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Optimal Poultry Litter Management through GIS-based Transportation Analysis System

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Abstract

Concentrated poultry production in the State of Alabama, U.S.A. results in excessive poultry litter. Application of poultry litter to pastures and row crops serves as a cheap alternative to commercial fertilizer. However, over the years, poultry litter application to perennial forage crops in the Appalachian Plateau region of North Alabama has resulted in phosphorus (P) buildup in soils. Phosphorus index (P-index) and comprehensive nutrient management plans (CNMP) are often used as a best management practice (BMP) for proper land application of litter. Because nutrient management planning is often not done for small animal feeding operations (AFOs), and also because, in case of excess litter, litter transportation infrastructure has not been developed, over application of poultry litter to near by area is a common practice. To alleviate this problem, optimal poultry litter management and transportation infrastructure needs to be developed. This paper presents a methodology to optimize poultry litter application and transportation through efficient nutrient management planning and transportation network analysis. The goal was accomplished through implementation of three important modules, a P-Index module, a CNMP module, and a transportation network analysis module within ArcGIS, a Geographic Information System (GIS). The CNMP and P-Index modules assist with land application of poultry litter at a rate that is protective of water quality, while the transportation network analysis module helps transport excess litter to areas requiring litter in the Appalachian Plateau and Black Belt (a nutrient-deficient area) regions. Once fully developed and implemented, such a system will help alleviate water quality problems in the Appalachian Plateau region and poor soil fertility problems in the Black Belt region by optimizing land application and transportation. The utility of the methodology is illustrated through a hypothetical case study.

Keywords : Poultry litter, Broiler litter, Nutrient management, Network analysis, Geographic information system, Transportation, Optimization.

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I. Introduction

Broiler litter (referred to as poultry litter hereafter) is a mixture of chicken manure with either wood shavings, peanut (*Arachis hypogaea L.*) hulls, rice (*Oryza sativa L.*) hulls, or some other bedding material (Moore, 1998; Mitchell and Tu, 2005). Even though litter management has previously been regarded as a disposal problem, it can now be regarded as a challenge for appropriate management and utilization (Naber and Burmerster, 1998). Poultry litter is an excellent fertilizer, acting as a source of nitrogen (N), phosphorus (P), and potassium (K). Poultry litter application also increases the organic matter content of soil and improves soil quality. Unfortunately, improper litter disposal and excessive application to agricultural land can adversely impact surface and ground water quality.

Alabama poultry farmers produce more than 1.7 million tons of manure and litter every year (ACES, 1995). In the Appalachian Plateau region of North Alabama, where most of the poultry industry is located, the fast growing poultry industry produces enormous amount of poultry litter annually that must be disposed off and/or utilized in a timely and environmentally safe manner (Bukenya et al., 1999). It is estimated that the nutrients available in litter can adequately fertilize every acre of corn, cotton, wheat, and sorghum produced in Alabama, or about 800,000 acres of bermuda or fescue pasture. A comprehensive nutrient management plan (CNMP) is usually used to encourage, through regulation and education, the implementation of appropriate storage, transportation, and land application of poultry litter. Alabama's 1999 Animal Feeding Operation (AFO)/Concentrated Feeding Operation (CAFO) rules (ADEM, 1999) under USEPA's (United States Environmental Protection Agency) NPDES (National Point Discharge Elimination Systems) permitting process requires only CAFOs to register and file a CNMP. Because nutrient management planning is often not done for AFOs, and also because, in case of excess litter, litter transportation infrastructure has not been developed, over application of poultry litter to near by area is a common practice. Because of the water quality issues associated with the massive amount of litter produced each year, the sustainability of the poultry industry in the Appalachian Plateau region is threatened. At the same time, in another part of the state, the Black Belt region, depressed agricultural economy stems from poor soil fertility in pastures, hayfields, and row crops. To achieve an optimal poultry litter management in Alabama, poultry litter produced in the concentrated production areas within the Appalachian Plateau region must be optimally distributed and land applied in this region or should be transported south for utilization in the Black Belt region.

