of making litter available to farmers. Sensitivity analyses were carried out to evaluate the effects

[45] A 40 percent increase in the county seat to county seat distance between surplus and deficit counties increased the average distance from the surplus to deficit counties by 52 miles.

Table V.10. Amounts, marginal and total costs of moving raw litter for the base case and with a 40 percent increase in delivery distance.

Percent of nitrogen requirement met	Tons of raw litter moved	Total cost of moving raw litter ($)[a]	Marginal cost of moving raw litter ($)
20	47637.90	1323874.30	
			33.79
30	71456.77	2128614.25	
			34.44
40	95275.82	2948912.40	
			35.89
50	119094.80	3803733.29	
			36.25
60	142913.75	4667222.83	
			36.95
61.14	145627.00	4767488.63	

[a]Total cost for raw litter movements includes costs of litter acquisition ($8/ton of raw litter acquired for shipments in raw form, assuming litter is stored on the poultry farm), testing, brokerage fee, delivery and application for movements of raw litter.

of selected changes in policy variables on the profit potential of litter handling. The results of those sensitivity analyses are presented in this section.

Effects of Storage Cost Subsidy

The government is currently providing a subsidy to growers for the construction of storage structures for storing litter to be used as fertilizer. If this subsidy were to be removed, then the on-farm cost of litter storage for the grower would increase from $2.16 to $4.11 per ton of raw litter. If the grower attempts to pass the cost increase on to the litter handler, the litter acquisition cost would increase, thereby reducing profits to the litter handling firm from transferring raw litter to the deficit areas. If the entire increase in storage cost is passed on to the litter handler, the total cost of transferring raw litter from surplus to deficit counties increases by ($4.11 - $2.16) x 145,627 = $283,972.65. As a results, profits to the litter handling firm after the increase in the raw litter storage cost are 1,005,943 - $283,973 = $721,970. This profit is less than the profits of $902,122 for composted litter as shown in the base case. These results imply that while the storage subsidy may add to the profitability of the litter handling industry, it is not necessary to make the industry profitable. Removal of the subsidy would simply encourage the industry to substitute centralized processing and storage for on-farm storage. Thus, the government may wish to consider removing the subsidy and using the resources saved to subsidize purchase of litter by crop farmers, to subsidize transportation of litter to demand areas, or to subsidize the establishment of centralized composting areas to promote composting.

Effects of Waste Management Requirements

Another policy variable that may affect the results of the analyses are the legal steps taken by some poultry producing areas (e.g., Rockingham County) to ensure environmentally safe disposal of poultry litter. As mentioned in chapter one, a zoning ordinance in effect in Rockingham County requires a poultry grower to have a nutrient management plan in order to get a permit for a poultry facility. The nutrient management plan has to make provisions for the safe disposal of 100 percent of the animal waste produced by each poultry facility. For growers who produce more litter than their land can absorb for crop crop production, giving the litter away free to a litter handling firm may be preferable to hauling it away themselves or reducing their production of poultry and poultry litter. This zoning ordinance may reduce the acquisition cost of litter and increase the profits to the litter handling firm if contracting for disposal of the litter with the litter handling firm is allowed as a means of disposal in the waste management plan. Suppose, the litter handling firm gets litter free from growers, then the total cost of transferring raw litter decreases by $8 x 145,627 = $1,165,016 or 29.66 percent for raw litter shipments. The profits to the litter handling firm from transferring raw litter from surplus to deficit areas increase by $1,165,016 over the base case to $2,170,959. Assuming zero acquisition cost for litter collected for composting, the total costs of transferring composted litter to deficit areas decrease by $5.84 x 145,627 = $850,462 or 31.39 percent and increase the profits to the firm by the same amount to $1,752,584. Under the zero litter acquisition cost assumption, the results indicate that transferring raw litter to deficit areas is more profitable than transferring composted litter.

Effects of Policy on Best Management Practices

The value of litter depends on the assumption made about the availability of nitrogen from commercial fertilizer to plants. One of the factors affecting the amount of nitrogen available from commercial fertilizer to plants is the frequency of application. A split application of commercial fertilizer increases the amount of nitrogen available to plants and thereby may decrease the amount of nitrogen leached to the groundwater (Alley et al., 1987). Thus in an effort to reduce groundwater pollution, the government may encourage farmers to adopt split application of commercial fertilizer instead of a single application. With more nitrogen available per ton of commercial fertilizer, less commercial fertilizer will be required to meet the same crop requirement compared to single application. The value of litter in Table IV.1 was estimated based on the assumption that 62 percent of commercial fertilizer nitrogen applied is available to plants in the year of application for a single application. For split application, it was assumed that 80 percent of commercial fertilizer nitrogen application is available in the year of application (Keeney, 1982). A split application of commercial fertilizer increases the cost of application by $9 due to the increase in the number of applications from two to four applications for a corn-wheat and barley-soybeans rotation. However, the amount and cost of commercial fertilizer application decreased by 25.09 pounds and $6.27 per acre, respectively with a split application because of the higher nitrogen availability. As a result, there was a net increase of $2.73 per acre in the value of commercial fertilizer replaced by poultry. With the split application assumption, the value of raw litter net of carrying cost was $35.60 per ton compared to $33.88 per ton of raw litter for a single application. Consequently, total revenues to the litter firm increased from $4,933,843 for the single application case to $35.60 x 145,627 = $5,184,321 for split application. The profits to the firm are $35.60 x 145,627 - $3,927,900 = $1,256,421 compared to $1,005,943 for a single application of commercial fertilizer in the base case.

For composted litter when the assumption of availability of nitrogen from commercial fertilizer was increased from 62 percent to 80 percent for a split application practice, the value of a ton of composted litter net of carrying cost was found to be $51.73 compared to $49.59 for the single application. Hence, the profits to the firm are $51.73 x 0.5 x 145,627 - $2,708,699) = $1,057,943 compared to $902,122 for single application case as shown in the base case implying that the profits to the firm are sensitive to the assumption made about the amount of nitrogen available to plants from commercial fertilizer applications.

Effects of Changes in Commercial Fertilizer Prices

The imputed value of litter depends on the price of commercial fertilizer. With changing fossil fuel prices, the prices of commercial fertilizer may increase in the future. Also, in order to encourage farmers to substitute poultry litter for commercial fertilizer, the government may impose a tax on commercial fertilizer, thereby increasing the price of commercial fertilizer. On the other hand, when the fertilizer dealers see potential competition from poultry litter as a fertilizer, they may decrease the price of commercial fertilizer as much as possible to remain in the business.

Hence, the commercial fertilizer prices may increase or decrease depending on the interplay of several factors. Since nitrogen is the major nutrient of concern from an environmental pollution point of view, the effects of commercial nitrogen fertilizer price changes were evaluated by increasing and decreasing the commercial nitrogen fertilizer prices by one cent per pound. When the commercial nitrogen price was increased from $0.25 to $0.26 per pound (4 percent), the imputed value of litter net of carrying cost were estimated to be $34.56 and $50.53 per ton of raw and composted litter, respectively for percentage increases of 2 and 1.89, respectively. Total revenues and profits increased by ($34.56 - $33.88) x 145,627 = $99,026 and ($50.53 - $49.59)/2 x 145,627 = $68,445 over the base case for raw and composted litter, respectively. Thus, for every 4 percent increase in the price of commercial nitrogen, there is an increase in litter value and profits of 2 and 9.84 percent, respectively for raw litter handling. For a 4 percent increase in the price of commercial nitrogen, there is an increase in litter value and profits of 1.89 and 7.59 percent, respectively for composted litter handling. So, profits to the litter handling firm are responsive to an increase in the commercial fertilizer nitrogen price. When the commercial nitrogen price was decreased from $0.25 to $0.24 per pound, the imputed value of litter net of carrying cost were estimated to be $33.20 and $48.65 per ton of raw and composted litter, respectively. Consequently, total revenues and profits decreased by ($33.88 - $33.20) x 145,627 = $99,026 and ($49.59 - $48.65)/2 x 145,627 = $68,445 for raw and composted litter, respectively. For a 4 percent drop in the price of commercial fertilizer nitrogen, there is a decrease in litter value and profits of 2 and 9.84 percent, respectively, for raw litter handling. The decreases in litter value and profits for a 4 percent decrease in the price of commercial fertilizer nitrogen were 1.89 and 7.59 percent, respectively, for composted litter handling. These results indicate that the profit potential of litter handling is very sensitive to the commercial nitrogen price.

V.4. Policy Implications

Market Creation

The development of poultry litter handling industry is likely to produce environmental advantages by dissipating the application of litter over a larger geographic area and reducing the potential for nutrient loadings to ground and surface water. The results of the base case analyses indicate that there is economic potential to establish a poultry litter handling industry to facilitate transfer of litter from surplus counties to deficit counties. However, there may be barriers to the emergence of such an industry. For example, marketing and promotional expenditures may be significant for a new firm. Farmers may be reluctant to purchase litter due to lack of information on the nutrient content and concern about the variability of nutrient content in litter. Concerns by potential entrepeneurs about lawsuits from poultry growers arising from disease transmission during litter handling and transport (Holden, 1989) may inhibit the industry. Uncertainty by entrepreneurs about government regulations affecting long distance hauling of poultry litter (Souder, 1989) may also restrain industry development. Due to these barriers, policy actions by the government may be needed to encourage the emergence of such an industry.

Policy Action to Promote Use of Litter as Fertilizer

The government may be able to help promote the use of poultry litter by farmers by promoting research and extension to document and disseminate the information about the advantages of litter as a crop fertilizer and the potential to reduce pollution by applying litter at rates no more than required to meet agronomic requirements of crops. There has been some progress made in this direction. The Virginia Department of Conservation and Historic Resources, Division of Soil and Water Conservation through its Chesapeake Bay Program, provided funding for an extension educational program administered by the department of agricultural engineering at Virginia Polytechnic Institute ans State University. This project was undertaken to educate farmers about the benefits of integrated nutrient management (Collins et al., 1988). The program involved six main thrusts: (1) development of supporting materials for use in nutrient management workshops for extension agents and others; (2) statewide extension nutrient management training workshops; (3) free manure sample testing for farmers; (4) development of user friendly computer software for planning manure management; (5) farm demonstrations of safe and effective nutrient management; and (6) development of individual farm manure and nutrient management plans (Collins et al., 1988). Although the results of investment on these educational programs will not be realized instantly, yet in the long run, they are important for increasing the awareness of farmers about the value and use of poulty litter and reducing the concerns of farmers about poultry litter. Educational programs will help change farmers and the general public's attitude from "litter as a nuisance" to "litter as a valuable commodity".

