Nutrient Input and Removal Trends for Agricultural Soils in Arkansas

By Nathan A. Slaton, Kristofor R. Brye, Mike B. Daniels, Tommy C. Daniel, Richard J. Norman, and David M. Miller

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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. Nationally, many of these areas coincide with regions having concentrated animal production. Water quality issues related to hypoxia, eutrophication or both in the Chesapeake Bay, northern Gulf of Mexico and Bosque River have implicated animal and row-crop agricultural enterprises as significant sources of nonpoint nutrient pollution.

In 2003 Arkansas ranked high among U.S. states in agricultural production: first in rice, second in broilers, third in turkeys, fourth in grain sorghum, fifth in cotton and ninth in soybeans. However, 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, it has not been adequately quantified or categorized into 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 in Arkansas. Additionally, the nutrient balance for specific land use management practices will be evaluated by the major commodities produced in each district to assess whether soil-test P and K should increase, remain static or decrease. This information will assist in developing solutions to nutrient management issues.

MATERIALS AND METHODS

A number of literature references and statistical resources were used to assess the nutrient balance within Arkansas for the 5-year period from 1997 to 2001. Arkansas was divided into the nine geographic districts used by the Arkansas Agricultural Statistics Service (AASS). Crop and animal production data were used to quantify soil nutrient removals by harvested crops and nutrient inputs from animal production. Because crop yields, hectares in production, animal populations and production practices often vary among years, 5-year mean data will be used.

Nutrient removal was determined by calculating the nutrient content of the seven primary crop commodities produced in Arkansas — corn, cotton, grain sorghum, oats, rice, soybeans and wheat. Nutrient removal was calculated by multiplying annual grain production by the grain concentrations of N, P and K. Nutrient concentrations from the USDA Natural Resources Conservation Service (NRCS) were used. We assumed all nutrients contained in row-crop straw and stubble residues were returned directly to the soil and harvested portions of each crop were not returned directly to the soil.

To allocate hay hectarage to each district, the 1997 Census of Agriculture county hay production estimates were totaled, and the proportion of the state hay hectarage was calculated for each county. In turn, these proportions were multiplied by the AASS (2003) estimate for state hay hectarage and the average hay yield to calculate total hay production. Total hay production for each district was estimated by summing respective county production. Pasture hectarage for each district was also obtained from the 1997 Census of Agriculture and assumed to be constant.

Total inorganic fertilizer nutrient sales for N, P and K were summarized by county and district from 1997 to 2001. We assumed 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 added to N, P and K contents from inorganic fertilizers for total N, P and K content. Nutrients in beef cattle manure were ignored since a large proportion of them is obtained from forage and deposited directly to pastures during grazing rather than being collected or stockpiled.

Total nutrient inputs attributed to Arkansas poultry production were determined using USDA historic estimates and standard referenced N, P and K nutrient concentrations. Annual nutrient production from dairy animals and swine was determined using the number of milk cows and hogs and NRCS values for excreted dairy and hog manure. Total nutrient input accounts for total inorganic fertilizer sales and production estimates of organic source nutrient content from broilers, turkeys, hogs 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.

The net nutrient balance for each district was calculated by subtracting total soil nutrients removed from total agricultural nutrient inputs, with the difference representing either a net deficit or excess. 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. Total harvested cropland included the seven row crops plus hay. Total land in agricultural use was total harvested cropland plus pasture. We assumed all excess or deficit nutrients were uniformly distributed across these categories.

RESULTS

The eastern one-third of Arkansas generally has flat to gently rolling alluvial soils. The western two-thirds generally consists of residual soils and widely varying slopes. Topographical constraints are well suited for their specialized agricultural enterprises. Lack of integration between row-crop and animal production presents a potential problem for sound nutrient management, especially in northwestern Arkansas.