The use of geographic information system (GIS) for transportation planning is one of the most important and rapidly growing applications of GIS (Miller and Shaw, 2001). ArcGIS Network Analyst (ESRI, 2005) for optimal transportation analysis is a powerful extension of the popular ArcGIS software that provides network-based spatial analysis including routing, travel directions, closest facility, and service area analysis. Using a sophisticated network data model, users can easily build networks from their GIS data with the ArcGIS Network Analyst. Applying this tool to the current problem will not only help sustain and enhance poultry industry in the Appalachian Plateau region, but will also help row crop agriculture to grow in the Black Belt region.

Recent research with poultry litter has focused on the environmental implications of excessive nutrients (Kingery et al., 1994; Ritter, 2000; Cabrera and Sims, 2000) and on the value of poultry litter as a fertilizer (Mitchell and Donald, 1995; Bukenya et al., 1999; Bagley and Evans, 1998; McKinley et al., 2000; Binford et al., 2001). Studies related to transportation network analysis have been mostly limited to urban transportation. For example, applications and research based on GIS for transportation include multi-dimensional transportation applications (Koncz and Adams, 2002), optimal urban rail transit corridor identification (Verma and Dhingra, 2005), multi-jurisdictional transportation analysis (Han et al., 2003), optimal routes selection models for agricultural products (Suh et al., 2004), and a geographic multimodal transportation network analysis for freight transportation demand elasticities (Beuthe et al., 2001). Examples that apply GIS-based transportation analysis for poultry litter management are less common, if not nonexistent.

The goal of this paper is to present a methodology for optimal management of poultry litter through comprehensive nutrient management planning and through transportation of excess poultry litter. Through a case study the paper illustrates how such a methodology can be implemented within an ArcGIS system. Once such a methodology is fully implemented, it will provide a comprehensive system to CAFOs/AFOs for cost-effective and environmentally-sound management of poultry litter.

Ⅱ. Optimal Poultry Litter Modeling

The system architecture for proposed system is shown in Fig. 1. This system has three

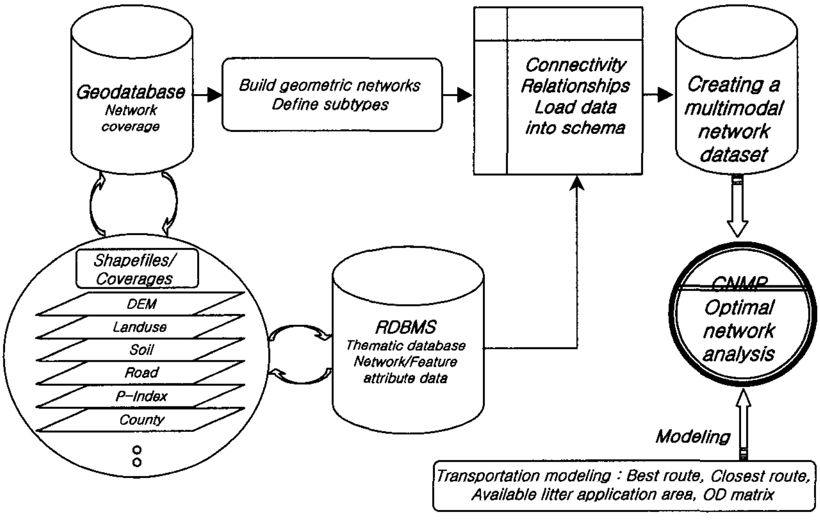

Fig. 1 A conceptual diagram showing the system architecture.