The results of the sensitivity analyses discussed above indicate that waste management requirements, composting and transportation subsidies, and commercial fertilizer nitrogen taxes seem to be the most effective policy actions to promote more effective utilization of poultry litter by transferring litter from surplus to deficit areas.

Incentives to Potential Entrepreneurs

The government could help potential litter handling firms to get started by developing necessary infrastructure for marketing poultry litter, by formulating some incentive programs including investment tax credits, low interest loans for purchase of some machinery and equipment, and by providing some venture capital funds. Along with such incentive programs, the government should also require the litter handling firms to follow the regulations and standards set by the government. The regulations should include standards for how litter handling firm would minimize disease transmission. The assurance that disease transmission potential will be minimized by enforcing a set of standards may encourage growers to release litter to a litter handling firm for transfer to other areas. Such standards could include a minimum distance between the composting site and commercial poultry houses. Holden (1989) indicates that in some cases they do not allow trucks directly to the poultry farm to pick up litter. Instead, the farmer dumps at a collection site away from the poultry house, and they pick it up from there. They haul from only one farm at a time and disinfect trucks between farms. Holden (1990) indicates that it costs about $0.10 to $0.20 per ton of raw litter for disinfecting the machinery and equipment used in litter collection and hauling. This cost is small relative to the total cost of hauling and applying litter and relative to the potential benefits of reduced disease transmission.

The government may also have to regulate large scale composting to ensure that sites are designed to minimize the potential for water pollution. This will benefit the entrepreneur by reducing potential community resistance to setting up a composting site. For example, regulation may require litter handling firms composting poultry litter (1) to build an embankment around the site to keep water from running through the site, (2) to make the site impermeable so as to impede leaching, (3) to provide a pond at the end of the site in order to catch runoff, (4) to seed the banks with grass to act as filters, and (5) to make provision for removal of excess water from the pond, (Holden, 1990). The costs of performing all these activities are included under "site development" cost as shown in the budget for cost of large scale composting.

Waste Management Plan

The government may also require growers to be part of a long-term litter management plan as is already the case in Rockingham County, Virginia. Under such a plan, growers may be required to designate the farm where litter will be applied or make arrangements with a litter handling firm or neighboring farmers with available land for safe disposal of litter. Growers who are producing more litter than they have land available for safe disposal of litter will be encouraged by such a waste management plan to either sell litter at a cheaper price or give it away free for hauling assuming that contract with a litter handling firm is an allowable outlet for manure under the plan. Depending on the profits from expanding the poultry operations compared to the cost of litter disposal, growers may even be willing to pay someone to haul litter away from their premises. Overall, the effect of a waste management plan may be to make litter available to litter handling firms at lower prices which helps strengthen the viability and increase the profitability of such an industry.

Chapter VI: Summary and Conclusions

VI.1. Summary and Conclusions

The problem of litter disposal due to rapidly expanding poultry production in concentrated areas has led to the search for better ways to use it. The proposed solution to the litter disposal problem in this study was to transfer it from surplus areas where litter production exceeds the capacity of adjoining land to use it productively to deficit areas where the capacity to use it for fertilizer and livestock feed exceeds local production.

Objective one of this study was to determine the profit potential of establishing a poultry litter handling industry to promote the use of litter as livestock feed and crop fertilizer. The value of litter as animal feed was estimated by evaluating the value of poultry litter relative to other feeds cow-calf and stocker rations using linear programming feed cost minimization models. The results of the analyses indicated that the high costs of additional handling and storage required in shifting from a traditional hay feeding system to a litter feeding system may limit the potential for expanding litter use as animal feed. The results indicated that a less capital intensive feeding system such as the Auburn system (using a front-end loader to haul litter and grain from the storage shed and feeding it in used tractor tires) is better suited for litter feeding than a capital intensive method such as a mixer wagon system for small farmers. For the Auburn system, the value of litter net of on-farm feeding and handling costs was estimated to be $17.40 per ton of raw litter in cow-calf rations and $25.80 and $29.00 per ton of litter for the 1-lb-a-day and 2-lbs-a-day rates of gain in body weight, respectively, for stocker rations. These values reflect what the farmer could afford to pay to have the litter delivered to the farm. The value of litter as animal feed depends on the type of animal, rate of gain in body weight, and the relative costs of competing feeds. The results indicated that using the Auburn system of litter feeding in a cow-calf ration, litter can be exported a maximum of 84 miles of radius from litter supply point before profits to the litter handling firm would be driven down to zero.

The economic value of poultry litter as a crop fertilizer was estimated by determining the value of commercial fertilizer replaced by poultry litter to meet the crop requirements for several selected crop rotations. The results of the analyses indicated that the value of litter as a fertilizer depends on the crop rotation, amount of nutrients available in the soil, form of litter (raw or composted), nutrients available from crop residues, commercial fertilizer application practice (single or split application), and crop nutrient requirements. In general, the value of litter is higher for crops with higher nutrient requirements than for crops with lower nutrient requirements because more of the nutrients in litter are valued. The value of litter is higher for crops grown in soils with low soil test levels for nutrients. The per ton value of litter is higher for lower litter application rates than for higher litter application rates because at higher application rates, all of phosphate and potash content in litter are not valued. The value of poultry litter as fertilizer in a corn grain-barley & wheat-soybeans rotation was estimated to be $33.88 per ton of raw litter and $49.59 per ton of composted litter.

The aggregate potential of litter surplus counties to supply litter for export to the litter deficit counties was estimated by deducting from total litter nitrogen production, the amounts of nitrogen required to meet the deficit crop nitrogen requirements over and above that available from dairy manure in each of the litter surplus counties. About 145,627 tons of poultry litter was found to be available for export to deficit areas. The aggregate potential to import litter nitrogen by the litter deficit counties was estimated by determining the nitrogen requirements of the crop rotations in these counties.

The objective of determining the profit potential of establishing a poultry litter handling industry to promote the transfer of litter from litter surplus to deficit areas for use as fertilizer was achieved by comparing the total cost of making litter available to users in the deficit counties with the total revenue from the sale of litter for use as fertilizer. A linear programming cost minimization model was used to find the minimum costs of transferring varying amounts of litter in both raw and composted forms from surplus to deficit areas. The results indicated that it is economically feasible to establish a poultry litter handling industry in order to facilitate the transfer of litter from surplus to deficit counties for use as fertilizer.

The sub-objective of objective one in this study was to determine appropriate methods of organizing a poultry litter handling industry in terms of services provided and means of providing those services. The services identified to be provided by a poultry litter handling industry are litter collection, storage, processing, testing, delivery, and application. The costs of these services were estimated using enterprise budgets. The results indicated that it is more profitable to market litter in raw form than in composted form for the base case. However, when the subsidy currently being provided for on-farm storage was removed composted litter became more profitable than raw litter.

The comparative analysis of handling, storing, processing, and application of poultry litter between the on-farm and centralized system indicated that the centralized system captured the economies of scale in litter processing and application. Sensitivity analyses were carried out to evaluate: (1) the effects of removing the subsidy on litter storage structure construction cost, (2) the effects of waste management plans on litter acquisition cost, (3) the effects of splitting the commercial fertilizer application rather than making a single application, (4) the effects of changes in commercial fertilizer prices, and (5) the effects of changes in the distance litter has to be transported from litter surplus to deficit counties. The results indicated that profits from transferring litter from surplus to deficit areas were sensitive to litter storage cost subsidy. Without the subsidy, the profits to the firm went down from $1,005,943 to $721,970. Without the subsidy, it became more profitable to transfer litter in composted form than in raw form while with the subsidy it was more profitable to transfer litter in raw form. Profits to the litter handling firm were also found to be sensitive to changes in the acquisition cost of litter that might be brought about by waste management plans designed to encourage better utilization of poultry litter. Assuming litter acquisition cost to be zero, the profits to the firm increased by $1,165,016 to $2,170,959 for raw litter, and by $850,462 to $1,752,584 for composted litter.

Profits to the firm were also affected by changes in the commercial fertilizer application practice. Changing fertilizer application practice from single to split method increased the imputed value net of carrying cost of a ton of raw and composted litter from $33.88 and $49.49 to $35.60 and $51.73 per ton, respectively. Consequently, the profits to the firm increased to $1,256,421 and $1,057,943 for raw and composted litter, respectively. The profits to the litter handling firm were also found to be sensitive to the changes in the commercial fertilizer prices. When the commercial nitrogen price was increased by 4 percent from $0.25 to $0.26 per pound, the profits to the firm increased by $99,026 for transferring raw litter and by $68,445 for transferring composted litter to the deficit areas. When the commercial nitrogen price was decreased by 4 percent from $0.25 to $0.24 per pound, the profits to the firm decreased by $99,026 and $68,445 for raw and composted litter movements, respectively. Profits to the firm were also found to be sensitive to the distance litter has to be transported. Profits decreased with the increase in the hauling distance from litter-surplus to litter-deficit areas. The results indicated that profits to the litter handling firm would be driven down to zero if raw litter had to be hauled additional 41 percent of the delivery distance from county seats in litter surplus to the county seats of litter deficit counties.

VI.2. Policy Recommendations

Proper and environmentally safe utilization of litter may reduce nitrate loadings into groundwater, reduce unpleasant odors, increase the value of litter as fertilizer to crop producers and as feed to livestock farmers, and increase growers' income by increasing the farm gate price of litter.

The second objective of this study was to evaluate government policies that may effectively promote the use of litter as crop fertilizers and animal feed. Despite positive economic profits to potential litter handling firms as indicated by the analyses in this study, there are still some barriers to widespread use of litter as fertilizer and feed, namely, (i) the lack of acceptance of poultry litter as a crop fertilizer by farmers due to lack of information on the nutrient content and concern about the variability of nutrient content in litter, (ii) concerns by potential entrepreneurs about lawsuits from poultry growers arising from disease transmission during litter handling and transport, and (iii) uncertainty by entrepreneurs about government regulations affecting long distance hauling of poultry litter.

As the distance litter needs to be hauled from its place of origin to its place of use increases, the profit potential to the litter handling firm declines rapidly due to increasing transportation cost. Since composting decreases the weight and volume of litter, it is cheaper to transport litter in composted form when it has to be transported farther away. Therefore, some incentive programs should be formulated in order to encourage litter handling firms to compost litter. These incentive programs may include tax credits, low interest loans, and venture capital for purchase of machinery and equipment for composting.

