A PRELIMINARY NUTRIENT USE GEOGRAPHIC INFORMATION SYSTEM (NUGIS) FOR THE U.S.

Q.B. Rund, P. Fixen, R. Williams

PAQ Interactive,
Monticello, IL, USA

ABSTRACT

NuGIS is a project of the International Plant Nutrition Institute (IPNI). The goal was to examine sources of nutrients (fertilizers and manure) and compare this to crop removal. The project used GIS and database analysis to create maps at the state and county level and then used GIS to migrate the budget analysis to the local watershed and regional watershed levels. This paper will cover the sources of data used, how the data was processed to generate county level numbers, and how GIS was used to migrate these data to watersheds.

INTRODUCTION

Several critical contemporary agricultural issues have the potential to impact nutrient balances for U.S. cropland. Production of bioenergy can alter nutrient removal due to changes in crop species and plant parts harvested, and can alter nutrient additions due to production of bioash and changes in manure composition induced by feeding distillers grain. Climate change may cause changes in crop yields, cropping patterns, and soil processes. Accelerated genetic changes have been promised that could alter crop yields and nutrient use efficiency. Recent major changes in fertilizer costs and crop prices have altered farm fertilizer use decisions. And, government policy can cause shifts in all of the above. Considering the potential future impact of these issues, it is critical to understand the current status of nutrient balances, temporal trends of those balances, and relevant inferences about nutrient use efficiency.

NuGIS integrates multiple data layers to create county-level estimates of nutrient removal by crops, fertilizer applied, and excreted and recoverable manure nutrients. Nutrient balances were estimated for the five Census years from 1987 through 2007. Geospatial techniques were used to migrate the county data to 8-digit hydrologic units for watershed evaluation. For a complete discussion of methods and the resulting maps and datasets, please see A preliminary nutrient use geographic information system (NuGIS) for the U.S. IPNI Publication No. 30-3270.

METHODS

In order to make consistent comparisons across space and time we selected years for our analysis where data were available from each source with some degree of consistency in reporting shows the availability of data by year of the Ag Census. This is not to say that 1982 Ag Census data do not exist, but they are not readily available in electronic format at the county level. Also, the lack of data from the American Association of Plant Food Control Officials (AAPFCO), would have changed the balancing procedure, so we chose to use the Ag Census data from 1987 to 2007 (which became available Feb 4, 2009).

Data Availability Matrix.

Source	1982	1987	1992	1997	2002	2007
AAPFCO		x	x	x	x	x
Ag Census		x	x	x	x	x
Kellogg	x	x	x	x	x	x
NASS	x	x	x	x	x	x

Estimating Nutrients from Commercial Fertilizers

Data for estimating the nutrients from commercial fertilizers was provided by the AAPFCO. This group provides commercial fertilizer sales data each year for fertilizer products sold as tons of single nutrient fertilizers, tons of multiple nutrient fertilizers, and total tons of N, P_2O_5, and K_2O that were contained in those fertilizers sold. We used the AAPFCO values for total tons of N, P_2O_5, and K_2O sold per year as a basis for estimating the nutrients applied with commercial fertilizers at the county level.

From the appendix to the Commercial Fertilizer series (Slater and Kirby, 2008), "Commercial Fertilizers is based on fertilizer consumption information submitted by state fertilizer control offices. The consumption data include total fertilizer sales or shipments for farm and non-farm use. Liming materials, peat, potting soils, soil amendments, soil additives, and soil conditioners are excluded. Materials used for the manufacture or blending of reported fertilizer grades or for use in other fertilizers are excluded to avoid duplicate reporting. Some states do not report final grades; therefore, basic materials including both single-nutrient and multiple-nutrient are reported. Significant effort was made to check the accuracy of and faithfully summarize each state’s data; however, AAPFCO is not responsible for the accuracy of the data.”

Commercial fertilizer data are available from AAPFCO dating back to 1985. The 1985-1994 data were compiled and originally published by the Tennessee Valley Authority (TVA). The structure of the data has remained fairly consistent over time. From the above statement, it is apparent that some safeguards are in place to help protect from counting sales of the same fertilizer more than once, but the conclusion is that the data are presented as-is.

Generally, AAPFCO data are provided at the county level for most states in the U.S., but this varies by state and year. Some states have values reported for every county in the state, some states only have values reported for some of the counties in the state, and some states only have a state total value reported. Many states also reported an ‘Unknown’ county value for fertilizer sales. These represent tons of fertilizer sold in a state that could not be attributed to a specific county.

Counties in the lower 48 states reporting fertilizer sales data, by year.

ear	Counties Reporting	% of all lower 48 state counties (3,117)
987	2253	72%
992	2259	72%
997	2235	72%
002	2249	72%
007	2198	71%

For each year, if sales data were reported for a county, we accepted the county values as they were reported. If data for an ‘Unknown’ county were also reported in the same state, then we apportioned the values for that ‘Unknown’ county to each county in that state that reported data to AAPFCO. If a state total was the only datum available, then the values from that total were apportioned to all counties in the state, based on each county’s expenditures on fertilizer.