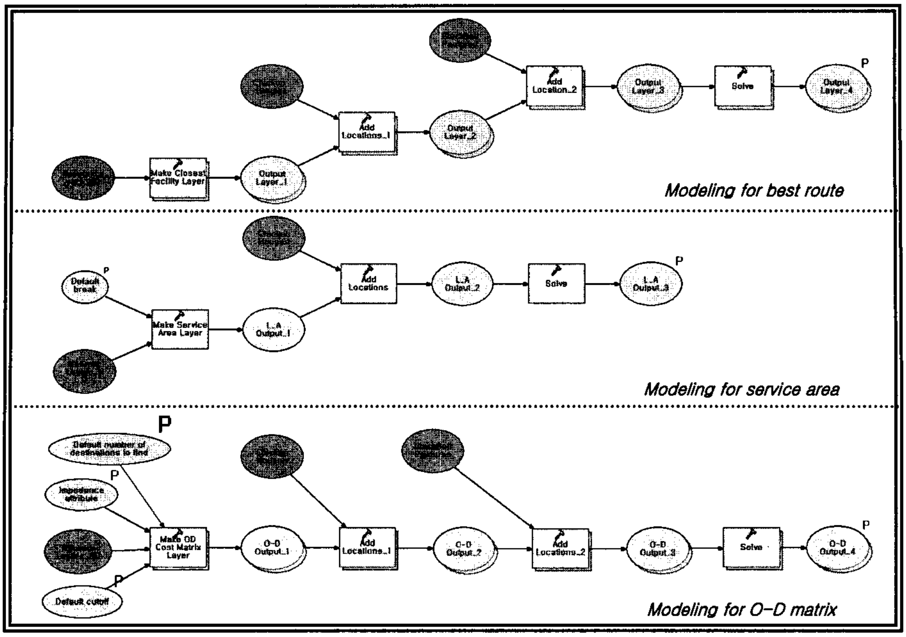

Fig. 2 Conceptual workflow for modeling various transportation network analyses using the ArcGIS NetworkModel.

important subsystems: the P-index, the CNMP module, and the transportation network analysis models. The geodatabase is the heart of spatial and operational information system and provides the central storage system that allows communication and intermediate storage among the various subsystems. This geodatabase, similar to the coverage model, supports a model of topologically integrated feature classes. It also extends the coverage model to support complex networks, topologies, relationships among feature classes, and other object-oriented features.

1. Transportation Analysis System

The model used for the transportation network analysis was created utilizing the NetworkModel toolbox in ArcGIS 9.1. The workflow used by Network Analyst in a model is the same as the workflow for Network Analyst in ArcMap. Models used to identify the optimum route, the closest route, land application boundary, and Origin-Destination (O-D) matrix using the ArcGIS NetworkModel is shown in Fig. 2.

2. Phosphorus Index (P-Index)

The P Index is a tool that is used to assess the site and management practices with regard to the potential risk posed by phosphorus movement to water bodies (USDA-NRCS, 2001). The ranking given by the P Index identifies fields where the risk of phosphorus movement is relatively higher than that of other sites.

The P Index uses specific field features and management practices to obtain an overall rating for each field (USDA-NRCS, 2001). Assigned to each of the field features and management practices (a total of eleven parameters) are weighted factors of 1, 2, or 3. Also, assigned to each of the field features and management practices are value rating of very low/low (0 points), medium (1 point), high (2 points), very high (4 points), and extremely high (8 points). Based on the summation of the points, which multiplies the weighed factor by the value rating, the field will fall into an overall category rating of very low/low, medium, high, very high, or extremely high (Table 1).

The planned P rate cannot exceed the P appli-

Table 1 Alabama phosphorus index, field vulnerability for phosphorus loss and P application rate according to P Index rating (USDA-NRCS, 2001; Mitchell and Tyson, 2000).

Item	Weight	Field feature and management practices value ratings				
		Very low/ Low (0 point)	Medium (1 point)	High (2 points)	Very high (4 points)	Extremely high (8 points)
(1)	1	Very low/Low	Medium	High	Very high	Extremely high
(2)	3	None applied	〈 60	60 - 120	120 - 180	〉 180
(3)	3	None applied	Injected deeper than 2"	Incorporated immediate ly or sprinkler applied	Surface applied & incorporated 〈 30 days	Surface applied, not incorporated
(4)	1	None	No access to water and/or not fed in sensitive area	Restricted access to water and/or not fed in sensitive area	Unlimited access to water and/or fed in sensitive area 〈 100 animals	Unlimited access to water and/or fed in sensitive area 〉 100 animals
(5)	3	None	Outlets empty onto at least 30 ft of grass filter strip	Outlets empty into grass waterway	〈30% of field has outlets emptying into drainage ways or waterbodies	〉 30% of field has outlets emptying into drainage ways or waterbodies
(6)	3	〈 3	3 - 5	5 - 10	10 - 15	〉 15
(7)	3	-	A	B	C	D
(8)	1	〈 1	1 - 3	3 - 5	5 - 8	〉 8
(9)	3	〉 400	200 - 400	100 - 200	50 - 100	〈 50
(10)	2	≥ 50	30 - 49	20 - 29	10 - 19	〈 10
(11)	3	Field not in watershed	〉 400	200 - 400	100 - 200	〈 100