The government may need to play a role in educating farmers and the general public about the advantages and the value of litter as a fertilizer and animal feed. Education based on research results may help to remove farmers' reluctance to use poultry litter for fertilizer and feed. Once the value of litter as fertilizer and feed is recognized by farmers, the potential entrepreneurs may enter into the business of litter handling and marketing to reap potential profits.

In order to promote the transfer of poultry litter from litter-surplus to litter-deficit counties, the government may wish to consider diverting resources from on-farm storage subsidies to other programs. These programs might include subsidizing the purchase of litter by crop farmers, subsidizing transportation of litter to deficit areas, and subsidizing the establishment of centralized composting areas to promote litter composting.

The economic viability of a litter handling firm depends on having an adequate supply of litter to meet the demand. Requiring waste management plan as is done in Rockingham County may be very helpful in making litter available to litter handling firms at lower prices from growers. Hence, the government should encourage or require other poultry-producing counties to implement similar plans in order to ensure a continuous supply of litter for the litter handling firms to help solve the problem of litter disposal.

Litter handling firms must required to take adequate preventive measures against disease transmission such as disinfecting the machinery and equipment used in litter handling and transportation. Growers must be convinced that adequate disease preventive measures are being undertaken by the litter handling firms in order to encourage adequate supplies of litter to the litter handling firms.

The viability of a litter handling industry may be encouraged by further research on several aspects of litter handling. More research could be done on the economics of backhauling litter from litter-surplus counties to the grain-producing but litter-deficit areas like the Northern Neck. Trucks carrying grain to the Shenandoah Valley could be loaded with litter for delivery to the Northern Neck. The cost of transporting litter might be reduced by using this backhaul option. There will be some additional cost involved arising from having to clean the trucks every time they are loaded with litter to get them ready for loading grain again. So, the savings in litter transportation cost will have to be compared with the increase in the cost due to additional cleaning of trucks.

Another research topic would be to look at the economics of the use of poultry litter for garden fertilizer marketed in small packages in unpelleted or pelleted form. Marketing litter as garden fertilizer might be a higher price alternative use of litter. Such a study may allow litter to capture a wider market and thereby make litter handling a more profitable business.

Lastly, future research could be done to keep an account of the actual reduction in nutrient loadings in the groundwater due to poultry litter use in place of commercial fertilizer in order to accurately value the benefits of litter use over commercial fertilizer. Information on the reduction in the nutrient loadings in groundwater due to effective use of poultry litter will help justify expenditures incurred by the government to facilitate transfer of litter from surplus to deficit areas.

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Appendix A: Commercial Fertilizer and Poultry Litter in Crop Rotations

Table A.1. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of wheat-soybeans rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	22.50	22.50	22.50
Phosphate required (lb)	80.00	80.00	80.00
Potash required (lb)	130.00	130.00	130.00
Inorganic nitrogen application (lb)	36.29	12.40	6.27
Inorganic nitrogen available in Year 1 (lb)	22.50	9.30	4.70
Organic nitrogen application (lb)	0.00	18.60	25.07
Organic nitrogen available in year 1 (lb)	0.00	9.30	12.54
Organic nitrogen available from previous litter application (lb)	0.00	3.91	5.26
Total available nitrogen (lb)	22.50	22.50	22.50
Phosphate applied as commercial fertilizer (lb)	80.00	58.26	48.61
Phosphate available from litter (lb)	0.00	21.74	31.39
Total available phosphate (lb)	80.00	80.00	80.00
Potash applied as commercial fertilizer (lb)	130.00	113.82	106.64
Potash available from litter (lb)	0.00	16.18	23.36
Total available potash (lb)	130.00	130.00	130.00
Litter applied (ton)		0.53	0.39
Nitrogen cost @ $.25/lb	9.07	0.00	0.00
Phosphate cost @ $.25/lb	20.00	14.57	12.15
Potash cost @ $.15/lb	19.50	17.07	16.00
Application cost ($)	9.00	4.50	4.50
Total commercial fertilizer cost($)	57.57	36.14	32.65
Value of litter ($/ton)		40.10	64.58
Value of litter net of carrying cost ($/ton)		39.84	64.10

Table A.2. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of corn silage-alfalfa hay rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	31.87	31.87	31.87
Phosphate required (lb)	40.78	40.78	40.78
Potash required (lb)	120.00	120.00	120.00
Inorganic nitrogen application (lb)	51.40	17.56	8.88
Inorganic nitrogen available in Year 1 (lb)	31.87	13.17	6.66
Organic nitrogen application (lb)	0.00	26.34	35.51
Organic nitrogen available in year 1 (lb)	0.00	13.17	17.76
Organic nitrogen available from previous litter application (lb)	0.00	5.53	7.46
Total available nitrogen (lb)	31.87	31.87	31.87
Phosphate applied as commercial fertilizer (lb)	40.78	9.99	0.00
Phosphate available from litter (lb)	0.00	30.79	44.46
Total available phosphate (lb)	40.78	40.78	44.46
Potash applied as commercial fertilizer (lb)	120.00	97.09	86.91
Potash available from litter (lb)	0.00	22.91	33.09
Total available potash (lb)	120.00	120.00	120.00
Litter applied (ton)		0.76	0.55
Nitrogen cost @ $.25/lb	12.85	0.00	0.00
Phosphate cost @ $.25/lb	10.20	2.50	0.00
Potash cost @ $.15/lb	18.00	14.56	13.04
Application cost ($)	9.00	4.50	4.50
Total commercial fertilizer cost($)	50.05	21.56	17.54
Value of litter ($/ton)		37.63	59.47
Value of litter net of carrying cost ($/ton)		37.37	58.98

Table A.3. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of tobacco-wheat rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	37.52	37.52	37.52
Phosphate required (lb)	29.00	29.00	29.00
Potash required (lb)	56.00	56.00	56.00
Inorganic nitrogen application (lb)	60.52	20.68	10.45
Inorganic nitrogen available in Year 1 (lb)	37.52	15.51	7.84
Organic nitrogen application (lb)	0.00	31.01	41.81
Organic nitrogen available in year 1 (lb)	0.00	15.51	20.90
Organic nitrogen available from previous litter application (lb)	0.00	6.51	8.78
Total available nitrogen (lb)	37.52	37.52	37.52
Phosphate applied as commercial fertilizer (lb)	29.00	0.00	0.00
Phosphate available from litter (lb)	0.00	36.25	52.35
Total available phosphate (lb)	29.00	36.25	52.35
Potash applied as commercial fertilizer (lb)	56.00	29.02	17.04
Potash available from litter (lb)	0.00	49.31	71.21
Total available potash (lb)	56.00	56.00	56.00
Litter applied (ton)		0.89	0.64
Nitrogen cost @ $.25/lb	15.13	0.00	0.00
Phosphate cost @ $.25/lb	7.25	0.00	0.00
Potash cost @ $.15/lb	8.40	4.35	2.56
Application cost ($)	9.00	4.50	4.50
Total commercial fertilizer cost($)	39.78	8.85	7.06
Value of litter ($/ton)		34.70	50.85
Value of litter net of carrying cost ($/ton)		34.44	50.36

Table A.4. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of corn silage-barley & wheat-alfalfa hay rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	43.19	43.19	43.19
Phosphate required (lb)	73.33	73.33	73.33
Potash required (lb)	150.00	150.00	150.00
Inorganic nitrogen application (lb)	69.66	23.80	12.03
Inorganic nitrogen available in Year 1 (lb)	43.19	17.85	9.02
Organic nitrogen application (lb)	0.00	35.70	48.12
Organic nitrogen available in year 1 (lb)	0.00	17.85	24.06
Organic nitrogen available from previous litter application (lb)	0.00	7.50	10.11
Total available nitrogen (lb)	43.19	43.19	43.19
Phosphate applied as commercial fertilizer (lb)	73.33	31.61	13.07
Phosphate available from litter (lb)	0.00	41.72	60.26
Total available phosphate (lb)	73.33	73.33	73.33
Potash applied as commercial fertilizer (lb)	150.00	118.95	105.15
Potash available from litter (lb)	0.00	31.05	44.85
Total available potash (lb)	150.00	150.00	150.00
Litter applied (ton)		1.03	0.74
Nitrogen cost @ $.25/lb	17.42	0.00	0.00
Phosphate cost @ $.25/lb	18.33	7.90	3.27
Potash cost @ $.15/lb	22.50	17.84	15.77
Application cost ($)	9.00	4.50	4.50
Total commercial fertilizer cost($)	67.25	22.34	20.27
Value of litter ($/ton)		43.77	63.41
Value of litter net of carrying cost ($/ton)		43.51	62.92

Table A.5. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of corn silage-barley-alfalfa hay rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	45.98	45.98	45.98
Phosphate required (lb)	52.22	52.22	52.22
Potash required (lb)	143.00	143.00	143.00
Inorganic nitrogen application (lb)	74.16	25.34	12.81
Inorganic nitrogen available in Year 1 (lb)	45.98	19.00	9.61
Organic nitrogen application (lb)	0.00	38.01	51.23
Organic nitrogen available in year 1 (lb)	0.00	19.00	25.62
Organic nitrogen available from previous litter application (lb)	0.00	7.98	10.76
Total available nitrogen (lb)	45.98	45.98	45.98
Phosphate applied as commercial fertilizer (lb)	52.22	7.80	0.00
Phosphate available from litter (lb)	0.00	44.42	64.15
Total available phosphate (lb)	52.22	52.22	52.22
Potash applied as commercial fertilizer (lb)	143.00	109.94	95.25
Potash available from litter (lb)	0.00	33.06	47.75
Total available potash (lb)	143.00	143.00	143.00
Litter applied (ton)		1.09	0.79
Nitrogen cost @ $.25/lb	18.54	0.00	0.00
Phosphate cost @ $.25/lb	13.06	1.95	0.00
Potash cost @ $.15/lb	21.45	16.49	14.29
Application cost ($)	9.00	4.50	4.50
Total commercial fertilizer cost($)	62.05	22.94	18.79
Value of litter ($/ton)		35.80	54.85
Value of litter net of carrying cost ($/ton)		35.54	54.36