During the 5 years from 1997 to 2001, Districts 3, 6 and 9 accounted for 95% of the row-crop hectarage and only 16% of hay and pasture hectarages in Arkansas, and for only 6% of poultry, 0% of turkey, 2% of hog and 11% of dairy populations. The three districts (1, 4 and 7) in the western one-third of Arkansas accounted for 55% of the hay hectarage, 50% of pasture hectarage and only 3% of 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.

Nutrient Inputs. Specialization of row crops in eastern Arkansas and animal agriculture in western Arkansas is reflected by the distribution of inorganic and manure-derived nutrients.

Manure-derived nutrients, especially P, are a significant proportion of the total nutrient sources in Arkansas. Poultry litter accounted for 92%, 96% and 92% of total manure-derived N, P and K, respectively, in this analysis. Due to the relatively low quantity of dairy- and hog-derived nutrients, appropriate management of them can probably be performed close to their points of origin. Efforts to redistribute excess manure-derived nutrients outside animal-producing areas should focus on poultry litter because it is the largest source and usually is collected as a relatively dry material.

The N to P ratio of total nutrients within each district describes an unbalanced nutrient distribution assuming 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 central and western districts suggest the potential for P to accumulate in the soil assuming animal manures are applied within 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 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. Districts with predominant row-crop enterprises (3, 6 and 9) removed the largest amounts of soil N and P. For K, however, districts with a large hay hectarage had slightly higher K removal than District 9. Row-crop agriculture accounted for 94% to 99% of total N, 89% to 97% of total P and 77% to 94% of total K removals in Districts 3, 6 and 9, but only a minor portion of nutrient removals in the other six districts.

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 narrower 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 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 in the state or district. 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 net balances for N and P were positive and negative for K. Inorganic P fertilizer sold accounted for 35% to 88% of total P removal for districts in central and western Arkansas. Therefore, a major portion of the poultry litter would have to be transported outside these western districts to establish a balanced situation for P.

Net Nutrient Distribution. The net nutrient distributions suggest the extent of nutrient accumulation or depletion on an area basis for three specified land uses. In Districts 3, 6 and 9, row crops represent 79% to 96% of the area used for crops, hay and pasture. In contrast, most land area in the western two-thirds of Arkansas is used for hay and pasture. In general, 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. The net balance for K is positive but not excessive and would probably maintain plant-available soil K considering that some K is lost via surface runoff, erosion and leaching.

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

Data show that K may be limiting forage and crop production in several districts in central and western Arkansas. However, the net nutrient balances per unit of land for N and P were positive. Assuming 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.

Arkansas soil-test data show 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. The median Mehlich 3–extractable P concentration has not changed appreciably for soils used to produce row crops, which are grown primarily in Districts 3, 6 and 9. Mehlich 3–extractable K has remained relatively constant for all crops, increasing only 0.50 to 0.55 mg K kg^{-1} yr^{-1}. Thus, the median soil-test P and K concentrations determined by crop tend to support information from the nutrient distribution assessment.

DISCUSSION

Our data show that poultry production produces the majority of excess collectable and transportable N and P in western Arkansas. Most of the poultry litter is 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 there because of the great distance between animal and row-crop production.

The low economic value of poultry litter as a fertilizer nutrient source is believed to prohibit its transport to the primary row-crop production area. A 1992 study 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, storage and transportation fees, the study 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 that study's data, transportation of broiler litter from western to eastern Arkansas would not be economically feasible. However, less tangible positive effects of poultry litter on soil quality in row-crop areas, such as improving soil water holding capacity and lowering bulk density to potentially better seedling emergence, more than likely add value to poultry litter.

If poultry litter transport across districts is not considered, a use other than land application must be developed to sustain the current level of poultry production and in large part the economy of central and western Arkansas. A recent lawsuit settlement between poultry integrators in northwest Arkansas and the city of Tulsa, OK, limits or prohibits poultry growers in the Eucha–Spavinaw watershed in northwestern Arkansas from applying poultry litter or other P sources to pastureland because the runoff is considered to accelerate eutrophication of the city's source of drinking water.

