ENVIRONMENTAL ISSUES

Nutrient Input and Removal Trends for Agricultural Soils in Nine Geographic Regions in Arkansas

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ABSTRACT

Knowledge of the balance between nutrient inputs and removals is required for identifying regions that possess an excess or deficit of nutrients. This assessment describes the balance between the agricultural nutrient inputs and removals for nine geographical districts within Arkansas from 1997 to 2001. The total N, P, and K inputs were summed for each district and included inorganic fertilizer and collectable nutrients excreted as poultry, turkey, dairy, and hog manures. Nutrients removed by harvested crops were summed and subtracted from total nutrient inputs to calculate the net nutrient balance. The net balances for N, P, and K were distributed across the hectarage used for row crop, hay, pasture, or combinations of these land uses. Row-crop agriculture predominates in the eastern one-third and animal agriculture predominates in the western two-thirds of Arkansas. Nutrients derived from poultry litter accounted for >92% of the total transportable manure N, P, and K. The three districts in the eastern one-third of Arkansas contained 95% of the row-crop hectarage and had net N and P balances that were near zero or negative. The six districts in the western two-thirds of Arkansas accounted for 89 to 100% of the animal populations, had positive net balances for N and P, and excess P ranged from 1 to 9 kg P ha^{-1} when distributed across row-crop, hay, and pasture hectarage. Transport of excess nutrients, primarily in poultry litter, outside of the districts in western Arkansas is needed to achieve a balance between soil inputs and removals of P and N.

A FUNDAMENTAL COMPONENT of developing nutrient management strategies is to determine the balance between nutrient inputs and outputs to identify areas where soil nutrient inputs are greater than removals (Daniel et al., 1998; Sims, 1997). Nationally, many of these critical areas have already been identified and coincide with regions having concentrated animal production. A shift away from diversified agriculture to more specialized agricultural enterprises has presented new challenges for the agricultural industry to manage nonpoint pollution and be recognized as a good environmental steward (Sharpley et al., 2001).

Water quality issues related to hypoxia, eutrophication, or both in the Chesapeake Bay (Boesch et al., 2001), northern Gulf of Mexico (Diaz, 2001), and the Bosque River (Sanderson et al., 2001) have implicated animal and row-crop agricultural enterprises as significant sources of nonpoint nutrient pollution and heightened public awareness of agricultural nutrient use. Strategies implemented to reduce nutrient loading attributed to agricultural production have impacted the agricultural industry and have probably set a precedent for future nutrient management guidelines, making it necessary for the agricultural industry to review nutrient usage and implement best management practices to improve nutrient-use efficiency and ensure that nutrient applications are balanced with the rate of removal.

Summaries of soil-test nutrient data often indicate that some states and nations have nutrient accumulation or depletion (Fixen, 2001; Tunney, 1990). However, soil-test data and nutrient balances summarized on a state- or nationwide basis are often misleading in this regard, especially when animal and row-crop agriculture are segregated. For example, Sharpley et al. (1999) showed that excessive nutrient accumulation occurred primarily in the animal-producing areas of Delaware, but were balanced in the crop-producing regions of the state. Nutrient balances are usually determined on field (nutrient management planning), regional, or national scales since nutrient input and removal statistics are most available at these levels (Tunney et al., 2003). Nord and Lanyon (2003) showed that the components of modern agricultural production were not well integrated within a watershed making it difficult to achieve balanced nutrient management on a watershed scale. Tunney et al. (2003) reported that identifying nutrient surpluses in Ireland followed by the refinement of nutrient-use recommendations and public educational programs has reduced the use of inorganic P fertilizer and caused soil-test P levels to plateau and start to decline.

The literature contains only a few formal reviews of nutrient balance assessments for agricultural systems similar to that provided for Delaware (Sims and Wolf, 1994), Ireland (Tunney, 1990), and Virginia (Bosch and Napit, 1992). Nutrient management issues (i.e., accumulation and deficiencies) that threaten environmental quality, the productivity of agricultural lands, or both are generally reacted to rather than anticipated. It is appropriate, and, now more than ever, essential that periodic assessments of nutrient balances for the common agricultural enterprises within a state be conducted. These assessments would provide an accurate and unbi-

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ased estimate of nutrient management to identify geographical areas that require both immediate and future attention in terms of both excessive and deficient nutrient applications.

In 2003, Arkansas ranked high among all U.S. states in agricultural production: first in rice (*Oryza sativa* L.), second in broiler, third in turkey, fourth in grain sorghum [*Sorghum bicolor* (L.) Moench], fifth in cotton (*Gossypium hirsutum* L.), and ninth in soybean [*Glycine max* (L.) Merr.] (Arkansas Agricultural Statistics Service, 2003). However, to date, the overall nutrient balance for the various regions in Arkansas with distinctly different agricultural enterprises is poorly documented. Although the excess nutrient problem in northwestern Arkansas is well documented (Kellogg et al., 2000), it has not been adequately quantified or categorized into individual components. Therefore, the primary objective of this manuscript is to describe the balance between the predominant inorganic and organic agricultural nutrient (i.e., N, P, and K) sources and the amount of nutrients removed by harvested crops for nine geographically defined districts within Arkansas. Additionally, the nutrient balance for specific land use management practices will be evaluated by the major commodities produced within each district to assess whether soil-test P and K should increase, remain static, or decrease. This information will assist scientists, public officials, and land managers in developing solutions to nutrient management issues in Arkansas and surrounding states.