Table A.6. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of corn grain-soybeans rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	48.66	48.66	48.66
Phosphate required (lb)	42.00	42.00	42.00
Potash required (lb)	42.33	42.33	42.33
Inorganic nitrogen application (lb)	78.48	26.82	13.55
Inorganic nitrogen available in Year 1 (lb)	48.66	20.11	10.17
Organic nitrogen application (lb)	0.00	40.22	54.22
Organic nitrogen available in year 1 (lb)	0.00	20.11	27.11
Organic nitrogen available from previous litter application (lb)	0.00	8.45	11.39
Total available nitrogen (lb)	48.66	48.67	48.66
Phosphate applied as commercial fertilizer (lb)	42.00	0.00	0.00
Phosphate available from litter (lb)	0.00	47.01	67.89
Total available phosphate (lb)	45.00	47.01	67.89
Potash applied as commercial fertilizer (lb)	42.33	7.34	0.00
Potash available from litter (lb)	0.00	34.99	50.53
Total available potash (lb)	42.33	42.33	50.53
Litter applied (ton)		1.16	0.83
Nitrogen cost @ $.25/lb	19.62	0.00	0.00
Phosphate cost @ $.25/lb	10.50	0.00	0.00
Potash cost @ $.15/lb	6.35	1.10	0.00
Application cost ($)	9.00	4.50	0.00
Total commercial fertilizer cost($)	45.47	5.60	0.00
Value of litter ($/ton)		34.49	54.48
Value of litter net of carrying cost ($/ton)		34.23	53.99

Table A.7. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of corn silage-soybeans rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	49.86	49.86	49.86
Phosphate required (lb)	45.00	45.00	45.00
Potash required (lb)	55.00	55.00	55.00
Inorganic nitrogen application (lb)	80.42	27.48	13.89
Inorganic nitrogen available in Year 1 (lb)	49.86	20.61	10.42
Organic nitrogen application (lb)	0.00	41.21	55.56
Organic nitrogen available in year 1 (lb)	0.00	20.61	27.78
Organic nitrogen available from previous litter application (lb)	0.00	8.66	11.67
Total available nitrogen (lb)	49.86	49.86	49.86
Phosphate applied as commercial fertilizer (lb)	45.00	0.00	0.00
Phosphate available from litter (lb)	0.00	48.17	69.56
Total available phosphate (lb)	45.00	48.17	69.56
Potash applied as commercial fertilizer (lb)	55.00	19.15	3.22
Potash available from litter (lb)	0.00	35.85	51.78
Total available potash (lb)	55.00	55.00	55.00
Litter applied (ton)		1.18	0.86
Nitrogen cost @ $.25/lb	20.10	0.00	0.00
Phosphate cost @ $.25/lb	11.25	0.00	0.00
Potash cost @ $.15/lb	8.25	2.87	0.48
Application cost ($)	9.00	4.50	4.50
Total commercial fertilizer cost($)	48.60	7.37	4.98
Value of litter ($/ton)		34.82	51.01
Value of litter net of carrying cost ($/ton)		34.55	50.52

Table A.8. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of corn grain-barley grain-soybeans rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	56.75	56.75	56.75
Phosphate required (lb)	59.33	59.33	59.33
Potash required (lb)	90.46	90.46	90.46
Inorganic nitrogen application (lb)	91.53	31.27	15.81
Inorganic nitrogen available in Year 1 (lb)	56.75	23.45	11.86
Organic nitrogen application (lb)	0.00	46.91	63.23
Organic nitrogen available in year 1 (lb)	0.00	23.45	31.62
Organic nitrogen available from previous litter application (lb)	0.00	9.85	13.28
Total available nitrogen (lb)	56.75	56.75	56.75
Phosphate applied as commercial fertilizer (lb)	59.33	4.51	0.00
Phosphate available from litter (lb)	0.00	54.82	79.18
Total available phosphate (lb)	59.33	59.33	79.18
Potash applied as commercial fertilizer (lb)	90.46	49.66	31.53
Potash available from litter (lb)	0.00	40.80	58.93
Total available potash (lb)	90.46	90.46	90.46
Litter applied (ton)		1.35	0.97
Nitrogen cost @ $.25/lb	22.88	0.00	0.00
Phosphate cost @ $.25/lb	14.83	1.13	0.00
Potash cost @ $.15/lb	13.57	7.45	4.73
Application cost ($)	9.00	4.50	4.50
Total commercial fertilizer cost($)	60.28	13.08	9.23
Value of litter ($/ton)		35.02	52.45
Value of litter net of carrying cost ($/ton)		34.76	51.96

Table A.9. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of corn silage-wheat rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	68.58	68.58	68.58
Phosphate required (lb)	45.00	45.00	45.00
Potash required (lb)	70.00	70.00	70.00
Inorganic nitrogen application (lb)	110.61	37.79	19.10
Inorganic nitrogen available in Year 1 (lb)	68.58	28.34	14.33
Organic nitrogen application (lb)	0.00	56.69	76.41
Organic nitrogen available in year 1 (lb)	0.00	28.34	38.21
Organic nitrogen available from previous litter application (lb)	0.00	11.90	16.05
Total available nitrogen (lb)	68.58	68.58	68.58
Phosphate applied as commercial fertilizer (lb)	45.00	0.00	0.00
Phosphate available from litter (lb)	0.00	66.25	95.68
Total available phosphate (lb)	45.00	66.25	95.68
Potash applied as commercial fertilizer (lb)	70.00	20.69	0.00
Potash available from litter (lb)	0.00	49.31	71.21
Total available potash (lb)	70.00	70.00	71.21
Litter applied (ton)		1.63	1.18
Nitrogen cost @ $.25/lb	27.65	0.00	0.00
Phosphate cost @ $.25/lb	11.25	0.00	0.00
Potash cost @ $.15/lb	10.50	3.10	0.00
Application cost ($)	9.00	4.50	0.00
Total commercial fertilizer cost($)	58.40	7.60	0.00
Value of litter ($/ton)		31.18	49.65
Value of litter net of carrying cost ($/ton)		30.92	49.16

Table A.10. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of continuous corn for grain rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	96.96	96.96	96.96
Phosphate required (lb)	50.00	50.00	50.00
Potash required (lb)	70.00	70.00	70.00
Inorganic nitrogen application (lb)	156.39	53.43	27.01
Inorganic nitrogen available in Year 1 (lb)	96.96	40.07	20.26
Organic nitrogen application (lb)	0.00	80.15	108.04
Organic nitrogen available in year 1 (lb)	0.00	40.07	54.02
Organic nitrogen available from previous litter application (lb)	0.00	16.83	22.69
Total available nitrogen (lb)	96.96	96.96	96.96
Phosphate applied as commercial fertilizer (lb)	50.00	0.00	0.00
Phosphate available from litter (lb)	0.00	93.67	135.28
Total available phosphate (lb)	50.00	93.67	135.28
Potash applied as commercial fertilizer (lb)	70.00	0.29	0.00
Potash available from litter (lb)	0.00	69.71	100.69
Total available potash (lb)	70.00	70.00	100.69
Litter applied (ton)		2.30	1.66
Nitrogen cost @ $.25/lb	39.10	0.00	0.00
Phosphate cost @ $.25/lb	12.50	0.00	0.00
Potash cost @ $.15/lb	10.50	0.04	0.00
Application cost ($)	9.00	4.50	0.00
Total commercial fertilizer cost($)	71.10	4.54	0.00
Value of litter ($/ton)		28.90	42.75
Value of litter net of carrying cost ($/ton)		28.64	42.26

Table A.11. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of continuous corn for silage rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	108.00	108.00	108.00
Phosphate required (lb)	65.00	65.00	65.00
Potash required (lb)	100.00	100.00	100.00
Inorganic nitrogen application (lb)	174.19	59.52	30.08
Inorganic nitrogen available in Year 1 (lb)	108.00	44.64	22.56
Organic nitrogen application (lb)	0.00	89.27	120.34
Organic nitrogen available in year 1 (lb)	0.00	44.64	60.17
Organic nitrogen available from previous litter application (lb)	0.00	18.75	25.27
Total available nitrogen (lb)	108.00	108.00	108.00
Phosphate applied as commercial fertilizer (lb)	65.00	0.00	0.00
Phosphate available from litter (lb)	0.00	104.33	150.68
Total available phosphate (lb)	65.00	104.33	150.68
Potash applied as commercial fertilizer (lb)	100.00	22.35	0.00
Potash available from litter (lb)	0.00	77.65	112.15
Total available potash (lb)	100.00	100.00	112.15
Litter applied (ton)		2.57	1.85
Nitrogen cost @ $.25/lb	43.55	0.00	0.00
Phosphate cost @ $.25/lb	16.25	0.00	0.00
Potash cost @ $.15/lb	15.00	3.35	0.00
Application cost ($)	9.00	4.50	0.00
Total commercial fertilizer cost($)	83.30	7.85	0.00
Value of litter ($/ton)		29.60	45.24
Value of litter net of carrying cost ($/ton)		29.34	44.75

Table A.12. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of corn silage-barley grain rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	137.25	137.25	137.25
Phosphate required (lb)	99.67	99.67	99.67
Potash required (lb)	169.33	169.33	169.33
Inorganic nitrogen application (lb)	221.37	75.63	38.23
Inorganic nitrogen available in Year 1 (lb)	137.25	56.73	28.67
Organic nitrogen application (lb)	0.00	113.45	152.93
Organic nitrogen available in year 1 (lb)	0.00	56.73	76.46
Organic nitrogen available from previous litter application (lb)	0.00	23.82	32.12
Total available nitrogen (lb)	137.25	137.25	137.25
Phosphate applied as commercial fertilizer (lb)	99.67	0.00	0.00
Phosphate available from litter (lb)	0.00	132.59	191.49
Total available phosphate (lb)	99.67	132.59	191.49
Potash applied as commercial fertilizer (lb)	169.33	70.65	26.81
Potash available from litter (lb)	0.00	98.68	142.52
Total available potash (lb)	169.33	169.33	169.33
Litter applied (ton)		3.26	2.35
Nitrogen cost @ $.25/lb	55.34	0.00	0.00
Phosphate cost @ $.25/lb	24.92	0.00	0.00
Potash cost @ $.15/lb	25.40	10.60	4.02
Application cost ($)	9.00	4.50	4.50
Total commercial fertilizer cost($)	114.66	15.10	8.52
Value of litter ($/ton)		30.54	45.08
Value of litter net of carrying cost ($/ton)		30.28	44.60

Table A.13. Estimated amount and cost of commercial fertilizer and amount of poultry litter required to satisfy nutrient requirements for a representative acre of corn silage-rye silage rotation.