Apportioning AAPFCO Unknown County Values

Unknown county values in the AAPFCO data were apportioned to each county in a state that was present in the AAPFCO data based on the fertilizer sales values each county reported.

The amount of the unknown value that was apportioned to each county was calculated based on an ‘Unknown county coefficient’. This coefficient was calculated for fertilizer N, P_2O_5, and K20 for each state by dividing the (Unknown county value) by the (Sum of reporting county values). The value to add to each county value was then calculated multiplying (County tons sold) by the (Unknown county coefficient). This calculated value was then added to any fertilizer sales values already reported for that county.

Apportioning State Total Fertilizer Sales to Counties in a State

When a state total of fertilizer sales was the only datum reported, that total was apportioned to all counties in that state. To help apportion fertilizer sales in this situation, we used data from the Census of Agriculture for ‘Dollars spent on Fertilizer and Lime Products’ for each county. The amount of state total fertilizer sales that were apportioned to each county was calculated based on a ‘Fertilizer $ to Fertilizer tons coefficient’. This coefficient was calculated for fertilizer N, P_2O_5, and K20 for each state by dividing the (State total tons X sold) by the (sum of $ spent on fertilizer and lime products in all counties in that state). The value for each county was then calculated using (County $ spent on fertilizer and lime products) X (Fertilizer $ to Fertilizer tons coefficient).

Estimating Dollars Spent on Fertilizer

Values for 'Dollars Spent on Fertilizer and Lime products' and 'Acres Fertilized' are reported by county in the Census of Ag. Each year, the value of 'Dollars spent on fertilizer and lime products' is undisclosed for some counties. When Dollars Spent on Fertilizer and Lime products was undisclosed for an individual county, the value from that county would still be included in the state total 'Dollars spent on Fertilizer and Lime products'. The sum of 'Dollars spent on Fertilizer and Lime products' was calculated for all counties disclosing this value in a state, and that sum was subtracted from the state total 'Dollars spent on Fertilizer and Lime products' yielding a 'State Remainder Dollars spent on Fertilizer and Lime products'.

This remainder was apportioned to all counties that were undisclosed using the value for 'Acres Fertilized'. A coefficient was calculated that represented the ratio of 'State remainder Dollars spent on fertilizer' to 'Acres fertilized in counties where dollars spent on fertilizer was undisclosed'.

Estimating Fertilized Acres

In some rare situations, neither 'Dollars spent on fertilizer and lime' nor 'acres fertilized' were disclosed in the Census of Ag. On these occasions we estimated the acres fertilized for that county using data from the Census of Ag for 'Number of Farms spending Dollars on Fertilizer and Lime products' the 'Average Farm size', and the 'state Total Cropland acres'. For counties that did not disclose dollars spent on Fertilizer and Lime products, we performed a rough estimate of fertilized acres using (Number of Farms spending dollars on Fertilizer and Lime products) X (Average Farm Size). Because not every acre on every farm is fertilized each year, this estimate was refined using a coefficient representing the average percent of cropland acres fertilized for each state, calculated using (State total acres fertilized) / (State Cropland). Our final Acres Fertilized estimate was calculated using:

((County 'A' Number of Farms Spending $ on Fertilizer and Lime) X (County 'A' Average Farm Size)) / ((State Total Acres Fertilized) / (State Cropland))

Estimating Farm and Non-Farm Fertilizer Use

The methods above describe how we estimate total fertilizer use for a county. However, not all fertilizer is used for farm (agricultural) purposes. Methods were described by Ruddy et al. (2006) where they used fertilizer product sales data reported to AAPFCO and population density data to estimate the amount and distribution of Farm and Non-Farm fertilizer N and P use at the county level. These estimates were performed for each year from 1982 thru 2001.

Ruddy estimated Farm and Non-farm fertilizer use by analyzing AAPFCO fertilizer mixture sales reports in states that reported sales of those mixtures as being for farm or non-farm uses. PAQ did not have access to these data. In the years between 1982 and 2001, only about 20 to 25 states reported sales like this in any given year. Ruddy calculated a total, for all the states that reported farm and non-farm sales, of the amount of each mixture sold into farm and non-farm categories. They then calculated a national ratio of farm to non-farm use for each of these fertilizer mixtures.

Ruddy then applied this national farm to non-farm use ratio to State fertilizer mixture sales data for each fertilizer mixture, in each of the 48 states. They then apportioned farm fertilizer to counties based on county expenditures of dollars on fertilizer from the Census of Agriculture and apportioned non-farm fertilizer based on county population and population density.

We used Ruddy's county level farm and non-farm fertilizer use estimates for 1987 through 2001 to calculate a coefficient of Farm fertilizer to Total Fertilizer. We then multiplied our Total Fertilizer estimate by that coefficient to estimate the amount of Farm Fertilizer used. For 2007, we used the same coefficients as 2001. We performed this process for N and P using Ruddy's data. To estimate Farm Use K Fertilizer we used the same coefficients as for N.