The soluble P 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. 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. In the meantime, these soils will need to be managed appropriately to reduce soil P contributions in runoff and to sustain high forage yields. The NRCS 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.

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 its source. 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 an N fertilizer.

If the average row-crop yield removes 20 kg P ha^{-1} and poultry litter is applied to replace only the removed P (1,400 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 production each year.

CONCLUSIONS

There is an excess of N and P 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 farthest 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.

This study shows that excessive N is not being applied to row-crop hectarage in the eastern one-third of Arkansas within the Mississippi flood plain. This may well suggest that if N is being lost it is not from excessive application, but perhaps from mismanagement after application.

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. Transport of excessive N and P contained in poultry litter outside of the central and western Arkansas districts 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.

The export of poultry litter from western Arkansas will require 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.

Editor's note: *Content was adapted from the paper "Nutrient Input and Removal Trends for Agricultural Soils in Nine Geographic Regions in Arkansas," which was published in the Journal of Environmental Quality, Vol. 33, September-October 2004, and is courtesy of the authors Nathan A. Slaton, Kristofor R. Brye, Mike B. Daniels, Tommy C. Daniel, Richard J. Norman and David M. Miller.*

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Nutrient Input and Removal Trends for Agricultural Soils in Arkansas

July/August Self-Study Examination

1. A factor associated with areas where soil nutrient inputs are often greater than removal is

[ ] a. intensive row crop agriculture.
[ ] b. concentrated animal production.
[ ] c. proximity to a large urban area.
[ ] d. Karst topography.

2. Determining the balance between nutrient inputs and outputs is a key component of

[ ] a. developing nutrient management plans.
[ ] b. designing animal waste treatment lagoons.
[ ] c. deciding when to apply certain fertilizers.
[ ] d. selecting the economically optimum rate of fertilizer to apply to a field.

3. Nutrient removal rates for crops can be calculated by

[ ] a. monitoring changes in soil pH over time.
[ ] b. multiplying grain production by the concentrations of nutrients in the grain.
[ ] c. carefully measuring fertilizer and manure applications.
[ ] d. determining residual nutrients in crop residue after harvest.

4. Nutrient balances were calculated by the researchers using all of the following EXCEPT

[ ] a. animal populations.
[ ] b. harvested crop area.
[ ] c. inorganic fertilizer sales.
[ ] d. grower-reported fertilizer application rates.

5. The region of Arkansas with the greatest excess of nutrients is

[ ] a. South Central.
[ ] b. Northwest.
[ ] c. Southeast.
[ ] d. East Central.

6. Most of the manure-derived nutrients in Arkansas come from

[ ] a. poultry.
[ ] b. swine.
[ ] c. cow-calf operations.
[ ] d. dairy.

7. A disadvantage of applying manure to land in permanent pasture is

[ ] a. mycotoxin problems associated with manure application.
[ ] b. access to fields during the growing season.
[ ] c. the manure causes the grass to taste bad to livestock.
[ ] d. the inability to mechanically incorporate manure into the soil.

8. Based on information referenced in this article, the approximate distance that poultry litter could be transported and still maintain its net worth is at least

[ ] a. 43 km.
[ ] b. 89 km.
[ ] c. 115 km.
[ ] d. 127 km.

Over

9. Maintaining livestock production in areas with excess nutrients may require
[ ] a. transporting manure into the area.
[ ] b. developing a use for manure other than land application.
[ ] c. composting manure to reduce nutrient levels.
[ ] d. decreasing N to P ratios below 2:1.

10. A zero or net-negative balance for nutrient distribution means
[ ] a. non-point source pollution will be eliminated.
[ ] b. the soil is being nutrient enriched over time.
[ ] c. nearly equal or greater amounts of nutrients are being removed by harvested crops than are land applied.
[ ] d. only inorganic fertilizer sources are being used in crop production.

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