	Fertilizer Sources		
	Commercial fertilizer	Raw litter	Composted litter
Nitrogen required (lb)	148.00	148.00	148.00
Phosphate required (lb)	130.00	130.00	130.00
Potash required (lb)	185.00	185.00	185.00
Inorganic nitrogen application (lb)	238.71	81.43	41.24
Inorganic nitrogen available in Year 1 (lb)	148.00	61.07	30.94
Organic nitrogen application (lb)	0.00	122.15	165.00
Organic nitrogen available in year 1 (lb)	0.00	61.07	82.50
Organic nitrogen available from previous litter application (lb)	0.00	25.65	34.65
Total available nitrogen (lb)	148.00	148.00	148.00
Phosphate applied as commercial fertilizer (lb)	130.00	0.00	0.00
Phosphate available from litter (lb)	0.00	142.75	206.60
Total available phosphate (lb)	130.00	142.75	206.60
Potash applied as commercial fertilizer (lb)	185.00	78.75	31.23
Potash available from litter (lb)	0.00	106.25	153.77
Total available potash (lb)	185.00	185.00	185.00
Litter applied (ton)		3.51	2.54
Nitrogen cost @ $.25/lb	59.68	0.00	0.00
Phosphate cost @ $.25/lb	32.50	0.00	0.00
Potash cost @ $.15/lb	27.75	11.81	4.68
Application cost ($)	9.00	4.50	4.50
Total commercial fertilizer cost($)	128.93	16.31	9.18
Value of litter ($/ton)		32.09	47.15
Value of litter net of carrying cost ($/ton)		31.83	46.66

Appendix B: Number of Miles from County Seat to County Seat

Table B. Number of miles from county seats of litter surplus counties to county seats of litter deficit counties[a].

County	Amelia	Cumberland	Page	Rockingham	Shenandoah
Essex	95.7	99.3	199.6	167.3	203.3
Gloucester	113.2	112.5	228.1	195.8	231.8
King &Queen	97.3	100.9	201.2	179.7	204.9
King George	95.8	109.8	83.3	115.4	115.8
King William	81.3	84.9	197.2	156.7	200.9
Lancaster	129.3	139.9	145.1	177.2	177.6
Mathews	131.2	129.5	238.1	205.8	241.8
Middlesex	106.6	105.9	210.5	178.2	214.2
Northumberland	126.3	135.9	143.5	175.6	176.0
Richmond	102.3	111.9	122.9	155.0	155.4
Westmoreland	115.3	124.9	109.9	142.0	142.4

[a]The distances between county seat to county seat were estimated using highway mileages from a Virginia state highway map (Ferguson, 1989).

Appendix C: Elevators, Trucks and Spreader Beds for Litter Application

The following assumptions are made in calculating the machinery requirement for litter application.

Volume of spreader = 20 cubic yards

A ton of raw litter weighs 1400 pounds

Capacity of spreader = 20x1400/2000 = 14 tons

Time required to apply 14 tons @ 2 tons/acre = 15 minutes

Total amount of litter applied = 145,627 tons

Total time required to apply 145,627 tons = (15/60)x(1/14)x145627 = 2592 hours

It is assumed that it takes 31.5 minutes to load 14 tons of litter (Souder, 1989). Therefore, time required to load 145,627 tons of litter

= (31.50/60)x145627/14

= 5461 hours.

Hence, total time for loading and application of 145627 tons of litter

= 2592 + 5461 = 8053 hours.

No. of fieldwork days for litter application in corn = 14.2 days

No. of fieldwork days for litter application in barley and wheat = 25.8 days

It is assumed that litter can be applied 12 hours per fieldwork day. The number of trucks and spreader beds required will be determined by the smaller of the number of fieldwork days in spring (for corn) and and fall (for barley and wheat). About 75 percent of the total nitrogen requirement for the corn grain-barley & wheat-soybeans rotation goes to corn. Hence, about 75 percent of total litter application can be assumed to be applied in spring. Therefore, the number of trucks and spreader beds required

= 8053 x 0.75/170.4

= 35 trucks and 35 spreader beds

The number of skid loaders and elevators required is also estimated in the same way. The number of skid loaders and elevators required

= 0.75 x 5461/170.4

= 24 elevators and 24 skid loaders.

Appendix D. Costs of Composting Selected Volumes of Poultry Litter

Table D.1. Costs of composting poultry litter in Amelia County[a].

	Unit	Quantity	Cost per unit	Cost ($)
Operating cost				
Tractor (65 hp)	hour	98.43	5.10	501.99
Composter	hour	98.43	2.50	246.07
Dump truck	hour	30.76	22.12	680.41
Site maintenance	acre	1.00	30.00	30.00
Labor	hour	155.03	5.00	775.14
Total operating cost				2233.61
Ownership cost[b]				
Composter				1337.79
Tractor (65 hp)				247.26
Dump truck				927.00
Land tax				10.00
Interest on land investment				120.00
Site development investment cost				140.55
Total ownership cost				2782.60
Total cost				5016.21
Cost/ton of raw litter				1.63

[a]Assumes an annual production of 1538 tons of compost from 3076 tons of raw litter. Labor hours include a 20 percent overhead for lubricating and servicing machines, and for getting to and from the composting site.
[b]One hundred percent of the composter, 9.84 percent of tractor, and 18.45 percent of dump truck were charged to the composting operation; land was priced at $1500 per acre; interest rate was set at 8 percent; land area used for composting was 1 acre; and land tax used was equal to $10 per acre. Tractor: useful life = 12,000 hours, purchase price = $18,200, and Composter: useful life = 12 years, purchase price = $9,500. Dump truck: useful life = 2000 hours, purchase price = $28,500, and tax, insurance, and housing cost = 2.8 percent of average investment cost.

Table D.2. Costs of composting of poultry litter in Cumberland County[a].

	Unit	Quantity	Cost per unit	Cost ($)
Operating cost				
Tractor (65 hp)	hour	216.80	5.10	1105.68
Composter	hour	216.80	2.50	542.00
Dump truck	hour	67.75	22.12	1498.63
Site maintenance	acre	2.00	30.00	60.00
Labor	hour	341.46	5.00	1707.30
Total operating cost				4913.61
Ownership cost[b]				
Composter				1337.79
Tractor (65 hp)				544.62
Dump truck				2042.42
Land tax				20.00
Interest on land investment				240.00
Site development investment cost				281.10
Total ownership cost				4465.93
Total cost				9379.54
Cost/ton of raw litter				1.38

[a]Assumes an annual production of 3387 tons of compost from 6775 tons of raw litter. Labor hours include a 20 percent overhead for lubricating and servicing machines, and for getting to and from the composting site.
[b]One hundred percent of the composter, 21.68 percent of tractor, and 40.65 percent of dump truck were charged to the composting operation; land was priced at $1500 per acre; interest rate was set at 8 percent; land area used for composting was 2 acres; and land tax used was equal to $10 per acre. Tractor: useful life = 12,000 hours, purchase price = $18,200, and Composter: useful life = 12 years, purchase price = $9,500. Dump truck: useful life = 2000 hours, purchase price = $28,500, and tax, insurance, and housing cost = 2.8 percent of average investment cost.

Table D.3. Costs of composting of poultry litter in Shenandoah County[a].

	Unit	Quantity	Cost per unit	Cost ($)
Operating cost				
Tractor (65 hp)	hour	226.11	5.10	1153.16
Composter	hour	226.11	2.50	565.27
Dump truck	hour	70.66	22.12	1562.99
Site maintenance	acre	2.00	30.00	60.00
Labor	hour	356.12	5.00	1780.62
Total operating cost				5122.04
Ownership cost[b]				
Composter				1388.68
Tractor (65 hp)				567.73
Dump truck				2130.14
Land tax				20.00
Interest on land investment				240.00
Site development investment cost				281.10
Total ownership cost				4627.65
Total cost				9749.69
Cost/ton of raw litter				1.38

[a]Assumes an annual production of 3533 tons of compost from 7066 tons of raw litter. Labor hours include a 20 percent overhead for lubricating and servicing machines, and for getting to and from the composting site.

[b]One hundred percent of the composter, 22.61 percent of tractor, and 42.39 percent of dump truck were charged to the composting operation; land was priced at $1500 per acre; interest rate was set at 8 percent; land area used for composting was 2 acres; and land tax used was equal to $10 per acre. Tractor: useful life = 12,000 hours, purchase price = $18,200, and Composter: useful life = 11 years, purchase price = $9,500. Dump truck: useful life = 2000 hours, purchase price = $28,500, and tax, insurance, and housing cost = 2.8 percent of average investment cost.

Table D.4. Costs of composting of poultry litter in Page County[a].

	Unit	Quantity	Cost per unit	Cost ($)
Operating cost				
Tractor (65 hp)	hour	738.11	5.10	3764.36
Composter	hour	738.11	2.50	1845.27
Dump truck	hour	230.66	22.12	5102.20
Site maintenance	acre	7.00	30.00	210.00
Labor	hour	1162.52	5.00	5812.62
Total operating cost				16,734.45
Ownership cost[b]				
Composter				3839.24
Tractor (65 hp)				1854.19
Dump truck				4565.25
Land tax				70.00
Interest on land investment				840.00
Site development investment cost				983.85
Total ownership cost				12152.53
Total cost				28886.98
Cost/ton of raw litter				1.25

[a]Assumes an annual production of 11,533 tons of compost from 23,066 tons of raw litter. Labor hours include a 20 percent overhead for lubricating and servicing machines, and for getting to and from the composting site.

[b]One hundred percent of the composter, 73.81 percent of tractor, and 100 percent of dump dump truck were charged to the composting operation; land was priced at $1500 per acre; interest rate was set at 8 percent; land area used for composting was 7 acre; and land tax used was equal to $10 per acre. Tractor: useful life = 12,000 hours, purchase price $18,200, and Composter: useful life = 12 years, purchase price = $9,500. Dump truck: useful life = 2000 hours, purchase price = $28,500, and tax, insurance, and housing cost = 2.8 percent of average investment cost.

Table D.5. Costs of composting litter from Amelia and Cumberland Counties at a central location[a].