MATERIALS AND METHODS

A number of literature references and statistical resources were used to assess the nutrient balance within Arkansas for the 5-yr period from 1997 to 2001. Nutrient balance assessment for the whole state would not accurately reflect the nutrient management issues for the different agricultural enterprises that predominate in each geographic region. Therefore, Arkansas was divided into the nine geographic districts used by the Arkansas Agricultural Statistics Service (Fig. 1). Crop and

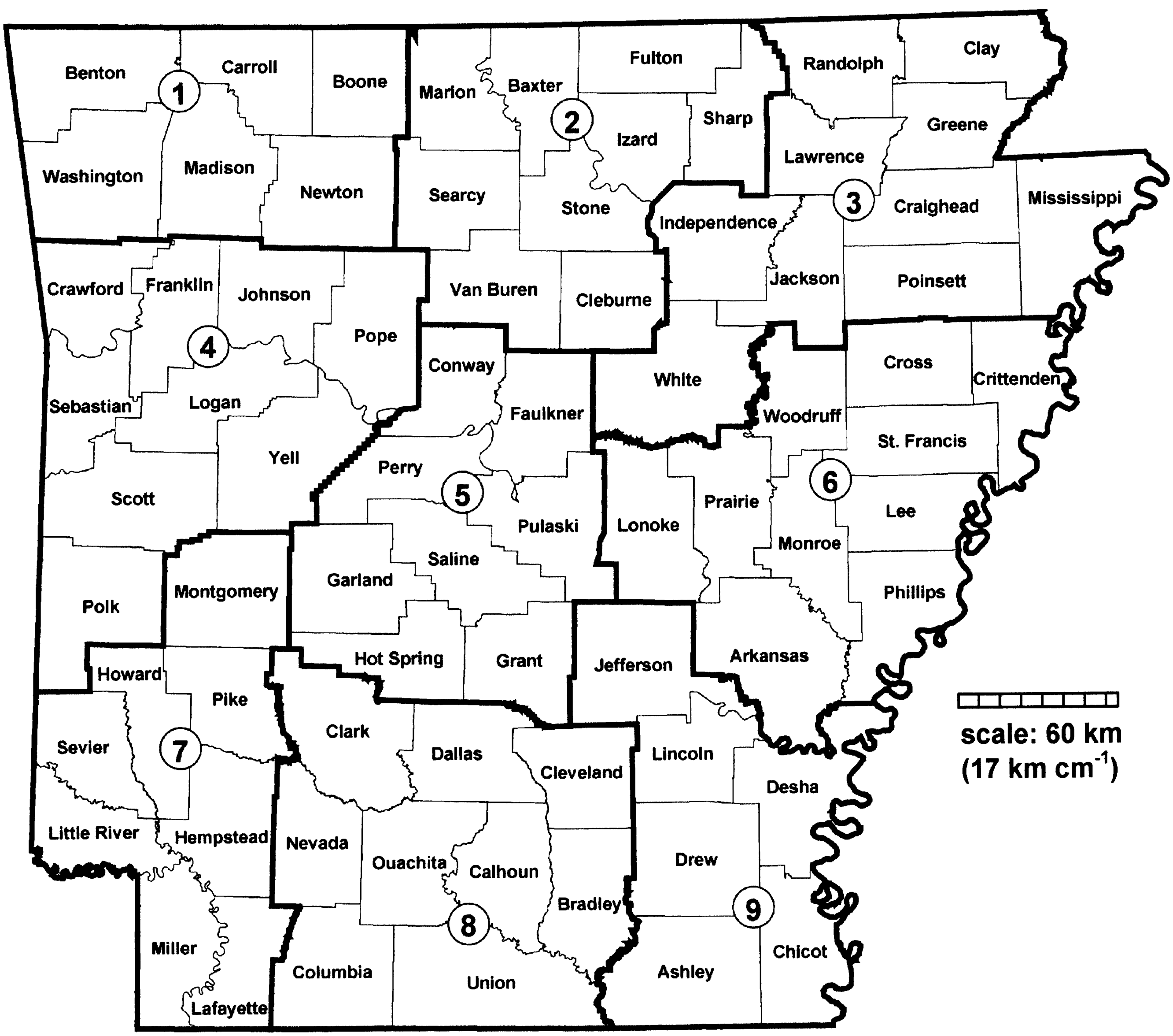

Fig. 1. Geographic boundaries for nine districts in Arkansas used to assess nutrient balances for N, P, and K.

animal production data from the AASS from 1997 to 2001 were used to quantify soil nutrient removals by harvested crops and nutrient inputs from animal production (Arkansas Agricultural Statistics Service, 2003). Because crop yields, crop hectares in production, animal populations, and agricultural production practices often vary among years, the 5-yr mean data will be presented. These data provide a reasonably accurate assessment of the nutrient balance for agricultural soils during this period, but do not necessarily describe past or future nutrient balances for soils within these districts.

Nutrient Removals from Agricultural Soils

Nutrient removal from soils used for agricultural purposes was determined by calculating the nutrient content of the seven primary crop commodities produced in Arkansas including corn (*Zea mays* L.), cotton, grain sorghum, oat (*Avena sativa* L.), rice, soybean, and wheat (*Triticum aestivum* L.). Nutrient removal was calculated by multiplying the annual grain production (Arkansas Agricultural Statistics Service, 2003) by the grain concentrations of N, P, and K as defined in Table 1. The nutrient concentrations from the USDA Natural Resources Conservation Service (2003) were used because they (i) represent values that will be used in developing farm nutrient-management plans, (ii) are readily available to the general public, and (iii) were generally comparable with other published sources. Furthermore, we assumed that all nutrients contained in row-crop straw and stubble residues were returned directly to the soil and the harvested portion of each crop, including such items as cotton seed and rice hulls, were not returned directly to the soil. Although other crop commodities (i.e., various species of fruit, nut, and vegetable crops) are produced and probably receive annual fertilizer applications, the seven row crops listed above account for the majority of the land area used for row-crop production within Arkansas. The average cotton yield in Arkansas is published as lint yield (i.e., 218 kg lint bale^{-1}), so the estimated seed-cotton yield (seed + lint) was calculated by dividing the average lint yield by 0.35 to more accurately describe nutrient removal in both cotton lint and seed.