Field vulnerability for phosphorus loss (Summation of the points multiplied the weighted factor by P Index rating)					
Total points from P Index	≤65	66 to 75	76 to 85	86 to 95	≥95
Generalized interpretation of P Index	Very low/Low	Medium	High	Very high	Extremely high
Basis of P application rate according to P Index rating	Nitrogen rate	3×P removal by crop	2×P removal by crop	1×P removal by crop	No application

Notes: (1) soil test P value, (2) P application rate (lbs. P_2O_5/ac/yr), (3) nutrient application method, (4) grazing animals, (5) underground outlet systems, (6) erosion rate (tons/ac/yr), (7) hydrologic soil group, (8) field slope (%), (9) P application distance to water (ft), (10) filter strip width (ft), and (12) impaired, outstanding, or critical habitat waters.

cation rate used in calculating the P Index. The use of the P Index should result in more rational, low cost efforts to minimize the impact of intensive agriculture on water quality. This rating is used to determine the specified areas (e.g., pastures) that should benefit and the poultry litter rates that should be applied. Nutrients are applied based on nitrogen limit and anticipated crop P removal (Table 1).

3. Comprehensive Nutrient Management Plan (CNMP)

The CNMP is based on the nutrient management planning developed by the Alabama Cooperative Extension System (Mitchell and Tyson, 2000). Since AFOs are not required by regulations to have CNMPs developed, the Certified Animal Waste Vendors (CAWVs) and AFO owners/operators are often not interested in the most comprehensive plan; they are more interested in simple plans that work. It is a simple nutrient management plan that "meets or exceeds" United State Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) nutrient management standards for the owner/operator of a poultry facility. A good nutrient management program optimizes crop production and protects water quality.

All animal feeding operators are required by federal and Alabama laws and ADEM regulations to follow all best management practices (BMPs) that are relevant, regardless of AFO/CAFO designation. However, limited technical staff available at County Conservation District Offices is able to only develop P-Index/CNMPs for CAFOs, and owners/operators of more than 4,000 AFOs do not get any assistance. To reduce this problem, the P-Index/CNMP module allows AFO owners/operators and CAWVs to develop P-Index and/or NMP for small farms.

A BMP blueprint that is applicable to all sizes of AFOs, CNMP is one way to help meet the USDA-NRCS technical standards and guidelines. According to ACES, the plan can be developed in five easy steps: 1) estimate poultry litter and compost production, 2) determine the nutrient value of the poultry litter and compost, 3) map and calculate the land area for spreading, 4) determine the target crop and nutrient needs, and 5) determine uses for excess litter/compost production and CAWV needs.

Ⅲ. Case Study

To demonstrate how the system being developed can be used to address excess poultry litter problem in the Appalachian Plateau region of North Alabama, we present a hypothetical case study. Based on the vulnerability of P loss from a field (Table 1), four different scenarios can be used as land application of poultry litter. These scenarios are:

Scenario 1: Nitrogen limit. This scenario assumes that P Index rating is very low/low. In this scenario, poultry litter is applied based on the N recommended for the crop to be grown.

Scenario 2: 3×P removal by crop. This scenario assumes that P Index rating is Medium. P application at the rate of three times P removal by crop is allowed.

Scenario 3: 2×P removal by crop. This scenario assumes that P Index rating is High. P application at the rate of two times P removal by crop is allowed.

Scenario 4: 1×P removal by crop. This scenario assumes that P Index rating is Very high. P application at the rate of one time P removal by crop is allowed.

In this case study, it was assumed that chicken houses producing poultry litter in the four major poultry producing counties can be represented by just one location in the center of each county. Further, it was assumed that the excess litter produced by each county cannot be land-applied in the Appalachian Plateau region and needs be transported and land-applied to thirteen major pastures in the Black Belt region of South Alabama.

In order to identify the amount of poultry litter produced in each county, the poultry data for each county were obtained from the National Agricultural Statistics Service (USDA-NASS, 2005). Cullman was the leading poultry county in the state, followed by DeKalb, Marshall, and Blount during the 2003 and 2004 marketing years. Thus, these top 4 leading counties, with about 400 million birds in poultry production, were used in this case study as the poultry production area. The chicken house layer was created as a point geodatabase. Forage pastures were selected for poultry litter application in the Black Belt region.