	Unit	Quantity	Cost per unit	Cost ($)
Operating cost				
Tractor (65 hp)	hour	315.20	5.10	1607.52
Composter	hour	315.20	2.50	788.00
Dump truck	hour	98.51	22.12	2179.04
Site maintenance	acre	3.00	30.00	90.00
Labor	hour	496.45	5.00	2482.26
Total operating cost				7146.82
Ownership cost[b]				
Composter				1597.96
Tractor (65 hp)				791.81
Dump truck				2964.39
Land tax				30.00
Interest on land investment				360.00
Site development investment cost				421.65
Total ownership cost				6165.81
Total cost				13312.63
Cost/ton of raw litter				1.35

[a]Assumes an annual production of 4925 tons of compost from 9851 tons of raw litter. Labor hours include a 20 percent overhead for lubricating and servicing machines, and for getting to and from the composting site.

[b]One hundred percent of the composter, 31.52 percent of tractor, and 59.00 percent of dump truck were charged to the composting operation; land was priced at $1500 per acre; interest rate was set at 8 percent; land area used for composting was 3 acres; and land tax used was equal to $10 per acre. Tractor: useful life = 12,000 hours, purchase price = $18,200, and Composter: useful life = 8 years, purchase price = $9,500. Dump truck: useful life = 2000 hours, purchase price = $28,500, and tax, insurance, and housing cost = 2.8 percent of average investment cost.

Table D.6. Costs of composting litter collected from Page, Shenandoah, and Rockingham County at a central location in Rockingham County[a].

	Unit	Quantity	Cost per unit	Cost ($)
Operating cost				
Tractor (105 hp)	hour	1358.00	9.32	12656.56
Composter	hour	1358.00	6.00	8148.00
Dump truck	hour	1358.00	22.12	30038.96
Site maintenance	acre	21.00	30.00	630.00
Labor[b]	hour	3259.20	5.00	16296.00
Total operating cost				67769.52
Ownership cost[c]				
Composter				14370.00
Tractor (105 hp)				6313.97
Dump truck				16381.80
Land tax				210.00
Interest on land investment				2520.0
Site development investment cost				2951.55
Total ownership cost				42747.32
Total cost				110,516.84
Cost/ton of raw litter				0.81

[a]Assumes an annual production of 67888 tons of compost from 135,776 tons of raw litter.
[b]Labor hours include a 20 percent ovehead to account for time lost in turning, and so on.
[c]One hundred percent of the composter, tractor and dump truck were charged to the composting operation; the dump truck was assumed to be a fixed item; land was priced at $1500 per acre; interest rate was set at 8 percent; land area used for composting was 21 acres; and land tax used was equal to $10 per acre. Tractor: useful life = 12,000 hours, purchase price = $47,046. Composter: useful life = 2 years, purchase price = $25,000, and tax, insurance, and housing cost = 2.8 percent of average investment cost.

Appendix E: Land Requirement for Large Scale Composting of Litter in Rockingham County

Scale of operation: 105,644 tons of raw litter used to make 52,822 tons of compost.

Windrow size:

width = 14 feet

height = 5 feet

Volume of a windrow = 9′x 5′x 1′ = 45 cu. ft./ft. of windrow length

Distance between 2 adjacent rows = 10 ft.

One foot of windrow length occupies = 10′ + 14′ = 24 sq. ft.

45 cu. ft./ft. length windrow = 1.67 cu.yd./ft. length windrow

24 sq. ft. area contains 1.67 cu. yd. of litter

Therefore, a sq. ft. area carries 1.67/24 = 0.06958 cu. yd. litter

Assume that 1 cu. yd. of poultry litter weighs 1400 lbs = 0.7 tons

Hence, 105,644 tons of litter = 105,644/0.7 = 150920 cu. yds.

Assume that one-third of total raw litter is always at the composting site at any given time, then volume of litter at the site is equal to

0.33 x 150920 = 49803.6 cu. yds.

Therefore, land requirement = 49803/0.06958 = 715766.02 sq. ft.

= 16 acres.

Appendix F. Feed Cost Minimization Model

The feed cost minimization model used to determine the least-cost ration including poultry litter for the Auburn system of litter feeding for cows nursing calves (first 3 to 4 months postpartum) is given below. The objective function coefficients in the model include the costs of litter acquisition, storage, and feeding for Auburn system of litter feeding.

```
// EXEC LP
//LP.SYSIN DD *
```

```
PROGRAM
INITIALZ
TITLE('FEED COST MINIMIZATION MODEL')
MOVE (XDATA,'SKMIN')
MOVE (XPBNAME,'DATA')
CONVERT ('CHECK','SUMMARY')
SETUP('MIN')
BCDOUT
PICTURE
TRANCOL
MOVE (XOBJ,'COST')
MOVE (XRHS,'RHS')
VARIFORM
SOLUTION
RANGE
EXIT
PEND
```

```
//GO.SYSIN DD *
NAME      SKMIN
ROWS
```

```
N  COST
G  DMMIN
L  DMMAX
G  NEM
G  PROTEIN
G  CALCIUM
G  PHOSPHO
L  ASFED
N  PHOACCT
G  CPMIN
L  LITMAX
G  PALLATB
```

COLUMNS

CORNG	COST	6.00	DMMIN	85.00
CORNG	DMMAX	85.00	NEM	86.70
CORNG	PROTEIN	8.50	CALCIUM	0.03
CORNG	PHOSPHO	0.34	ASFED	100.00
CORNG	PHOACCT	0.34	CPMIN	0.03
CORNG	LITMAX	-198.10	PALLATB	100.00
CORNS	COST	2.16	DMMIN	32.00
CORNS	DMMAX	32.00	NEM	22.72
CORNS	PROTEIN	2.56	CALCIUM	0.09
CORNS	PHOSPHO	0.07	ASFED	100.00
CORNS	PHOACCT	0.07	CPMIN	0.09
CORNS	LITMAX	-74.56		
POULL	COST	1.88	DMMIN	70.00
POULL	DMMAX	70.00	NEM	22.72
POULL	PROTEIN	20.80	CALCIUM	1.61
POULL	PHOSPHO	1.27	ASFED	100.00
POULL	PHOACCT	1.27	CPMIN	1.61
POULL	LITMAX	70.00	PALLATB	-15.00
SOYAM	COST	13.95	DMMIN	90.00
SOYAM	DMMAX	90.00	NEM	79.20
SOYAM	PROTEIN	45.70	CALCIUM	0.32
SOYAM	PHOSPHO	0.67	ASFED	100.00
SOYAM	PHOACCT	0.67	CPMIN	0.32
SOYAM	LITMAX	-209.70		
ALFAH	COST	5.57	DMMIN	90.00

ALFAH	DMMAX	90.00	NEM	45.90
ALFAH	PROTEIN	15.39	CALCIUM	1.13
ALFAH	PHOSPHO	0.198	ASFED	100.00
ALFAH	PHOACCT	0.198	CPMIN	1.13
ALFAH	LITMAX	-209.70		
CLOVH	CSOT	4.32	DMMIN	90.00
CLOVH	DMMAX	90.00	NEM	50.40
CLOVH	PROTEIN	13.32	CALCIUM	1.45
CLOVH	PHOSPHO	0.07	ASFED	100.00
CLOVH	PHOACCT	0.070	CPMIN	1.45
CLOVH	LITMAX	-209.70		
FESCH	COST	3.07	DMMIN	90.00
FESCH	DMMAX	90.00	NEM	54.00
FESCH	PROTEIN	9.45	CALCIUM	0.45
FESCH	PHOSPHO	0.32	ASFED	100.00
FESCH	PHOACCT	0.32	CPMIN	0.45
FESCH	LITMAX	-209.70		
ORCGH	COST	3.57	DMMIN	90.00
ORCGH	DMMAX	90.00	NEM	51.30
ORCGH	PROTEIN	9.90	CALCIUM	0.40
ORCGH	PHOSPHO	0.33	ASFED	100.00
ORCGH	PHOACCT	0.33	CPMIN	0.40
ORCGH	LITMAX	-209.70		
RYESI	COST	2.45	DMMIN	40.00
RYESI	DMMAX	40.00	NEM	22.40

RYESI	PROTEIN	5.60	CALCIUM	0.16
RYESI	PHOSPHO	0.09	ASFED	100.00
RYESI	PHOACCT	0.09	CPMIN	0.16
RYESI	LITMAX	-93.20		
MIXDH	COST	3.79	DMMIN	90.00
MIXDH	DMMAX	90.00	NEM	52.90
MIXDH	PROTEIN	10.61	CALCIUM	0.75
MIXDH	PHOSPHO	0.245	ASFED	100.00
MIXDH	PHOACCT	0.245	CPMIN	0.75
MIXDH	LITMAX	-209.70		
BARLG	COST	5.62	DMMIN	89.00
BARLG	DMMAX	89.00	NEM	86.33
BARLG	PROTEIN	11.57	CALCIUM	0.08
BARLG	PHOSPHO	0.42	ASFED	100.00
BARLG	PHOACCT	0.42	CPMIN	0.08
BARLG	LITMAX	-207.40	PALLATB	100.00

RHS

```
RHS        DMMIN      21.60
RHS        DMMAX      24.19
RHS        NEM        11.54
RHS        PROTEIN    2.00
RHS        CALCIUM    0.059
RHS        PHOSPHO    0.048
RHS        ASFED      66.00
RHS        PHOACCT    0.00
RHS        CPMIN      0.00
RHS        LITMAX     0.00
RHS        PALLATB    0.00

ENDATA
/*
//
```

Key:

COST = objective function row

CORNG = corn grain

CORNS = corn silage

POULL = poultry litter

SOYAM = soybean meal

ALFAH = alfalfa hay

CLOVH = clover hay

FESCH = fescue hay

ORCGH = orchard grass hay

RYESI = rye silage

MIXDH = mixed hay

BARLG = barley grain

PHOSP = phosphorus activity

DMMIN = minimum dry matter

DMMAX = maximum dry matter

NEM = net energy for metabolism

PROTEIN = protein

CALCIUM = calcium

PHOSPHO = phosphorus

ASFED = as fed

PHOSACCT = phosphorus accounting

LITMAX = maximum allowable litter

PALLATB = pallatibility.

Appendix G.1: Calculation of Poultry Litter Production

The poultry litter production in each litter-producing county was determined by multiplying the number of birds produced in a year by the litter yield per bird per year. Litter yield figures (tons/year) for different kinds of poultry birds are given below.