Specific county and district production estimates for hay are not provided by the Arkansas Agricultural Statistics Service, but total state hectarage and average production estimates are provided for a general hay category. Data from the 1997 Census of Agriculture included county hay hectarage estimates (USDA National Agricultural Statistics Service, 2003). To allocate hay hectarage to each district, the 1997 Census of Agriculture county hay production estimates were compiled and totaled, and the proportion of the state hay hectarage was calculated for each county. In turn, these proportions were multiplied by the Arkansas Agricultural Statistics Service (2003) estimate for state hay hectarage and the average hay yield to calculate the total hay production. Total hay production for each district was estimated by summing respective county production. For simplicity and because specific species of hay were not described, all hay was assumed to be bermudagrass [*Cynodon dactylon* (L.) Pers.] with the average N, P, and K nutrient concentrations listed in Table 1. Pasture hectarage for each district was also obtained from the 1997 Census of Agriculture and was assumed to be constant during the 5-yr period. Although the crop yields and nutrient concentrations may vary among soils, cultivars, management practices, and years, the methods used here provide a reasonable, unbiased estimate of soil nutrient removals.

Table 1. Nutrient concentrations of selected crop species and poultry litter used to calculate the nutrient inputs and removals within Arkansas from 1997 to 2001.

Source	Nutrient concentration		
	N	P	K
	g kg^{-1}		
Bermudagrass hay†	13.7	1.9	15.5
Corn†	16.4	3.1	3.4
Cotton (seed + lint)†	33.0	4.1	4.9
Grain sorghum†	18.7	3.3	3.9
Oat†	20.9	3.8	4.6
Rice†	13.9	2.9	4.5
Soybean†	65.7	6.7	15.4
Winter wheat†	19.4	3.7	4.5
Poultry litter‡	40.8	14.3	20.7

† Referenced values for dry material from the USDA Natural Resources Conservation Service (2003).
‡ Values are the average nutrient concentration from Edwards and Daniel (1992).

Nutrient Inputs to Agricultural Soils

The total inorganic fertilizer nutrient sales for N, P, and K were summarized by county and district from 1997 to 2001 (University of Arkansas Cooperative Extension Service and Arkansas State Plant Board, unpublished data). We assumed that all inorganic fertilizer nutrients were applied to soils used for agricultural purposes within Arkansas. Estimates of the nutrient content from broiler, turkey, dairy, and swine production were calculated and added to N, P, and K contents from inorganic fertilizers for total N, P, and K content. The nutrient content of inorganic fertilizers and animal manures will be considered and referred to as agricultural nutrient inputs that are collectable and transportable and applied to soils used for agricultural purposes. Nutrients contained in beef cattle manure were ignored in nutrient source estimates since a large proportion of these nutrients are obtained from the forage and deposited directly (i.e., recycled) to pastures during grazing rather than collected in lagoons or stockpiled from confined animal production facilities. Likewise, nutrients contained in biosolids (i.e., sewage sludge) were not considered in this analysis since estimates of the amount of biosolids applied to agricultural land within Arkansas are not available.

Total nutrient inputs attributed to Arkansas poultry production enterprises were determined using USDA historic estimates for annual broiler and turkey production (Arkansas Agricultural Statistics Service, 2003), referenced values for manure production per 1000 broilers, and standard referenced N, P, and K nutrient concentrations of broiler and turkey litter. Malone (1992) reviewed the literature on poultry-litter production and reported the average litter production by broilers was about 1000 dry kg (1000 broilers)$^{-1}$. For simplicity and because turkey populations are relatively small compared with broilers, turkey litter production was calculated assuming the same litter production rate and nutrient concentrations as for broilers. Broiler litter nutrient concentrations cited by Edwards and Daniel (1992) were multiplied by the mean litter production rate to calculate nutrient content from broiler and turkey production. Nutrient concentrations cited by Edwards and Daniel (1992) are within the range of concentrations for N, P, and K observed for broiler litter in Arkansas.

Annual nutrient production from dairy and swine animals were determined using the number of milk cows and hogs (Arkansas Agricultural Statistics Service, 2003) and Natural Resources Conservation Service (Barth, 1999) values of 0.204 kg N, 0.032 kg P, and 0.118 kg K d^{-1} 454 kg^{-1} animal weight for excreted dairy manure and 0.191 kg N, 0.073 kg P, and 0.10 kg K d^{-1} 454 kg^{-1} animal weight for excreted hog manure. Nutrient content in dairy and hog manures were calculated on an "as excreted" basis as defined by the Natural Resources

Conservation Service (Barth, 1999). The assumptions used to estimate excreted nutrient content for dairy manure were that the average milk cow weighed 454 kg and was lactating. The assumptions used to estimate excreted nutrient content for hogs were that the average hog weighed 59 kg and was classified as a grower hog (18–100 kg). Total nutrient input accounts for total inorganic fertilizer sales and production estimates of organic source nutrient content from broiler, turkey, hog, and dairy animals. Calculated nutrient contents from manure sources represent reasonable estimates from animal-production enterprises in Arkansas that are considered both collectable and transportable.