1. Available Nutrients and Nutrient Needs

In order to develop the CNMP, poultry litter and compost production was estimated for the selected counties (Table 2). According to the reports by USDA-NASS (2005), the total number of broilers produced from Alabama's four leading poultry counties was a total of 391 million birds in 2004 (Table 2). From these four counties, the total compost and actual poultry litter available for on-farm land application were 52,140 and 346,888 ton, respectively.

The nutrient values of poultry litter and compost for each county are also shown in Table 2. According to Bukenya et al. (1999), the economic value of the poultry litter produced in Alabama was estimated at about $30 million.

For each scenario, nutrient needs for each pasture in the Black Belt region were calculated based on the nitrogen limits suggested by soil test recommendations from Auburn University's Soil Testing Laboratory (Adams and Mitchell,

Table 2 Poultry, poultry litter, and compost production in four leading poultry producing counties in Alabama in 2004.

County	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cullman	165,160	168,559	7,866	19,665	22,025	146,534	420 - 579 - 450	3,124 - 3,855 - 2,991
Dekalb	107,160	109,366	5,104	12,759	14,290	95,075	272 - 376 - 292	2,027 - 2501 - 1,914
Marshall	64,204	65,526	3,058	7,645	8,562	56,964	163 - 225 - 175	1,214 - 1,499 - 1,163
Blount	54,456	55,577	2,594	6,484	7,262	48,315	138 - 191 - 148	1,030 - 1,271 - 986
Sum	390,980	399,028	18,621	46,553	52,140	346,888	993 - 1,372 - 1,064	7,395 - 9,126 - 7,081

Notes: (1) birds produced (thousand), (2) total poultry litter (ton), (3) dead bird weight (ton), (4) litter needed to compost dead birds (ton), (5) total compost produced (ton), (6) actual poultry litter (ton), (7) available nutrients in compost, N-P_2O_5-K_2O (ton), and (8) available nutrients in poultry litter, N-P_2O_5-K_2O (ton).

2000) and anticipated crop P removal (Table 3). The total area of all pasture land was 48,354 ha, with individual pastures ranging from 1,572 to 10,880 ha. The total amount of poultry litter calculated from nutrient needs increases as P-Index changes from "very high (Scenario 4)" to "very low/low (Scenario 1)". In the case of Scenarios 1 through 4, the total amounts of poultry litter required were 142,239, 74,161, 49,440, and 24,720 tons, respectively. Dead bird compost was not considered for land application in the Black Belt region because farmers are required to use the dead bird compost on the farm where it is generated before spreading any litter.

Table 3 Poultry litter need (tons) for each field in the Black Belt region for various Scenarios.

Field number	Pasture area (ha)	Scenario 1	Scenario 2	Scenario 3	Scenario 4
0	3,431	10,093	5,262	3,508	1,754
1	3,320	9,766	5,092	3,395	1,697
2	2,925	8,604	4,486	2,991	1,495
3	1,677	4,933	2,572	1,715	857
4	2,218	6,525	3,402	2,268	1,134
5	5,358	15,761	8,218	5,478	2,739
6	3,558	10,466	5,457	3,638	1,819
7	10,880	32,005	16,687	11,124	5,562
8	2,673	7,863	4,100	2,733	1,367
9	1,572	4,624	2,411	1,607	804
10	3,700	10,884	5,675	3,783	1,892
11	3,589	10,557	5,504	3,670	1,835
12	1,755	5,163	2,692	1,794	897
13	1,698	4,995	2,604	1,736	868
Sum	48,354	142,239	74,161	49,440	24,720
(%)*		41	21	14	7

Note: *means proportion of actual poultry litter produced in four counties that can be applied to pastures in the Black Belt region.

2. Network Analysis for Transportation

Closest Facility in this study consists of the closest pasture that can be use to land-apply litter from a chicken house at a given place. It also generates the fastest route from each of the chicken houses that will be provided to each driver (distance cost). Fig. 3 shows the route of the closest land application area (Black Belt region) from each of the chicken houses. The cutoff value (distance cost) was set at 200 miles. The number of land application areas to find was a single pasture. As shown in Fig. 3, the closest pastures from each chicken house suitable for the application of poultry litter were pasture ID 2 for Cullman, Marshall, and Blount and pasture ID 8 for DeKalb. The longest travel distance among the closest routes was from DeKalb to pasture ID 8, with a value of 167 miles. The shortest was from Blount to pasture ID 2 with a value of 125 miles.