- Chicken

```
broiler      = 0.0013
pullets      = 0.0026
layers       = 0.0150
breeders     = 0.0220
breeder hens = 0.0250
```

- Turkey

```
hens        = 0.0080
toms        = 0.0100
breeders    = 0.0250
```

Source: Litter per bird coefficients for chickens and turkeys were obtained from Dr. William Weaver, and Dr. Michael Hulet, respectively, Dept. of Poultry Science, Virginia Polytechnic Institute and State University.

Appendix G.2: Dairy Manure Production and Nitrogen from Dairy Manure

Dairy manure production was obtained by multiplying the number of dairy cows as of 1987 in each litter-producing county by manure yield per year per cow. It was assumed that 70 percent of dairy manure is recoverable (Halstead, 1988). Each cow was assumed to produce 85 pounds of manure per day (Halstead, 1988). Hence, in a year a cow produces 365x85 = 31025 pounds of manure out of which 70 percent is recoverable. Therefore, the quantity of manure available from a cow in a year is equal to .70x31025 = 21717.5 pounds = 10.85 tons.

The amount of nitrogen available from dairy manure was based on the assumption that a ton of dairy manure contains an average of 10.95 pounds of total nitrogen (Halstead, 1988). It was assumed that approximately 35.43 percent of this total nitrogen occurs in inorganic form and 64.57 percent occurs in organic form of nitrogen (Halstead, 1988). Twenty five percent of inorganic nitrogen was assumed to be available to the plants in the year of manure application (Halstead, 1988). According to Willrich et al. (1974), about 50, 15, 5, and 3 percent of the organic nitrogen in dairy manure are available in the years 1, 2, 3, and 4 of dairy manure application. Assuming continuous application of dairy manure, the amount of nitrogen available in any given year is the sum of the amounts of nitrogen released in years 1, 2, 3, and 4:

1. Year 1: 0.25x3.88 + 0.50x7.07 = 4.50

2. Year 2: 0.15x7.07 = 1.06

3. Year 3: 0.05x7.07 = 0.35

4. Year 4: 0.03x7.07 = 0.21

5. Total nitrogen available = 6.12 lbs.

Appendix H: Crop Removal of Nutrients

- Wheat-soybeans rotation

  N requirement = 67 lbs/acre for wheat (Norris, 1988)

  N fixed by soybeans = 105.8 lbs/acre (Shibles et al., 1975)

  N requirement = 143 lbs/acre for soybeans (Norris, 1988)

  Wheat yield = 40 bushels/acre (Norris, 1988)

  Soybeans yield = 27 bushels/acre (Norris, 1988)

  P_2O_5 = 40 lbs/acre for wheat (Norris, 1988)

  P_2O_5 = 40 lbs/acre for soybeans (Norris, 1988)

  K_2O = 80 lbs/acre for wheat (Norris, 1988)

  K_2O = 50 lbs/acre for soybeans (Norris, 1988)

  Nitrogen from soil organic matter = 30 lbs/acre (Norris, 1988)

  Nitrogen from soybean and wheat crop residues = 14.491 bs/acre

  Net nitrogen to be added externally = 67 - 30 - 14.49 = 22.50 lbs/acre

- Tobacco-wheat rotation

  N requirement = 80 lbs/acre for tobacco (Donohue et al.,1984)

  N requirement = 67 lbs/acre for wheat (Norris, 1988)

  Tobacco leaf yield = 1200 lbs/acre (Donohue et al., 1984)

Wheat yield = 40 bushels/acre (Norris, 1988)

P_2O_5 = 40 lbs/acre for wheat (Norris, 1988)

K_2O = 80 lbs/acre for wheat (Norris, 1988)

- Corn silage-barley & wheat-alfalfa hay rotation

N requirement = 138 lbs/acre for corn silage (Norris, 1988)

= 67 lbs/acre for wheat (Norris, 1988)

= 74 lbs/acre for barley (Norris, 1988)

= 180 lbs/acre for alfalfa hay (White, 1980)

P_2O_5 = 40 lb/acre for wheat

P_2O_5 = 65 lb/acre for corn silage

P_2O_5 = 40 lb/acre for barley

P_2O_5 = 65 lb/acre for alfalfa (White, 1980)

K_2O = 80 lbs/acre for wheat (Norris, 1988)

K_2O = 80 lbs/acre for barley (Norris, 1988)

K_2O = 150 lbs/acre for barley (White, 1980)

N requirement (net of N from soil organic matter and crop residues) to be added externally = 43.19 lbs/acre of rotation

- Corn silage-barley-alfalfa hay rotation

N requirement = 138 lbs/acre for corn silage (Norris, 1988)

= 74 lbs/acre for barley (Norris, 1988)

= 180 lbs/acre for alfalfa hay (White, 1980)

N requirement (net of N available from crop residues and soil organic matter) to be added externally = 43.19 lbs/acre of rotation

- Corn silage-soybeans rotation

N requirement = 138 lbs/acre for corn silage (Norris, 1988)

= 143 lbs/acre for soybeans (Norris, 1988)

P_2O_5 = 50 lb/acre for corn silage (Norris, 1988)

P_2O_5 = 40 lb/acre for soybeans (Norris, 1988)

K_2O = 60 lbs/acre for corn silage

K_2O = 50 lbs/acre for soybeans

N to be added externally net of N from crop residues and soil organic matter = 49.86.

- Corn grain-barley-soybeans rotation

  Corn grain yield = 88 bushels/acre

  Barley grain yield = 52 bushels/acre

  Soybean yield = 27 bushels/acre

  N requirement = 120.96 lbs/acre for corn grain

  = 64.32 lbs/acre for barley

  = 148.5 lbs/acre for soybeans

- Corn silage-wheat rotation

  N requirement = 137 lbs/acre for corn silage

  = 67 lbs/acre for wheat

- Continuous corn grain rotation: N requirement = 138 lbs/acre

  P_2O_5 = 50 lbs/acre for corn grain (West Central Budget, 1989)

  K_2O = 70 lbs/acre for corn grain (West Central Budget, 1989)

  N available from organic matter = 30 lbs/acre

  N available from crop residues = 11.04 lbs/acre

  Net N to be added externally = 96.96 lbs/acre

- Continuous corn silage rotation: N requirement = 138 lbs/acre

  P_2O_5 = 65 lbs/acre for corn silage (West Central Budget, 1989)

  K_2O = 100 lbs/acre for corn silage (West Central Budget, 1989)

N available from organic matter = 30 lbs/acre

N available from crop residues = 0.00 lbs/acre

Net N to be added externally = 108 lbs/acre

- Corn silage-barley grain rotation

  Barley grain yield = 52 bushels (1988)

  N requirement = 138 lbs/acre for corn silage (Norris, 1988)

  = 64.31 lbs/acre for barley

  P_2O_5 = 65 lbs/acre for corn silage (West Central Budget, 1989)

  K_2O = 100 lbs/acre for corn silage (West Central Budget, 1989)

  P_2O_5 = 34.67 lbs/acre for barley

  K_2O = 69.33 lbs/acre for barley

- Corn silage-rye silage rotation: N requirement = 138 lbs/acre for corn silage

Appendix I. Litter Marketing Cost Minimization Model.

```
// EXEC LP
//LP.SYSIN DD *
```

```
PROGRAM
INITIALZ
TITLE('LITTER MARKETING COST MINIMIZATION MODEL')
MOVE (XDATA,'SKMIN')
MOVE (XPBNAME,'DATA')
CONVERT ('CHECK','SUMMARY')
SETUP('MIN')
BCDOUT
PICTURE
TRANCOL
MOVE (XOBJ,'COST')
MOVE (XRHS,'RHS')
VARIFORM
SOLUTION
RANGE
EXIT
PEND
```

```
//GO.SYSIN DD *
NAME     SKMIN
ROWS
```

```
N  COST
L  AMELIA
L  CUMBERL
L  PAGE
L  ROCKING
L  SHENAND
L  ESSEX
L  GLOUCES
L  KINGGEO
L  K&QUEEN
L  KWILLIA
L  LANCAST
L  MATHEWS
L  MIDDLES
L  NORTHUM
L  RICHMON
L  WESTMOR
G  NORNECK
```

COLUMNS

AMELESSR	COST	22.13	AMELIA	1.0
AMELESSR	ESSEX	42.10	NORNECK	42.10
AMELGLOR	COST	23.88	AMELIA	1.0
AMELGLOR	GLOUCES	42.10	NORNECK	42.10
AMELKGER	COST	22.14	AMELIA	1.0
AMELKGER	KINGGEO	42.10	NORNECK	42.10
AMELK&QR	COST	22.29	AMELIA	1.0
AMELK&QR	K&QUEEN	42.10	NORNECK	42.10
AMELKWIR	COST	20.69	AMELIA	1.0
AMELKWIR	KWILLIA	42.10	NORNECK	42.10
AMELLANR	COST	25.49	AMELIA	1.0
AMELLANR	LANCAST	42.10	NORNECK	42.10
AMELMATR	COST	25.68	AMELIA	1.0
AMELMATR	MATHEWS	42.10	NORNECK	42.10
AMELMIDR	COST	23.22	AMELIA	1.0
AMELMIDR	MIDDLES	42.10	NORNECK	42.10
AMELNORR	COST	25.19	AMELIA	1.0
AMELNORR	NORTHUM	42.10	NORNECK	42.10
AMELRICR	COST	22.79	AMELIA	1.0
AMELRICR	RICHMON	42.10	NORNECK	42.10
AMELWESR	COST	24.09	AMELIA	1.0
AMELWESR	WESTMOR	42.10	NORNECK	42.10
CUMBESSR	COST	22.49	CUMBERL	1.0
CUMBESSR	ESSEX	42.10	NORNECK	42.10

CUMBGLOR	COST	23.81	CUMBERL	1.0
CUMBGLOR	GLOUCES	42.10	NORNECK	42.10
CUMBKGER	COST	23.54	CUMBERL	1.0
CUMBKGER	KINGGEO	42.10	NORNECK	42.10
CUMBK&QR	COST	22.65	CUMBERL	1.0
CUMBK&QR	K&QUEEN	42.10	NORNECK	42.10
CUMBKWIR	COST	21.05	CUMBERL	1.0
CUMBKWIR	KWILLIA	42.10	NORNECK	42.10
CUMBLANR	COST	26.55	CUMBERL	1.0
CUMBLANR	LANCAST	42.10	NORNECK	42.10
CUMBMATR	COST	25.51	CUMBERL	1.0
CUMBMATR	MATHEWS	42.10	NORNECK	42.10
CUMBMIDR	COST	23.15	CUMBERL	1.0
CUMBMIDR	MIDDLES	42.10	NORNECK	42.10
CUMBNORR	COST	26.15	CUMBERL	1.0
CUMBNORR	NORTHUM	42.10	NORNECK	42.10
CUMBRICR	COST	23.75	CUMBERL	1.0
CUMBRICR	RICHMON	42.10	NORNECK	42.10
CUMBWESR	COST	25.05	CUMBERL	1.0
CUMBWESR	WESTMOR	42.10	NORNECK	42.10
PAGEESSR	COST	32.52	PAGE	1.0
PAGEESSR	ESSEX	42.10	NORNECK	42.10
PAGEGLOR	COST	35.37	PAGE	1.0
PAGEGLOR	GLOUCES	42.10	NORNECK	42.10