Nutrient Balance and Distribution

The net nutrient balance for each district was calculated by subtracting total soil nutrients removed from the total amount of agricultural nutrient inputs, with the difference representing either a net deficit or excess. The net nutrient balance was then expressed on an area basis for the categories of harvested row-crop, total-harvested cropland, and total-land hectarage in agricultural use. Urbanized land that may receive nutrient applications was not considered in net nutrient balance calculations. Harvested row-crop hectarages were the sum of the seven previously listed row-crop commodities. Total-harvested cropland included the seven row-crop commodities plus hay hectarage. The total-land hectarage in agricultural use was the total-harvested cropland plus pasture hectarage. We assumed that all excess or deficit nutrients were uniformly distributed across these land-use categories. Expression of the nutrient balance per unit of each defined land-use category provides an indication of whether the land-use categories are sufficient or inadequate to handle the net nutrient surplus or deficit for each district and should coincide with trends shown in soil-test summaries during the past decade. While this type of information is generally used to identify areas of nutrient surplus, it also has value for the identification of areas where potential nutrient deficits could occur.

RESULTS

Geographic Description of Agricultural Enterprises

The eastern one-third of Arkansas generally consists of flat to gently rolling alluvial soils situated in the Mississippi River flood plain and remnant terraces. In contrast, the western two-thirds of Arkansas generally consists of residual soils and widely varying slopes situated in the Ozark Highlands and Boston and Ouachita Mountain ranges. The topographical constraints in these geographic areas within Arkansas are well suited for the specialized-agricultural enterprises common to each region. The lack of integration between row-crop and animal production presents a potential problem for agronomically and environmentally sound nutrient management, especially in northwestern Arkansas.

During the 5-yr period from 1997 to 2001, Districts 3, 6, and 9 (Fig. 1) accounted for 95% of the row-crop hectarage and only 16% of the hay and pasture hectarages in Arkansas (Table 2), and for only 6% of poultry, 0% of turkey, 2% of hog, and 11% of dairy animal populations. The three districts (1, 4, and 7) located in the western one-third of Arkansas accounted for 55% of the hay hectarage, 50% of the pasture hectarage, and only 3% of the row-crop hectarage. Animal production was also concentrated in the western one-third of Arkansas with 76% of poultry, 88% of turkey, 85% of hog, and 49% of the dairy populations in Districts 1, 4, and 7 (Table 2). Although beef cattle were not considered in this analysis, 56% of the beef populations were located in Districts 1, 4, and 7, while only 15% of the beef populations were in Districts 3, 6, and 9 (data not shown).

Nutrient Inputs to Agricultural Soils

Inorganic fertilizer nutrients accounted for 84% of the total N, 68% of the total P, and 80% of the total K in Arkansas (Table 3). A significant amount of P is produced by animal agriculture within Arkansas; however, these state statistics do not adequately describe the distribution of total, inorganic, or manure-derived nutrients for each district. The specialization of row-crop agriculture in eastern Arkansas and animal agriculture in western Arkansas is reflected by the distribution of inorganic-fertilizer and manure-derived nutrients. Districts 3, 6, and 9 accounted for 82 to 86% of the inorganic N, P, and K fertilizers sold in Arkansas. Within each of the three eastern Arkansas districts, the percent of total nutrient inputs represented by inorganic fertilizers was >96% for N, >85% for P, and >93% for K (Table 3). In contrast, inorganic fertilizer sales in the

Table 2. Mean animal populations and crop hectarage statistics by district for 1997 to 2001 in Arkansas.

Region, district	Hectarage			Animal populations			
	Row crop	Hay	Pasture	Broiler†	Turkey†	Dairy	Hog
	ha			number of animals			
West							
1	3 314	110 005	386 856	361 891	11 572	14 680	185 400
4	31 886	107 972	309 390	281 497	12 989	6 600	196 400
7	54 046	60 025	210 789	253 678	0	1 620	247 000
Central							
2	3 830	63 661	382 899	65 895	3 385	10 060	15 800
5	49 797	54 800	145 829	55 168	70	7 440	65 400
8	4 612	26 677	73 444	95 011	0	760	12 400
East							
3	1 000 898	58 060	213 040	26 283	0	2 840	9 500
6	1 236 309	15 612	41 361	707	0	2 100	4 600
9	445 981	8 987	37 920	40 551	0	300	3 500
State	2 830 673	505 799	1 801 528	1 180 681	28 016	46 400	740 000

† Multiply listed values by 1000 for broiler and turkey populations.

Table 3. The 5-yr means for total nutrient inputs (inorganic plus manure nutrients) and the percentages of total inorganic nutrients contained in inorganic fertilizers sold within Arkansas from 1997 to 2001.

Region, district	Total nutrient inputs†			Total inorganic nutrient inputs‡		
	N	P	K	N	P	K
	kg × 10^6			% of total nutrients inputs		
West						
1	23.54	6.77	11.33	30	18	26
4	18.22	5.35	8.90	31	19	28
7	20.02	5.36	7.40	47	31	28
Central						
2	10.73	2.47	5.83	64	54	66
5	11.12	2.06	4.97	74	56	66
8	6.23	1.80	2.95	37	24	32
East						
3	92.14	12.91	40.22	99	97	98
6	101.78	16.05	43.24	>99	>99	>99
9	41.51	3.91	13.15	96	85	93
State	325.30	56.67	137.99	84	68	80

† Nutrient inputs include nutrients from inorganic fertilizer and broiler, turkey, hog, and dairy animal manures.
‡ Percentage of total nutrient inputs from only inorganic fertilizers sold in Arkansas.

western one-third of Arkansas accounted for low percentages of the total nutrient inputs.