Estimating Nutrients from Manure

Estimating Manure Volume

Manure volume is not a value that is reported in any national datasets. A combination of livestock inventory and sales data from the Census of Ag, and findings from previously published studies was used to estimate the annual volume of manure generated by several different species of livestock, by county. Estimates of average annual manure excretion and nutrient content of that excreted manure are available for numerous livestock species and categories. These estimates are reported per "Animal Unit", which represent 1,000 pounds of live animal weight.

Manure excretion and nutrient content of that manure differs between animals within these species (e.g. Beef Cows and Beef Heifers generate different amounts of manure and that manure has different nutrient concentrations). Also, differences in feeding and livestock management affect the amount of excreted manure per animal and the nutrient quantity per unit of manure.

Finally, the ability to physically collect and remove manure for application on the field and the volatility of the nutrients in that manure differ based on animal species and manure handling practices. Because of this, estimation of Recoverable Manure Nutrients is a multi-step process that involves:

1. Estimating average annual animal units by species and type
2. Estimating excreted manure by species and type
3. Estimating % of excreted manure nutrients that can be recovered for use as fertilizer

Estimating Average Livestock Animal Units

Kellogg et al. (2000) published a paper with the USDA titled "Manure Nutrients Relative to the Capacity of Cropland and Pastureland to Assimilate

Nutrients". Here, Kellogg describes a very detailed methodology for using 1982 - 1997 Census of Agriculture data to estimate Animal Units, excreted manure, manure nutrient content and manure recoverability for various groups of livestock including cattle, poultry, and swine. Kellogg used numerous algorithms to perform these estimates.

Average number of animals on farms per year is not reported by the Census of Ag. However, values of year-end livestock populations and sales are provided by the Census of Ag, and these values were used in combination with algorithms and assumptions based on those published by Lander et al. (1998) and later Kellogg et al. (2000), to estimate Average Annual Animal Units for each livestock type, including: Cows, Heifers, Bulls , Steers & Calves, Fattened Cattle, Calves Sold, Cattle over 500 lbs Sold, etc; or Laying Poultry, Broiler Poultry, Pullets that will become Layers, Pullets Sold for Layers, Pullets Sold for Broilers, etc.

County level livestock inventory and sales data were available from the Census of Ag, but many individual livestock types were undisclosed in many counties, as well as some states. The extent of county level non-disclosure for some livestock categories was large and made estimations of manure using the county level Census of Ag data problematic. Values for most of these livestock categories were disclosed at the state level for most years. Consequently, it was decided to calculate State-level excreted manure volume and excreted manure nutrient estimations for each year in our study, and apportion those state-level estimates to each county in each state based on findings published by Kellogg et al. (2000).

As a test of the methods we used to estimate State-level animal units using Census of Ag data, we summed Animal Units reported by Kellogg for 1997 by State, grouped by livestock category, and compared those summaries to our State-level estimates. This comparison yielded a coefficient of determination (r^2) of 0.996, which indicated very close agreement.

Estimating Excreted Manure and Nutrients at the State Level

After using the modified Kellogg algorithms to estimate State level Animal units for each year, we multiplied those Animal Unit (AU) values by coefficients defining the amount of manure per animal unit per year, and coefficients defining the amount of N and P included in each ton of excreted manure. This gave us the State Total Excreted Manure, Excreted Manure N, Excreted Manure P, and Excreted Manure K by livestock type. These values were then summed across livestock types to give a State Total Excreted Manure, Excreted Manure N, Excreted Manure P, and Excreted Manure K.

While we were confident that we could estimate Animal Units and Excreted Manure at the state level, we were not confident that we could improve Kellogg's County-level estimates by attempting to perform our own county level calculations, primarily due to the fact the Kellogg had access to data that were undisclosed to us. Therefore we decided to apportion the State-level estimates of Excreted Manure and Excreted Manure Nutrients to each county in the state using Kellogg’s published county-level data.

Why didn't we just use previously published results directly?

Kellogg et al., (2000) published estimates of excreted and recoverable manure N and P, at the county level for all states in the U.S. Ruddy et al. (2006) also published similar estimates for all counties in the lower-48 states. We chose to perform our own estimates instead of using these datasets directly for a couple reasons: Kellogg's study included years 1982 – 1997, Ruddy's study included years 1982 – 2001. Our NuGIS study covers years 1987 – 2007, so we needed to be able to create a dataset that would cover all the years in our study. A second primary reason is that the Kellogg et al. and Ruddyet al. state and county data include the total amount of manure and excreted and recoverable manure nutrients, but they do not report Animal Units by livestock type. We wanted to have Animal Unit values for each livestock type so that, if we chose, the excreted manure, recoverable manure, and associated manure nutrient coefficients could be adjusted and values for manure and manure nutrients could be recalculated. This would be particularly important if we wish to compare different 'Animal Unit to Excreted Manure' ratios for distinct regions, or for individual years.