PAGEKGER	COST	20.89	PAGE	1.0
PAGEKGER	KINGGEO	42.10	NORNECK	42.10
PAGEK&QR	COST	32.68	PAGE	1.0
PAGEK&QR	K&QUEEN	42.10	NORNECK	42.10
PAGEKWIR	COST	32.28	PAGE	1.0
PAGEKWIR	KWILLIA	42.10	NORNECK	42.10
PAGELANR	COST	27.07	PAGE	1.0
PAGELANR	LANCAST	42.10	NORNECK	42.10
PAGEMATR	COST	36.37	PAGE	1.0
PAGEMATR	MATHEWS	42.10	NORNECK	42.10
PAGEMIDR	COST	33.61	PAGE	1.0
PAGEMIDR	MIDDLES	42.10	NORNECK	42.10
PAGENORR	COST	26.91	PAGE	1.0
PAGENORR	NORTHUM	42.10	NORNECK	42.10
PAGERICR	COST	24.85	PAGE	1.0
PAGERICR	RICHMON	42.10	NORNECK	42.10
PAGEWESR	COST	23.55	PAGE	1.0
PAGEWESR	WESTMOR	42.10	NORNECK	42.10
ROCKESSR	COST	29.29	ROCKING	1.0
ROCKESSR	ESSEX	42.10	NORNECK	42.10
ROCKGLOR	COST	32.14	ROCKING	1.0
ROCKGLOR	GLOUCES	42.10	NORNECK	42.10
ROCKKGER	COST	24.10	ROCKING	1.0
ROCKKGER	KINGGEO	42.10	NORNECK	42.10

ROCKK&QR	COST	30.53	ROCKING	1.0
ROCKK&QR	K&QUEEN	42.10	NORNECK	42.10
ROCKKWIR	COST	28.23	ROCKING	1.0
ROCKKWIR	KWILLIA	42.10	NORNECK	42.10
ROCKLANR	COST	30.28	ROCKING	1.0
ROCKLANR	LANCAST	42.10	NORNECK	42.10
ROCKMATR	COST	33.14	ROCKING	1.0
ROCKMATR	MATHEWS	42.10	NORNECK	42.10
ROCKMIDR	COST	30.38	ROCKING	1.0
ROCKMIDR	MIDDLES	42.10	NORNECK	42.10
ROCKNORR	COST	30.12	ROCKING	1.0
ROCKNORR	NORTHUM	42.10	NORNECK	42.10
ROCKRICR	COST	28.06	ROCKING	1.0
ROCKRICR	RICHMON	42.10	NORNECK	42.10
ROCKWESR	COST	26.76	ROCKING	1.0
ROCKWESR	WESTMOR	42.10	NORNECK	42.10

SHENESSR	COST	32.89	SHENAND	1.0
SHENESSR	ESSEX	42.10	NORNECK	42.10
SHENGLOR	COST	35.74	SHENAND	1.0
SHENGLOR	GLOUCES	42.10	NORNECK	42.10
SHENKGER	COST	24.14	SHENAND	1.0
SHENKGER	KINGGEO	42.10	NORNECK	42.10
SHENK&QR	COST	33.05	SHENAND	1.0
SHENK&QR	K&QUEEN	42.10	NORNECK	42.10

SHENKWIR	COST	32.65	SHENAND	1.0
SHENKWIR	KWILLIA	42.10	NORNECK	42.10
SHENLANR	COST	30.32	SHENAND	1.0
SHENLANR	LANCAST	42.10	NORNECK	42.10
SHENMATR	COST	36.74	SHENAND	1.0
SHENMATR	MATHEWS	42.10	NORNECK	42.10
SHENMIDR	COST	33.98	SHENAND	1.0
SHENMIDR	MIDDLES	42.10	NORNECK	42.10
SHENNORR	COST	30.16	SHENAND	1.0
SHENNORR	NORTHUM	42.10	NORNECK	42.10
SHENRICR	COST	28.10	SHENAND	1.0
SHENRICR	RICHMON	42.10	NORNECK	42.10
SHENWESR	COST	26.80	SHENAND	1.0
SHENWESR	WESTMOR	42.10	NORNECK	42.10

RHS

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    RHS       AMELIA     3076.0
    RHS       CUMBERL    6775.0
    RHS       PAGE       23066.0
    RHS       ROCKING    105644.0
    RHS       SHENAND    7066.0

    RHS       ESSEX      1598765.0
    RHS       GLOUCES    511931.0
    RHS       KINGGEO    425006.0
    RHS       K&QUEEN    1318492.0
    RHS       KWILLIA    1224327.0
    RHS       LANCAST    433135.0
    RHS       MATHEWS    141200.0
    RHS       MIDDLES    483898.0
    RHS       NORTHUM    1467093.0
    RHS       RICHMON    996758.0
    RHS       WESTMOR    1427178.0

    RHS       NORNECK    6130896.7

ENDATA
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Key:

COST = objective function row

AMELIA = Amelia County

CUMBERL = Cumberland County

PAGE = Page County

ROCKING = Rockingham County

SHENAND = Shenandoah County

ESSEX = Essex County

GLOUCES = Gloucester County

KINGGEO = King George County

K&QUEEN = King and Queen County

KWILLIA = King William County

LANCAST = Lancaster County

MATHEWS = Mathews County

MIDDLES = Middlesex County

NORTHUM = Northumberland County

RICHMON = Richmond County

WESTMOR = Westmoreland County

NORNECK = Northern Neck regional total demand

Column names were constructed by combining the first four letters of each litter-surplus county name and the first three letters of the litter-deficit county name suffixed by R to indicate movement of raw litter. For example, AMELESSR represents the activity of moving raw litter from litter-surplus county, Amelia, to litter-deficit county, Essex. SHENWESR represents movement of raw litter from the litter-surplus county, Shenandoah, to litter-deficit county, Westmoreland.

Appendix J. Distribution of Amounts of Litter for Base Case

Table J.1. Tons of raw litter moved from surplus to deficit counties for the base case for the model with the regional total nitrogen demand constraint.

From litter surplus county	To litter deficit county	Tons of raw litter moved
Amelia	King & Queen	3,076
Cumberland	King & Queen	6,775
Page	Northumberland	1,048
Page	Westmoreland	22,018
Rockingham	Essex	37,951
Rockingham	King George	3,029
Rockingham	King William	29,081
Rockingham	Richmond	23,676
Rockingham	Westmoreland	11,882
Shenandoah	King George	7,066
Total		145,627

Table J.2. Tons of composted litter moved from surplus to deficit counties for the base case for the model with the regional total nitrogen demand constraint.

From litter surplus county	To litter deficit county	Tons of composted litter moved[a]
Amelia	King William	3,076
Cumberland	King William	6,775
Page	King George	14,580
Page	Westmoreland	8486
Rockingham	Essex	5892
Rockingham	King William	32,150
Rockingham	Richmond	34,194
Rockingham	Westmoreland	33,408
Shenandoah	Westmoreland	7,066
Total		145,627

[a]Tons of composted litter are expressed in tons of raw litter equivalent.

Appendix K. Calculation of Weighted Average Distances.

The weighted average distance from poultry operations to the county seat of Rockingham County was obtained by weighting the distance from each sub-region to the county seat by the proportion of poultry litter produced in each sub-region. Hence, the weighted average distance of litter collection for Rockingham County is:

$= 6 \times 0.35 + 8 \times 0.17 + 18 \times 0.07 + 7 \times 0.21 + 16 \times 0.17 + 24 \times 0.02$

$= 9.40$ miles

Since there was no information about the distribution of poultry operations in other counties, the weighted average collection distance for Rockingham County was used to derive the weighted average distances for other counties by using the geographic area of each county as a weight to adjust the weighted average distance for Rockingham County. For example, land area in Rockingham, Shenandoah, Page, Amelia, and Cumberland counties were 865, 512, 313, 357, and 300 square miles (Spar, 1989). The weighted average collection distance for each of the other four surplus counties are obtained as follows:

Amelia = 9.4 x 357/865 = 3.88 miles,

Cumberland = 9.4 x 300/865 = 3.26 miles,

Page = 9.4 x 313/865 = 3.40 miles, and

Shenandoah = 9.4 x 512/865 = 5.56 miles.

The raw litter collection distance from Shenandoah County to Rockingham County was estimated to be 37 miles. The raw litter collection distance from Page County to Rockingham County was estimated to be 25 miles. The raw litter collection distance from Cumberland County to the border between Amelia and Cumberland counties was estimated to be 15.26 miles. Finally, the raw litter collection distance from Amelia County to the border between Amelia and Cumberland counties was estimated to be 27.88 miles.

Vita

Krishna Bahadur Napit was born in the village of Bode, Bishnu Gha Tole, Bhaktapur District in Nepal. He went to Demonstration Multi-Purpose High School, Sano Thimi, Nepal and graduated with distinction. He went to Amrit Science Campus, Tribhuban University in Nepal for Certificate Level in Science and passed with merit. After graduation he went to G. B. Pant University of Agriculture and Technology, Pantnagar, India for B. Sc. Agri. & Animal Science under a USAID scholarship and graduated with honors in 1979. Upon returning to Nepal, he taught Principles of Economics at the Institute of Agriculture and Animal Science, Tribhuvan University, Nepal for a year. Then he worked for four years for the Department of Agriculture, His Majesty's Government of Nepal as an Extension Agent in a Salyan district which was one of the five districts in the Rapti Integrated Rural Development Project Area. In 1984, he received Fulbright scholarship to pursue masters program in agricultural economics at Virginia Polytechnic Institute and State University to begin his masters program in agricultural economics. He completed his M. S. in 1986 and continued to pursue his Ph.D. degree in agricultural economics which he completed in 1990.

Krishna Bahadur Napit