Manure-derived nutrients, especially P, represent a significant proportion of the total nutrient sources within Arkansas (Table 3). Poultry litter accounted for 92, 96, and 92% of the total manure-derived N, P, and K, respectively, represented in this analysis for Arkansas (data not shown). Excreted hog and dairy manures accounted for <13% of the manure-derived P in all districts except District 6, which is a row-crop producing area that has only a small proportion of the total animal population in Arkansas (Table 2). From a district and state perspective, nutrients derived from excreted dairy and hog manures represented a relatively insignificant amount of the total nutrient inputs and perhaps not all of these manures are actually collected and transportable. Due to the relatively low quantity of dairy- and hog-derived nutrients, appropriate management of these nutrients can probably be performed within a district close to the points of nutrient origin. Although a significant proportion of the soils used for forage production has excessive soil-test P, 15 to 20% of these soils do have low to medium soil-test P and could probably handle nutrients from hog and dairy production (DeLong et al., 2003). Efforts to redistribute excess manure-derived nutrients outside of the animal-producing areas (i.e., Districts 1, 2, 4, 5, 7, and 8) should focus on poultry litter because it is the largest source and usually collected as a relatively dry material (<30% moisture) as opposed to dairy and hog manures that are collected as slurries, which are more difficult to collect and transport (Kellogg et al., 2000).

Although the nutrient input statistics alone (Table 3) do not directly indicate nutrient management problems within the state or within certain districts, the N to P ratio of total nutrients within each district does describe an unbalanced nutrient distribution assuming that the nutrients are applied to agricultural land within each district. The three largest row-crop production areas, Districts 3, 6, and 9, have a wide total N to P ratio (6 to 11:1). The remaining six districts, which also contain the highest animal populations, have total N to P ratios of ≤5:1. The narrow total N to P nutrient ratios combined with the lack of harvested cropland in the central and western districts suggest the potential for P to accumulate in the soil assuming animal manures are applied within the district boundaries. The N to K ratios for the nine districts ranged from 1.8 to 3.2 with a state N to K ratio of 2.4. The total N to K ratios for each district do not indicate a significant imbalance of N or K. The ratio of total nutrient inputs in Districts 3, 6, and 9 approximates the nutrient ratios in inorganic fertilizer blends recommended for crops grown on soils that have low to medium soil-test P and K levels.

Nutrient Removals from Agricultural Soils

Districts with predominant row-crop agricultural enterprises (e.g., Districts 3, 6, and 9) removed the largest amounts of soil N and P (Table 4). For K, however, districts with a large hay hectarage (e.g., District 1 and 4, Table 2) had slightly higher K removal than District 9. Row-crop agriculture accounted for 94 to 99% of total N, 89 to 97%

Table 4. The 5-yr means for total and row crop only nutrient removals and the net nutrient balances for nine districts within Arkansas.†

Region, district	Total nutrient removal‡			Total row crop nutrient removal§			Net nutrient balance¶		
	N	P	K	N	P	K	N	P	K
	kg × 10^6								
West									
1	12.14	3.14	12.99	0.25	<0.03	<0.06	11.40	3.63	(1.66)
4	12.42	2.90	11.28	2.61	0.34	0.61	5.80	2.45	(2.38)
7	11.06	2.45	8.75	3.85	0.57	0.91	8.96	2.91	(1.35)
Central									
2	5.93	1.51	6.20	0.28	<0.04	0.06	4.80	0.96	(0.37)
5	9.98	2.04	7.19	4.32	0.57	1.04	1.14	0.02	(2.22)
8	3.60	0.87	3.47	0.51	0.06	0.12	2.63	0.93	(0.52)
East									
3	94.28	13.77	27.73	88.48	12.25	21.42	(2.14)	(0.86)	12.49
6	122.18	16.72	31.39	120.42	16.26	29.47	(20.40)	(0.67)	11.85
9	42.15	5.69	10.55	41.21	5.44	9.53	(0.64)	(1.78)	2.60
State	313.74	49.09	119.55	261.93	35.56	63.22	11.55	7.59	18.44

† Values in parentheses indicate negative numbers where total nutrient removals were greater than total nutrient inputs.
‡ Total nutrient content of the harvested portion of corn, cotton, grain sorghum, hay, oat, rice, soybean, and wheat.
§ Total nutrient content of the harvested portion of corn, cotton, grain sorghum, oat, rice, soybean, and wheat.
¶ Net nutrient balance is the difference between total nutrient inputs (Table 3) and total nutrient removals (shown above).

of total P, and 77 to 94% of total K removals in Districts 3, 6, and 9, but only a minor portion, 2 to 43% for N, <1 to 28% for P, and <1 to 17% for K, of nutrient removals in the other six districts (Table 4). Kellogg et al. (2000) also found that the soils and their associated uses in eastern Arkansas had a greater capacity to assimilate (i.e., remove) N and P than soils in western Arkansas.

Districts 1, 2, 4, 5, 7, and 8 had total N to K removal ratios of about 1.0, but total N to P removal ratios were 3.9 to 4.9. In comparison, the row-crop agricultural Districts 3, 6, and 9 had wider total N to K (3.4–4.0) and total N to P (6.9–7.4) removal ratios than animal-agricultural districts. Although the more narrow N to P removal ratio for western Arkansas districts indicates greater P removal, which may be advantageous, nutrients removed by forage crops are usually fed or recycled on-farm rather than exported outside the district boundaries.

Net Nutrient Balance

The net nutrient balance is the difference between total nutrient inputs and removals with a positive value indicating an excess of nutrients within the state or district (Table 4). The state summary shows a net excess of N, P, and K. The calculated nutrient balance is affected by inorganic fertilizer sales, animal populations, harvested crop area, and crop yields. Districts 3, 6, and 9 had net balances that were negative or near zero for N and P and positive for K. For districts in central and western Arkansas, the net balances for N and P were positive and negative for K. The amount of inorganic P fertilizer sold (Table 3) accounted for 35 to 88% of the total P removal (Table 4) for districts in central and western Arkansas. Therefore, a major portion of the poultry litter would have to be transported outside of these western districts to establish a balanced situation for P.