Apportioning State Excreted Manure Nutrients to Counties

County-level Excreted Manure estimates for 1987 – 1997

State total manure nutrient estimates, calculated using Census of Ag data for 1987 – 1997 were apportioned to counties using a 'State-to-County Manure Nutrient' coefficient calculated with the Kellogg et al. county level manure nutrient estimates. The coefficient represents the percent of state total excreted manure nutrient that Kellogg et al. apportioned to each county.

State totals of Excreted Manure Nutrients calculated using the Census of Ag data were then apportioned to each county in a state by multiplying the State Total Excreted Manure Nutrient value by the State-to-County manure nutrient Coefficient for each county.

This apportioned the NuGIS State Total Excreted Manure Nutrients to counties in the same proportion as the Kellogg et al. excreted manure nutrient estimates.

We performed these calculations for all counties in all states in the lower-48, for excreted manure N, excreted manure P, and excreted manure K, for 1987, 1992, and 1997.

Because K was not reported by Kellogg et al., it was not possible to calculate a State-to-County Coefficient for Manure K. After discussion with colleagues, it was determined that excreted Manure K would likely have a State-to-County coefficient similar to the State-to-County Coefficient for Excreted Manure Nitrogen. Therefore, Excreted Manure K was estimated using the State-to-County excreted manure N coefficient.

County Level Excreted Manure Estimates for 2002 - 2007

For years 2002 - 2007, excreted manure, excreted manure N, excreted manure P and excreted manure K were calculated at the state level using values reported in the 2002 and 2007 Census of Agriculture, as done for previous years, but there were no county level estimates from Kellogg et al. for these years, and therefore no State-to-County Coefficients. For these years, the state-level data were apportioned to each county in each state using a *forecast* "State-to-County manure N Coefficient" and a forecast "State-to-County manure P Coefficient".

Forecasting State to County Manure Nutrient Coefficients for 2002 & 2007

These forecast state-to-county manure nutrient coefficients were calculated using the Kellogg et al. historical estimates of lbs of N and P in excreted manure, and lbs of N and P recoverable from that manure, by county, for 4 years. The Kellogg et al. excreted lbs N and excreted lbs P values were input into a forecast function in Excel for Ag Census years 1982, 1987, 1992, and 1997, and used to calculate the forecast county level excreted lbs N and excreted lbs P for 2002 and 2007.

The goal of forecasting excreted lbs N and P was to predict what percentage of the state total excreted and state total recoverable manure N and P would be in each county. We calculated this percentage by summing the forecast county level excreted lbs N and excreted lbs P values by state, to yield the forecast state excreted manure N and forecast state excreted manure P values. Next, we divided the forecast county level excreted manure N value and forecast county level excreted manure P value by the forecast state excreted manure N and forecast state excreted manure P values. This gave us the forecast ratio of state to county manure N & P.

Apportioning 2002 & 2007 State Total Excreted Manure Nutrients to counties

Finally, County-level Excreted Manure N was estimated by multiplying the State-total Excreted Manure N by the Forecast State-to-County manure N Coefficient for each county. County-level Excreted Manure P was estimated by multiplying the State-total Excreted Manure P by the Forecast State-to-County manure P Coefficient for each County.

Because K was not reported by Kellogg et al., it was not possible to calculate a Forecast State-to-County Coefficient for Manure K. After discussion with colleagues, it was determined that Excreted Manure K would likely have a State-to-County coefficient similar to the State-to-County Coefficient for Excreted Manure Nitrogen. Therefore, Excreted Manure K was estimated using the Forecast State-to-County excreted manure N coefficient.

Estimating Recoverable Manure Nutrients

Recoverable Manure represents the amount of nutrients from excreted manure that would be available to apply to the land as fertilizer. A variable amount of nutrients in excreted manure are lost during storage and handling, because of actual losses of the excreted manure to processes such as runoff (N,P,K) and because of losses to the air (N only). Kellogg et al. estimated recoverable manure for each livestock category using an equation that accounted for the 'confinement factor' representing the percentage of animals that were confined, a ‘recoverability factor’ representing how well the physical excretions could be collected, and the amount of nutrients that would likely be lost due to leaching and volatilization during storage and handling. Confinement, recoverability, and losses during storage and handling varied by county and by farm due to regional differences in livestock and manure storage practices.

Due to the extent of undisclosed Census of Ag data at the county level, calculating a confinement factor using Census of Ag data was problematic. Kellogg et al. had access to all county data, without the problems of non-disclosure, and provided estimates of Excreted and Recoverable Manure Nutrients. To calculate the amount of recoverable manure for counties, we examined the ratio of excreted to recoverable manure nutrients as reported by Kellogg. This ratio was then applied as a coefficient to the NuGIS County-level Excreted Manure nutrient estimates to calculate a NuGIS County-level Recoverable manure nutrient estimate.

Because K was not reported by Kellogg et al, it was not possible to calculate an Excreted to Recoverable Manure Coefficient using the Kellogg et al. data. for K recoverability at the State-level were from IPNI (Appendix 6.3 in PPI/PPIC/FAR, 2002). These data from IPNI were used to calculate an Excreted to Recoverable Manure K coefficient. Because data were available only at the State-level, all counties in a state received the same K recoverability coefficient.