The feasible area for the application of poultry litter can also be created using a series of polygons representing the distance that can be reached from a chicken house that is within a specified amount of cost based on travel distance. Fig. 3 shows the results based on calculation of 50 miles, 100 miles, and 200 miles service area polygons for each of the chicken houses, which can reveal how many land application locations (pastures) lie within each of these areas. This can also be used to determine how best to relocate the least accessible chicken houses or place new ones to facilitate land application of the poultry litter produced. In the case of Cullman county, for examples, pastures ID 0, 2, 3, 5, 6, 7, 9, and 10 could be economically be supplied

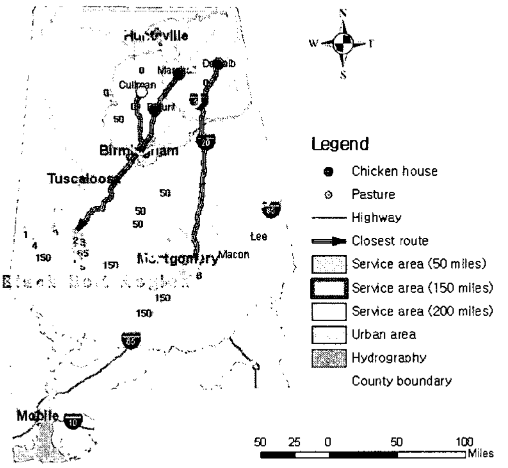

Fig. 3 Closest route from each chicken house to a pasture within the 200 miles cutoff and the available area polygons for the economic supply of poultry litter.

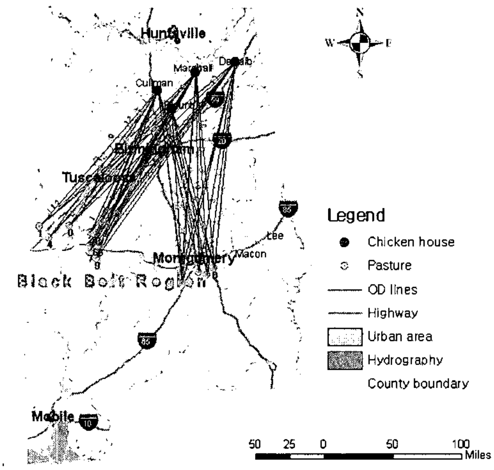

Fig. 4 Origin-Destination (O-D) matrix with a cut-off value of 200 miles.

with poultry litter given a distance of 150 miles.

An Origin-Destination (O-D) cost matrix was created to illustrate deliveries from the chicken houses to each pasture. The results of this matrix can be used to identify the land application areas that will be serviced by each chicken house within a specific travel distance. Also, it determines the total travel distance from each chicken house to its land application pastures. Fig. 4 shows the Origin-Destination route layer. The O-D cost matrix was calculated based on travel distance in this study using a cutoff value of 200 miles. The number of lines in this study was 55 because the distance from DeKalb to pasture ID 4 was over the cutoff value of 200 miles, ensuring that all destinations were within the specified cutoff distance. The parameter for the destination (land application area) to find was the set of all pastures in the Black Belt region. The output shape type was selected to be a straight line.

Table 4 shows the ranking according to travel distance representing the O-D cost matrix from each of the chicken houses in the selected counties to pastures within a 200 miles travel distance in the Black Belt region. Travel distances according to destination range from 125 to 149 miles for Blount county chicken house to 167 to 200 miles for DeKalb chicken house.

3. Optimal Management of Poultry Litter

For the comprehensive nutrient management plan for poultry litter, the optimal transportation for land application and value of poultry litter were estimated based on the results of O-D matrix analysis (Table 5).

Based on the rank and considering travel distance, in case of Scenario 1, it is economically most effective to deliver poultry litter produced from chicken houses in Blount and Cullman counties to pasture ID 2, with a range of 125 to 158 miles travel distance. Total travel distance

Table 4 The attributes of lines representing the O-D cost matrix from each chicken house in the selected counties to pastures in the Black Belt region within a 200 miles travel distance.