Net Nutrient Distribution

Although the total net nutrient balance values (Table 4) show the relative magnitude of nutrient accumulation or depletion among districts, they do not indicate the distribution of nutrients within each district. The net nutrient distributions (Table 5) suggest the extent of nutrient accumulation or depletion on an area basis for three specified land uses. The three land use categories are shown because the predominant agricultural enterprises of each district differ and require different descriptions for accurate assessment of nutrient distribution. In Districts 3, 6, and 9, row crops (Table 2) represent 79 to 96% of the area used for crop, hay, and pasture production. In contrast, the majority of land area in the western two-thirds of Arkansas is used for hay and pasture production. The net balance for nutrient distributions shown only for row-crop hectarage assumes that all excess or deficit nutrients are applied only to land used for row- crop production and provides a fairly accurate description for the eastern one-third of Arkansas. In general, the row-crop hectarage in Districts 3, 6, and 9 is sufficient to prevent accumulation of N and P in the soil and with current usage should not result in rapid soil depletion of these nutrients (Table 5). Although the net balance for K (row-crop ha)$^{-1}$ is positive, it is not excessive and would probably maintain plant available soil K considering that some K is lost via surface runoff, erosion, and leaching below the root zone.

A near zero or net negative balance for nutrient distribution does not mean that nutrients like N and P cannot contribute to nonpoint-source pollution via runoff or sedimentation. Rather, a near zero balance between nutrient inputs and removals means that agricultural nutrient-management practices during this 5-yr period would maintain, but not rapidly enrich or deplete, soil nutrient contents.

In the six districts in central and western Arkansas, total cropland is the most appropriate category to evaluate net nutrient balance because row-crop hectarage is low and animal populations are high. Data show that K may be limiting forage and crop production in several districts in central and western Arkansas (Table 5). However, regardless of the land-use category, the net

Table 5. The 5-yr mean net nutrient balance per unit of land area for various cropping systems in nine districts within Arkansas.†

Region, district	Net balance								
	Row crop land‡			Row crop and hay land§			Total cropland¶		
	N	P	K	N	P	K	N	P	K
	kg ha^{-1}								
West									
1	3663	1095	(501)	101	32	(15)	23	7	(3)
4	182	77	(75)	42	18	(17)	13	6	(5)
7	166	54	(25)	79	26	(12)	28	9	(4)
Central									
2	1253	251	(97)	71	14	(6)	11	2	(1)
5	23	<1	(45)	11	<1	(21)	5	<1	(9)
8	570	202	(113)	84	30	(17)	25	9	(5)
East									
3	(2)	(1)	13	(2)	(1)	12	(2)	(1)	10
6	(17)	(1)	10	(16)	(1)	10	(16)	(1)	9
9	(1)	(4)	6	(1)	(4)	6	(1)	(4)	5
State#	4	3	7	4	2	6	2	2	4

† Values in parentheses indicate negative numbers where total nutrient removals were greater than total nutrient inputs.
‡ Net nutrient balance distributed across row-crop (corn, cotton, grain sorghum, oat, rice, soybean, and wheat) hectarage.
§ Net nutrient balance distributed across row-crop and hay hectarage.
¶ Net nutrient balance distributed across row-crop, hay, and pasture hectarage.
# Calculated using state totals for net nutrient balance and land hectarage.

nutrient balances per unit of land for N and P were positive. Assuming that the district row-crop, hay, and pasture hectarage estimates are representative and nutrients are applied within each district, all animal-producing districts have excess N and P, which will increase soil N and P when applied exclusively to land used for agricultural purposes. This is especially important considering that most soils used for warm- and cool-season grass production in Arkansas already have adequate Mehlich 3–extractable P levels that do not require additional P fertilization for forage production (DeLong et al., 2003).

Arkansas soil-test data show that the median Mehlich 3–extractable P for established warm- and cool-season grasses increased by 2.5 mg P kg^{-1} yr^{-1} between 1995 and 2002 (Fig. 2a). The median Mehlich 3–extractable P concentration has not changed appreciably for soils used to produce row crops (Fig. 2b), which are grown primarily in Districts 3, 6, and 9 in eastern Arkansas. Mehlich 3–extractable K has remained relatively constant for all crops, showing an increase of only 0.50 to 0.55 mg K kg^{-1} yr^{-1} (data not shown). Thus, the median soil-test P and K concentrations determined by crop