Because K data were only available for 1997, Excreted to Recoverable Manure N and Excreted to Recoverable Manure P coefficients were calculated using the Kellogg et al. Excreted and Recoverable Manure N and Excreted and Recoverable Manure P estimates for 1997 only. The 1997 Excreted to Recoverable Manure Nutrient coefficients were then applied to the NuGIS County-level Excreted Manure Nutrient estimates for N, P, and K, for all counties, for 1987, 1992, 1997, 2002, and 2007, to calculate the NuGIS County-level Recoverable Manure Nutrient estimates.

Conversion of P and K to P_2O_5 and K_2O

Values for Excreted and Recoverable Manure P and K needed to be converted to equivalents of P_2O_5 and K_2O to be used as input to the Nutrient Balance equations. Pounds of P and K were converted to pounds of P_2O_5 and K_2O using: 1 lb P = 2.92 lbs P_2O_5; 1 lb K = 1.2 lbs K_2O

Handling the Kellogg et al. Undisclosed Counties

In a situation similar to that encountered in the NASS Annual Summary datasets, Kellogg et al. combined the values for manure tonnage and manure nutrient tonnage for several nearby counties together if it was deemed that reporting those counties individually might identify an individual producer. Kellogg et al. reported the values for these combined counties as one record and provided a companion table identifying which counties were included in each combination. However, there was no information identifying how much of each value was attributed to each county in the combination.

A similar study was performed by Ruddy et. al, and it also used the methods and algorithms used by Kellogg et al. However, Ruddy et al. reported their findings for every county. The authors in the Ruddy et al. paper appear confident that their method provided an accurate representation of the distribution of livestock among counties in a State, although the estimated total numbers of livestock in that State might not be as accurate as other methods.

When Kellogg et al. reported data for "grouped counties", estimates for individual counties within each group were performed using a ratio developed with data from Ruddy et al. The first step in calculating this ratio was to get a list of counties in each of the Kellogg et al. combined counties records. For each individual combination, the estimates by Ruddy et al. for excreted and recoverable manure N, and P were obtained for each county within that combination. Those county values were then summed, to create a 'Ruddy et al. combined total'. Each county value was divided by its associated Ruddy et al. combined total to yield a % of combination total coefficient. We then multiplied the Kellogg et al. combined county value by the '% of combination total coefficient'

We are confident that this method retains the regional accuracy of the Kellogg et al. method, while enhancing the spatial precision gained from the Ruddy et al. method.

Fate of Non-recoverable Manure Nutrients

Non-recoverable manure nutrients are those in manure that are not collected for land application (e.g. that which is deposited while grazing in pastures) and the nutrients considered unavailable owing to losses during collection, transfer, storage, and treatment. The method used for estimating recoverable manure nutrients takes into account both recoverability of the manure and losses of each nutrient in the recovered manure (Kellogg et al., 2000).

Nutrients deposited on pastures replenish nutrients removed by grazing, a portion of the nutrient cycle that is not reflected in NuGIS crop nutrient balances. Such nutrients do comprise an important potential non-point source of water contamination. Risks of harm to water quality are managed primarily by managing grazing intensity (frequency and stocking rate) with the goal of maintaining sufficient vegetative cover of the soil to prevent erosion and minimize surface runoff losses.

The nutrients in recovered manure that are considered unavailable also pose potential risks of environmental harm. The management of these risks falls more under the scope of managing livestock rather than plant nutrition; nevertheless, steps taken to improve nutrient availability in manure, particularly by minimizing nitrogen losses, can benefit crop nutrition. Nitrogen losses can be significant from the moment of manure excretion, in the barn, during handling, and during storage.

Recent Changes in Livestock Feeding Practices

Livestock producers have been made aware of nutrient imbalances arising from continued application of manure, particularly on farms that import significant quantities of feed. As a consequence of the adoption of more rigorous nutrient management plans, producers have also adopted practices (precision feeding for ruminants, phytase for monogastrics) that reduce the amount of nutrients excreted by their livestock. As an example, Swink et al. estimated that the amount of P excreted per dairy cow per production period has been reduced from 62 to 40 pounds. Figures from The Fertilizer Institute indicate that total domestic feedgrade phosphate sales peaked around 1996, declined by 30% by 2006 and for the last two years (2008-2009) have been down to only 44% of the 1996 peak level. A considerable portion of this decline may have been offset by increases in use of dried distillers grains with soluble (DDGS) from the ethanol industry. Nevertheless, the change in P input in livestock feeds is likely to be reducing considerably the amount of P in manure excreted, and this trend since 1996 is not reflected in the NuGIS recoverable manure nutrient estimates.

Estimating Nutrient Removal and N Fixation by Harvested Crops

The same harvested crop removal coefficients were used for all states (IPNI 2010). Nitrogen fixation by peanuts, soybeans, and alfalfa was considered to be equal to N removal by these crops.