Origin ID	Cullman		DeKalb		Marshall		Blount	
(1)	(2)	(3)	(2)	(3)	(2)	(3)	(2)	(3)
1	2	134.2	8	167.5	2	154.6	2	125.2
2	3	135.1	10	170.9	3	155.5	3	126.1
3	0	135.4	12	172.2	5	157.2	5	127.8
4	5	136.9	2	178.7	0	160.2	0	130.9
5	6	143.4	3	179.6	6	163.8	6	134.4
6	10	145.8	11	180.9	8	164.0	10	135.7
7	9	146.8	5	181.3	10	165.1	9	137.8
8	7	147.9	0	184.6	9	167.2	7	138.9
9	1	150.7	13	184.9	7	168.2	12	140.8
10	12	150.9	6	187.9	12	168.7	8	141.7
11	8	151.8	9	191.3	11	173.4	11	144.1
12	4	153.7	7	192.4	1	175.5	1	146.1
13	11	154.2	1	199.8	13	177.7	13	148.3
14	13	158.4	-	-	4	178.6	4	149.2

Notes: (1) destination rank, (2) destination ID (pasture), and (3) travel distance (mile).

decreased as the P Index rating changed from "very low/low (Scenario 1)" with 2148 miles to "very high (Scenario 4) with 1,927 miles". To obtain the maximum economic benefit from the plant nutrients of the poultry litter and protect our water bodies from excessive nutrient runoff or leaching, poultry litter should be applied to match the specific nutrient needs of each pasture (Mitchell and Donald, 1995).

Total nutrient need from all pastures based on the P-Index rating of the "very low/low (Scenario 1)" was 142,239 ton in poultry litter, with a range of 4,933 to 32,005 ton for each pasture. In other words, the amount of land application in Scenario 1 that should be served by chicken houses in Blount and Cullman counties was 142,239 ton. In the case of pasture ID 6 for Scenario 1, land application will be served from Blount and Cullman chicken houses at the same time, with values of 8,924 ton and 1,543 ton, respectively, because of the lack of excess litter in Blount County.

Following a thorough review of the available literature concerning the value of poultry litter as a fertilizer, there appears to be a range of about $30 to $ 41 per ton for poultry litter, not including spreading and transportation costs. Mitchell and Donald (1995) and Bukenya et al. (1999) suggested an estimated value of about $37 per ton based on the 1995 retail cost. According to Bagley and Evans (1998), poultry litter would be worth about $30 to $40 per ton as a fertilizer, and McKinley et al. (2000) reported value of poultry litter to be $31.5 per ton as a fertilizer. Binford et al. (2001) also suggested that the value of available nutrients for

Table 5 Optimal land application and value of poultry litter estimated from O-D matrix analysis according to each Scenario.

	Scenario 1						Scenario 2					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(2)	(3)	(4)	(5)	(6)	(7)
1	B-2	125.2	8,604	8,604	39,711	318,358	B-2	125.2	4,486	4,486	43,829	165,985
2	B-3	126.1	4,933	4,933	34,777	182,525	B-3	126.1	2,572	2,572	41,257	95,165
3	B-5	127.8	15,761	15,761	19,016	583,166	B-5	127.8	8,218	8,218	33,039	304,051
4	B-0	130.9	10,093	10,093	8,924	373,431	B-0	130.9	5,262	5,262	27,777	194,699
5	B-6	134.4	10,466	8,924	0	330,170	B-6	134.4	5,457	5,457	22,320	201,906
5	C-6	143.4	10,466	1,543	144,992	57,084	B-10	135.7	5,675	5,675	16,645	209,964
6	C-10	145.8	10,884	10,884	134,108	402,709	B-9	137.8	2,411	2,411	14,234	89,206
7	C-9	146.8	4,624	4,624	129,483	171,097	B-7	138.9	16,687	14,234	0	526,673
8	C-7	147.9	32,005	32,005	97,478	1,184,181	C-7	147.9	16,687	2,452	144,082	90,735
9	C-1	150.7	9,766	9,766	87,712	361,349	C-1	150.7	5,092	5,092	138,990	188,400
10	C-12	150.9	5,163	5,163	82,550	191,015	C-12	150.9	2,692	2,692	136,299	99,591
11	C-8	151.8	7,863	7,863	74,687	290,930	C-8	151.8	4,100	4,100	132,199	151,685
12	C-4	153.7	6,525	6,525	68,162	241,408	C-4	153.7	3,402	3,402	128,797	125,865
13	C-11	154.2	10,557	10,557	57,605	390,627	C-11	154.2	5,504	5,504	123,293	203,665
14	C-13	158.4	4,995	4,995	52,610	184,811	C-13	158.4	2,604	2,604	120,689	96,356
Sum	-	2148.0	142,239	142,239	-	5,262,858	-	2124.3	74,161	74,161	-	2,743,945