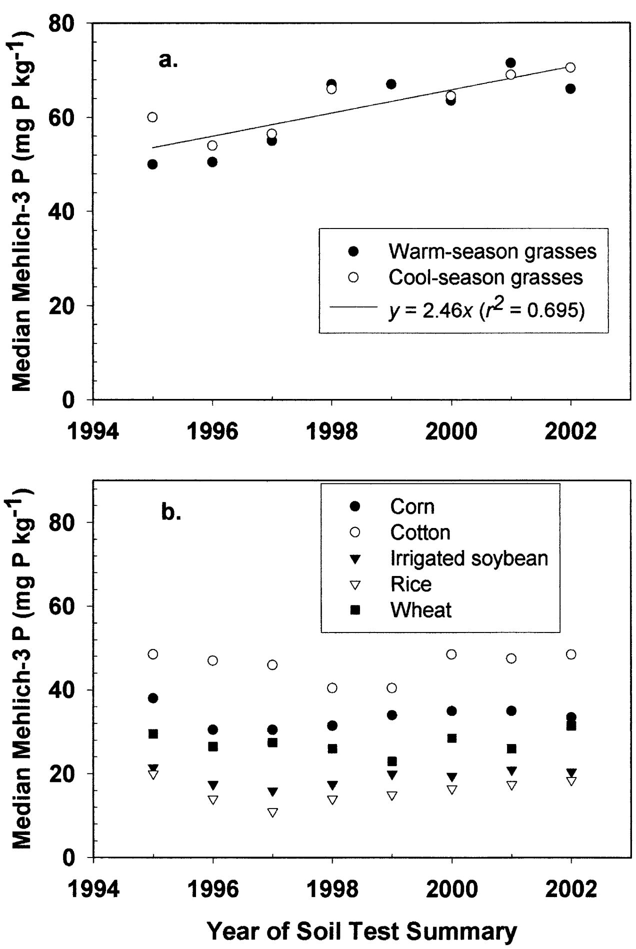

Fig. 2. Median Mehlich 3–extractable P concentrations of soils used for established warm- and cool-season grasses (a) and row-crop (b) production from 1995 to 2002 from University of Arkansas soil test data summaries (DeLong et al., 1996, 1997, 1998, 1999, 2000, 2001, 2002, and 2003).

tend to support information from the nutrient distribution assessment.

DISCUSSION

Kellogg et al. (2000) showed an excess of manure-derived N and P in western Arkansas and very low amounts in eastern Arkansas, but did not include inorganic fertilizers in their analyses. Our data show that poultry production produces the majority of excess collectable and transportable N and P in western Arkansas. Nutrients are imported in the form of animal feed and recycled as manure on the farm (Sauer et al., 2000) with most of the poultry litter applied to pastures and hay fields near the poultry houses to meet the N requirements of hay and forage crops. Long-term application of poultry litter to a limited land area that also has a limited capacity to remove P from the soil in the form of harvested crops eventually leads to accumulation of soil P.

Inorganic fertilizers are used almost exclusively as the nutrient fertilizer sources for row-crop production in eastern Arkansas. Organic nutrient sources are seldom applied to land used for row-crop production because animal manures are not readily available due to the great distance between animal and row-crop production. About 91 Mg of poultry litter are transported to eastern Arkansas each year (Kellogg et al., 2000) for amending precision-graded soils to help restore soil productivity (Miller et al., 1990).

Transporting manure outside the animal-producing areas to row-crop producing areas is one of the many potential solutions (Sims, 1997) proposed to alleviate the accumulation of soil P in areas of intensive animal production, such as in northwestern Arkansas. The low economic value of poultry litter, which represents the majority of organic nutrient sources produced in Arkansas, as a fertilizer nutrient source is believed to prohibit its transport to the primary row-crop production area. Bosch and Napit (1992) proposed the fertilizer value of poultry litter ranged from \$22.10 to \$31.42 Mg^{-1} for several crops in Virginia based on estimated litter application rates to meet crop N, P, and K fertilizer requirements. Based on litter removal (i.e., clean-out), storage, and transportation fees, Bosch and Napit (1992) concluded that litter could be transported from 127 to 262 km before the net worth of the inorganic fertilizer value of the litter was exceeded. Based on their data, transportation of broiler litter from western to eastern Arkansas would not be economically feasible. However, the less tangible, positive effects of poultry litter on soil quality in row-crop production areas, such as improving soil water holding capacity and lowering bulk density to potentially better seedling emergence (Brye et al., 2004), are not yet economically quantifiable, but more than likely add extra value to poultry litter.

If poultry litter transport across district boundaries is not considered, a use other than land application must be developed in the very near future to sustain the current level of poultry production and to a large part the economy of central and western Arkansas. In 2001, the poultry and egg industry accounted for nearly 54% of the total agricultural commodity cash receipts ($5.13 billion) and 78% of the livestock, poultry, and dairy meat animal cash receipts in Arkansas (Arkansas Agricultural Statistics Service, 2003). A recent lawsuit settlement between poultry integrators in northwestern Arkansas and the city of Tulsa, OK, limits or in some cases prohibits poultry growers in the Eucha–Spavinaw watershed in northwestern Arkansas from applying poultry litter or other P sources to pastureland because runoff from such areas is considered to further accelerate eutrophication of the city's source of drinking water (Davis, 2004).

Soil P determined by routine soil-test methods is correlated to the amount of dissolved P in runoff (Pote et al., 1996). The soluble P contained in surface-applied manures or inorganic P fertilizers may contribute much more to dissolved P in runoff than the more stable, less soluble soil P (Sauer et al., 2000; DeLaune and Moore, 2001). Transporting P and N contained in poultry litter out of critical watersheds is an important step toward decreasing nonpoint-source pollution in central and western Arkansas. The high to excessive soil-test P levels common to central and western Arkansas will eventually decline as additional P is withheld, but for some soils this process may take decades before supplemental P is needed to sustain forage production (McCollum, 1991). In the meantime, these soils will still need to be managed appropriately to reduce soil P contributions in runoff and to sustain high forage yields. The Natural Resources Conservation Service in Arkansas is now preparing P-based nutrient management plans to determine application rates of poultry litter that should help reduce P concentrations in runoff (J. Caudle, Arkansas NRCS, personal communication, 2003).

Best management practices will also be needed on soils in eastern Arkansas with low to medium soil-test P levels that will eventually receive P, regardless of whether the source is poultry litter or inorganic fertilizer. One advantage of applying poultry litter to land used for row-crop production rather than permanent pasture is that opportunities exist for mechanically incorporating the litter into the soil immediately after application. Soil incorporation may reduce P concentrations in runoff unless soil erosion is excessive and also reduce gaseous losses of N, which will improve the efficiency and value of poultry litter as a N fertilizer.