NASS, the Census of Ag, and the ERS were sources of data for planted acres, harvested acres, average yield, and production of crops at the County level. Data were analyzed for Alfalfa, Apples, Barley, Dry Beans, Canola, Corn for grain, Corn for silage, Cotton, Other Hay, Oranges, Peanuts, Potatoes, Rice, Sorghum, Soybeans, Sugar beets, Sugarcane, Sunflower, Sweet corn, Tobacco, and Wheat. Other Hay is considered any hay reported in the Census of Agriculture or NASS Annual Summaries that is not Alfalfa. Wheat included Winter Wheat.

County crop production data were used in conjunction with crop nutrient removal coefficients for N, P_2O_5, and K_2O, to estimate the nutrient removal by crops. Crop Production, Harvested Acres and Planted Acres data were averaged over a three year period, centered on the Census of Agriculture years of 1987, 1992, 1997, 2002, and 2007.

Census of Agriculture

Estimations of Farm Production, Expenditures, Inventory, Size, Extent of Cultural Practices, and more are provided by the USDA-NASS Census of Agriculture, conducted every 5 years. Farms with more than $1,000 in annual sales are asked to provide information on their operation. This Census information is used by NASS to estimate statistical data about agriculture in the US. These data are made available to the public, but if data could be attributed to a specific producer they are withheld to protect their privacy. When this occurs, the data for the specific commodity are listed as undisclosed for that county and no value is published. Often, although the value for a specific commodity is undisclosed at the county level, this value is included in the state total for that commodity. Fertilizer expenditure data were undisclosed for some counties and fertilized acres data were undisclosed for about half of those.

Crop Production Data Sources

The majority of the Crop Production, Harvested Acres, and Planted Acres data comes from the "NASS Annual Ag Statistics Summary" datasets, though data for some crops were not included in these annual statistics datasets. When production data were not available from NASS summaries, other sources were investigated, including the Census of Agriculture, State NASS office publications and ERS Publications.

At times, data for a particular crop were available from NASS Annual Summaries for some years, but not available for all years. In these cases, we included the Annual NASS data when reported and used Census of Ag data or State NASS publications, when available, for the remaining years. If production data were only available from the Census of Ag, we used those data even though they only represented one year, instead of the 3-year average we typically used.

While the NASS Annual Summaries and the Census of Ag provide comparable data, they report crop acreage and production using different methods and handle non-disclosure differently. The NASS Annual Statistics datasets report harvested acres, planted acres and production for a particular crop in one record; Crop name, county, year, planted acres, harvested acres, and harvested volume (production) are all fields in a single record. The Census of Agriculture datasets report harvested acres and production for a particular crop in separate records; Crop name, County, year, and harvested acres are fields in one record, and Crop name, County, year, and harvested volume (production) are fields in a different record. Planted acres are not reported for individual crops in the Census of Ag; Harvested acres are used in the place of planted acres when Census of Ag data are used to provide acreage data.

Working with Undisclosed Data

When working with NASS and Census of Ag datasets, we frequently encountered undisclosed data. Data for a County are undisclosed if it could identify an individual farmer or producer, or there was not enough information available that year to make a statistically sound estimate.

In the NASS Annual summary datasets, when data for a county are undisclosed, the value of that item is combined with data from other counties in that state for the same item, and there is no individual record for that item for any of the counties that are combined. Instead, the data for these counties are reported as "Combined Counties". Typically, county data is combined with neighboring counties within the same Agricultural Statistics District, and the data are reported as "District # Combined Counties". (# is replaced by the Ag Statistics District ID, such as 50). However, sometimes the counties are not combined within an Ag Statistics District but are combined with other counties within a State. When this is done, the combined data are reported as "District 98 Combined Districts".

In the Census of Ag datasets when data for a county are undisclosed there is still a record for that county, but a '(D)' replaces the item value. The value for this undisclosed item is included in the state total.

Total Cropland Acreage Estimates

While the methods used to estimate values for undisclosed items in NASS Annual Statistics and Census of Ag datasets differ, they both use the county "Total Cropland acres" value reported by the Census of Ag to help perform these estimates.

Estimations of Total Cropland Acres by county are provided by the Census of Ag. These values are used to aid in estimating crop acreage, crop production, and other values for counties when items for a county are undisclosed.

However, each year total cropland values for counties were themselves undisclosed for some counties. In order to estimate these undisclosed counties, we used a linear fill tool using total cropland acreage values for the years when those data were disclosed. If a county's total cropland acreage data were undisclosed for all years in our study, its acreage was considered zero.

The linear fill tool took in the total cropland acreage data and total cropland acreage data flags from the Census of Ag for each of our study years, 1987, 1992, 1997, 2002, and 2007. If the total cropland acreage data flag indicated that data were undisclosed for 1992, the tool took the total cropland acreage data for 1987 and 1997, calculated the difference in total cropland acreage values for those years and divided it by two. This value was then added to the 1987 value. This effectively yielded the average of the two years. If the total cropland acreage value for 1987 was also undisclosed, then the tool set the 1987 and 1992 data equal to the 1997 data.