	Scenario 3						Scenario 4					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(2)	(3)	(4)	(5)	(6)	(7)
1	B-2	125.2	2,991	2,991	45,324	110,657	B-2	125.2	1,495	1,495	46,819	55,328
2	B-3	126.1	1,715	1,715	43,609	63,443	B-3	126.1	857	857	45,962	31,722
3	B-5	127.8	5,478	5,478	38,131	202,700	B-5	127.8	2,739	2,739	43,223	101,350
4	B-0	130.9	3,508	3,508	34,623	129,799	B-0	130.9	1,754	1,754	41,469	64,900
5	B-6	134.4	3,638	3,638	30,985	134,604	B-6	134.4	1,819	1,819	39,650	67,302
5	B-10	135.7	3,783	3,783	27,202	139,976	B-10	135.7	1,892	1,892	37,758	69,988
6	B-9	137.8	1,607	1,607	25,595	59,471	B-9	137.8	804	804	36,955	29,735
7	B-7	138.9	11,124	11,124	14,470	411,605	B-7	138.9	5,562	5,562	31,392	205,803
8	B-12	140.8	1,794	1,794	12,676	66,394	B-12	140.8	897	897	30,495	33,197
9	B-8	141.7	2,733	2,733	9,943	101,123	B-8	141.7	1,367	1,367	29,129	50,562
10	B-11	144.1	3,670	3,670	6,273	135,777	B-11	144.1	1,835	1,835	27,294	67,888
11	B-1	146.1	3,395	3,395	2,878	125,600	B-1	146.1	1,697	1,697	25,597	62,800
12	B-13	148.3	1,736	1,736	1,142	64,238	B-13	148.3	868	868	24,729	32,119
13	B-4	149.2	2,268	1,142	0	42,261	B-4	149.2	1,134	1,134	23,595	41,955
14	C-13	158.4	1,736	594	145,940	21,976	-	-	-	-	-	-
Sum	-	2085.2	49,440	49,440	-	1,809,624	-	1926.8	24,720	24,720	-	914,648

Notes: B means Blount county and C means Cullman county. (1) rank for land application, (2) Origin-Destination ID (48,315 ton and 146,534 ton poultry litter available for land application from Blount and Cullman Counties, respectively), (3) travel distance (mile) estimated from O-D matrix, (4) nutrient need of pasture in poultry litter with P rating of medium (ton), (5) amount of land application served (ton), (6) amount of excess litter, and (7) value of poultry litter as a fertilizer for land application.

the initial year of application was $29.65 per ton and the total nutrient value for subsequent years was $41.69 per ton. Based on the above literature values, the value of poultry litter as a fertilizer for each pasture was calculated to have an estimated value of $37 per ton in this study (Table 5). The total value of poultry litter applications from Blount and Cullman counties therefore amounts to over $5.3 million for Scenario 1. It can be seen that the total value of poultry litter increased as amount for land application increased from "very high (Scenario 4)" to "very low/low (Scenario 1)".

The value, excluding spreading and transportation costs, of total poultry litter production in Alabama is estimated to be about $40 million based on the methods used in this study. As mentioned earlier, ACES (Mitchell and Donald, 1995) has reported that the poultry litter produced in the state could be worth about $30 million annually.

Ⅳ. Summary and Conclusions

This paper present a methodology for optimal management of poultry litter produced in the concentrated production areas of North Alabama through transportation and land application in the Black Belt region of South Alabama (a nutrient-deficient area). The methodology is developed in ArcGIS and utilizes three important modules: the P-Index, the CNMP, and the transportation network analysis. The utility of the methodology is demonstrated through a hypothetical case study that considers four different P-index ratings for the pastures in the Black Belt area for land application of litter. This work will insure that the litter application protects the water quality in the Appalachian Plateau regions, minimizes transportation costs, and improves soil fertility in the Black Belt region. Hence, this study will help alleviate water quality problems in the Appalachian Plateau region and poor soil fertility problems in the Black Belt region through optimal land application and transportation of excess poultry litter.

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