Kellogg et al. (2000) showed that soils in eastern Arkansas had the greatest capacity to assimilate N and P from animal manures primarily due to the large number of hectares that are used for row-crop production. They also showed that soils in western Arkansas had a greater assimilative capacity per unit of agricultural land area for P due to the greater removal of soil P from harvested forages compared with row crops. However, the use of nutrient management plans to prescribe soil nutrients will influence P soil inputs since manure, as well as inorganic fertilizer, application rates will be limited or sometimes prohibited due to soil-test P level.

In northwestern Arkansas, DeLaune and Moore (2001) reported that Mehlich-3 P increased 1 mg P kg^{-1} per 4 kg P ha^{-1} for a Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiudult) with an initial Mehlich-3 P concentration of 117 mg P kg^{-1}. In contrast, the silt-loam soils used for rice and irrigated-soybean production in eastern Arkansas have much lower soil-test P and require about 5 kg P ha^{-1} to increase Mehlich-3 P by 1 mg P kg^{-1} (Slaton et al., 2003). However, the rate of increase is somewhat misleading because 25 to 50 kg P ha^{-1} yr^{-1} were needed to replace P removed by harvested crops and maintain the initial soil-test P. The alternating aerobic–anaerobic status of soils used for flood-irrigated rice production tends to retard increases in soil-test P by fixing P into forms that are less soluble and apparently not extracted by most routine soil-test methods even when relatively high P fertilizer rates are applied. Some evidence of this is shown in Fig. 2b. Flood-irrigated rice and irrigated soybean are usually grown in rotation on soils with the lowest soil-test P levels. However, rice is grown in rotation with corn and cotton less frequently or not at all on most farms and this fact is at least partially responsible for the higher soil-test P levels associated with soils used to produce these upland crops. These data, coupled with P removal by row crops, indicate that accumulation of soil P would be slower for soils in eastern Arkansas, which make these low-P soils well suited for land application of excess poultry litter from western Arkansas.

Assuming that 5 kg P ha^{-1} are required to increase soil-test P by 1 mg P kg^{-1}, the 2.5 mg P kg^{-1} yr^{-1} increase observed between 1995 and 2002 for soils cropped to warm- and cool-season grasses indicates that 12.5 kg P ha^{-1} are applied in excess of the amount required to maintain soil-test P. This range corresponds closely to the amount of excess P applied to soils in some of the six districts located in the western two-thirds of Arkansas (Table 5). If the average row-crop yield removes 20 kg P ha^{-1} and poultry litter is applied to replace only the removed P (1400 kg poultry litter ha^{-1}), approximately 2.6 million ha of soils with low to medium soil-test P are needed to distribute all the P from Arkansas poultry and turkey production each year.

CONCLUSIONS

The nutrient balance assessment for nine districts within Arkansas shows that an excess of N and P exists in the western two-thirds of Arkansas where animal populations are greatest and row-crop hectarage is least. The greatest excess of N and P exists in District 1, which is furthest away from the row-crop producing area in eastern Arkansas. Nutrients removed in the harvested portion of crops account for nearly all of the nutrients derived from inorganic fertilizers and animal manures in the eastern one-third of Arkansas, which is the predominant row-crop producing area. Data demonstrate that nutrient assessments performed within state boundaries usually do not accurately represent all geographic regions within a state due to differences in agricultural enterprises. Although the nutrient-balance assessment performed by multicounty districts is an improvement over a statewide assessment, county or specific watershed boundaries are needed to identify the most critical areas within these districts. Because county data were used to compile the district data, albeit more tedious, this same analysis could be performed by county with relative ease. However, data on a smaller scale (i.e., specific watershed) would be more difficult to collect and summarize without the cooperation and direct assistance of the targeted producers and landowners (Nord and Lanyon, 2003).

While nutrient balance data on either a county or district basis should not be used to make recommendations at the field or farm level, they can be very useful data for natural resource planners to address nonpoint-source pollution on a watershed or regional scale and develop appropriate total maximum daily loads (TMDLs) and nonpoint control strategies. For example, eastern Arkansas is a part of the drainage basin for the Gulf of Mexico where concerns have grown over the hypoxic zone. This study shows that excessive N is not being applied to the row-crop hectarage in the eastern one-third of Arkansas within the Mississippi flood plain. While this does not imply that cropping practices in eastern Arkansas are not contributing N to the gulf, it may well suggest that if N is being lost, it is not from excessive application, but perhaps from mismanagement after application. This type of information may assist planners with developing strategies that effectively address the issue while avoiding unnecessary economic hardships on agricultural producers.

The results from this assessment may help reinforce the thought that current nutrient application strategies in western Arkansas are not sustainable without the danger of creating and/or exacerbating water-quality issues from excessive nutrients. Transport of excessive N and P contained in poultry litter outside of the central and western Arkansas districts that have restricted land area available for nutrient application is needed if the current poultry production levels are to be maintained. If poultry litter is eventually transported to eastern Arkansas, the use of inorganic fertilizers will need to be reduced from current levels so that these soils are not eventually enriched to the point of excessive P content as observed in some areas of western Arkansas. While redistribution of nutrients, especially P, contained in poultry litter is needed to address environmental quality concerns in western Arkansas, best management practices are needed so that nonpoint-source pollution does not further degrade the surface and ground water resources of eastern Arkansas.

The literature contains volumes of information on manure-nutrient management, but few of these studies have been conducted on the soils and cropping systems common to eastern Arkansas. Thus, additional research and grower education concerning how to best manage these nutrients are required. Likewise, the export of poultry litter from western Arkansas will require the prescriptive use of inorganic N and K fertilizers to maintain the productivity of soils used for pasture and forage production in western Arkansas that were previously amended almost solely with poultry litter. Use of inorganic fertilizers on forage hectarage will also require comprehensive educational and research programs for both growers and fertilizer distributors.

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