If data for multiple years were undisclosed within our study years, but the first and last years were disclosed, the tool performed the linear fill by distributing the difference between the first and last year among the 3 missing years.

Estimating Undisclosed County Data in the NASS Annual Summary

The NASS Annual summary datasets report undisclosed data as combined counties within a district, or combined districts within a State. To apportion the data from these combinations to individual counties requires multiple 'passes' over the NASS Annual Summary dataset. We created a new "Master" table populated with all the Counties in the contemporaneous U.S., once for each commodity and each year.

1. Individual county commodity reports from the NASS Annual Summary were placed in the Master table.
2. Data were estimated for combined counties and placed in the Master table.
3. Data were estimated for counties within the combined districts and placed in the Master table.

To apportion data from combined counties within a district, we first identified which counties were within that district. Next, we identified which counties within that district reported data for this commodity and removed those from consideration. This provided a list of counties within a district that did not have individual commodity reports, and were thus likely to be members of the combined counties within that district. To refine this list, we examined the Census of Ag data for the year nearest this year. If a county did not report data (a number, (D), or -) to the Census of Ag for harvested acres or production of this commodity, in that year, it is assumed that that county did not produce any of this commodity, and that county was excluded from the list of counties in that combination . We then compared the Total Cropland Acres for each individual county in the combination list to the sum of Total Cropland Acres of all of the counties in that combination list, in that district (for each year, and each commodity individually). This gave a ratio that we used to apportion the data reported for the Combined Counties within that district to each county within that combination.

To apportion data from combined districts within a state, a list was created of the counties within that state which did not already have data associated with them from either individual reports or combined county reports. To refine this list, we examined the Census of Ag data for the year nearest that particular year. If a county did not report data (a number, (D), or -) to the Census of Ag for harvested acres or production of this commodity, in that year, then it was excluded from the list of counties in that 'state-wide' combination. The value reported for the Combined Districts was then apportioned to the individual counties in that list using the familiar method of comparing the total cropland acres of each county in that list to the total cropland acres of all the counties in that list. This gave a ratio that we then used to apportion data reported from the Combined Districts within that State to each county within that combination.

Estimating Undisclosed County data in the Census of Agriculture

The Census of Agriculture datasets report undisclosed county data by replacing the undisclosed value with a "(D)". Census of Ag data typically reports a state total for most commodities.

There are four common non-disclosure scenarios encountered when working with Census of Ag data:

For a single county, in a particular year, for a particular crop:

1. Harvested Acreage and Production are both disclosed
2. Harvested Acreage is disclosed, but Production is not
3. Production is disclosed, but Harvested Acreage is not
4. Neither Harvested Acreage nor Production are disclosed

In Scenario #1, nothing further needs to be done to the data

In Scenario #2, we estimate Production based on the value of County Total Harvested Acres and an estimated state average yield specific to undisclosed counties

In Scenario #3, we estimate Harvested Acreage based on the value of County Total Cropland Acres and a state average ratio of Harvested Acres to Total Cropland specific to undisclosed counties

In Scenario #4, we first estimate Harvested Acres as described above, then estimate Production, also as described above.

Estimating Undisclosed Harvested Acreage Data in the Census of Ag

When Census of Ag Harvested acreage for a commodity is undisclosed for some counties in a state, subtracting the sum of disclosed harvested acres for a commodity from the state total harvested acres for that same commodity yields a remainder. We call this remainder the ‘State Harvested Acres Remainder’; this remainder represents the sum of harvested acres in undisclosed counties. We apportion the State Harvested Acres Remainder to each non-disclosed county in a state based on each county’s Total Cropland acres as reported in the Census of Ag.

For each commodity, the amount of remainder that is apportioned to each undisclosed county was calculated using a ‘Harvested Acres to Total Cropland Acres coefficient’. This coefficient was calculated, for each commodity, in each state, by dividing the (State Harvested Acres Remainder) by the (Sum of Total Cropland Acres in counties with non-disclosed harvested acres). The County Harvested Acres were then calculated using:

(County Total Cropland Acres) X (Harvested Acres to Total Cropland Acres coefficient).

Estimating Undisclosed Crop Production Data in the Census of Ag

When Census of Ag Production data for a commodity were not disclosed for some counties in a state, subtracting the sum of disclosed production for a commodity from the state total production for that same commodity yielded a remainder. We call this remainder the ‘State Production Remainder’; this remainder represents the sum of production in non-disclosed counties for that commodity. We apportion the State Production Remainder for this commodity to each county in a state with non-disclosed production for this commodity, based on each county’s harvested acres of this commodity as reported in the Census of Ag or as estimated as described above.

For each commodity, the amount of State Production Remainder that is apportioned to each county with a non-disclosed production value was calculated using a ‘Production to Harvested Acres coefficient’; this could also be thought of as an estimated yield. This coefficient was calculated, for each commodity, in each state, by dividing the (State Production Remainder) by the (Sum of Harvested Acres in counties with non-disclosed Production). The county crop production was then calculated using

(County Total Cropland Acres) X (Harvested Acres to Total Cropland Acres coefficient).

Another value that can be reported by the Census of Ag for Acreage or Production, besides a numeric value, or “D” for non-disclosed, or “-“ for zero, is an “N” or “NA”; representing “not available” or “not reported”. We do not apportion data to records with “N” or “NA” except in one situation: where, for a particular item, no counties are listed as undisclosed, but the sum of county values for that item within a state is not equal to the state total for that item. A similar situation can occur if the harvested acres or production data for a particular commodity were only reported as a state total, and no values were reported for any counties in the state for that commodity. In this situation, if any counties reported an “N”, indicating their report was “Not Available” the remainder from the state total was apportioned to these “N” counties using the same methods used to apportion values to non-disclosed counties.

The ‘hierarchy’ we settled on for the use of crop production data is as follows:

1. NASS Annual Summary data reported for a county
2. NASS Annual Summary data reported as part of a group of counties
3. NASS Annual Summary data reported as part of a group of districts
4. Census of Agriculture data
5. Data from a State NASS office or ERS (Sweet corn, Apples, Oranges)
6. Any county that does not have data reported in any of these sources is given a value of 0 for production.

If data were not available from the first source, they were estimated using data from the second source, and so on.

Estimating Production

Data from all the resources described above were compiled for three- year periods surrounding the Census of Ag years (1986, ’87’, 88; 1991, ’92’,’93; 1996, ’97’, 98; 2001, ’02’, 03; 2006, ’07’, 08). These data were then averaged for each 3-year period. If data for a certain commodity were not available for all 3 years, we calculated the average by dividing the sum of the values reported by the number of years available. (A county with data for 2 years had its values for those 2 years divided by 2; If only 1 year was available that value was divided by 1).

Calculating Removal

Removal values were calculated by multiplying the estimated 3-year average production of each crop by that crop's nutrient removal coefficient, for each county. Removal values for each crop were then summed together for each county to provide a total N, P_2O_5, and K_2O removal value for each county.

After reviewing State crop production data for 1998 - 2000 compiled by PPI staff from multiple sources including USDA, ERS, and NASS, including State Offices (PPI, 2002), it was apparent that for some states, particularly those producing specialty crops, we were still representing less than 90% of crop removal even including data from 21 crops. We compared the 80 crops listed in the PPI bulletin to the crops included in the data that we had compiled for NuGIS from the NASS and Census of Ag data sources. If a crop was listed in the PPI bulletin but not in our NuGIS crops data, it indicated that we were missing removal data for that crop. Some of the data for these crops wer not available at the county level or not easily attainable for all the years we are studying.

To account for the nutrient removal represented by these missing crops, we calculated a ‘State Adjustment Factor’ for each state. The State Adjustment Factor represents the nutrients removed by the 21 crops included in NuGIS as a percentage of total nutrients removed considering all 80 crops in the PPI bulletin. This percentage was calculated for each nutrient in each state. This ‘State

Adjustment Factor' was then used to adjust our estimates of county N, P_2O_5 and K_2O removal by crops, for each year.

The State Adjustment Factor was calculated by dividing the average annual removal from 1996-1998 for the 21 NuGIS crops by the sum of this 21-crop removal and the average annual removal from 1998-2000 for the other 59 crops reported by PPI. This same State Adjustment Factor was used for all five years of the NuGIS data and was applied to all counties in each state.

Migration of County Data to Watershed Data

Input from fertilizers, manure, and crop N fixation, removal by crops, and planted and harvested acreage data were aggregated from the county to the watershed scale. Boundaries for watersheds were intersected with county boundaries to produce discrete polygons where each watershed and county overlapped. These polygons included data for their area, which county they were in and which watershed they were in. These polygons allowed us to identify how much area of each county was included within each watershed. Using that area, we calculated the percentage of each county within each watershed. This percentage was then applied to the estimated county nutrient balances for each county in each watershed. This produced a table for each watershed, describing what counties were in that watershed, what percentage of each county was in that watershed, and each county's values for inputs from fertilizer, manure, and N fixation, removal by crops, and planted and harvested acres were multiplied by that percentage. The procedure used is outlined below.

- Intersected HUC (hydrologic unit code) 8 polygons with counties.
- Re-calculated area of counties in Lambert Conformal Conic (LCC) projection.
- Calculated area of polygons created by intersect process in LCC.
- Brought table into Access, built query to compare county area to intersected area and calculate what % of each county's area is in each HUC-8 polygon.
- Recalculated input, removal, and acreage values for each polygon representing a unique watershed-county combination

The input, removal, and acreage values calculated for the portions of each county were then summed by watershed to produce input, removal, and acreage data at the watershed scale. Nutrient balances, Removal to Use Ratios, and balances per Planted Acre were then recalculated using this watershed scale data.

Watershed 8-digit HUC codes are a dissectible code, in that its first 2 digits identify the Hydrologic Region, the next 2 + the first 2 identify the Sub Basin, the next 2 plus the first 4 identify the Basin, and the whole 8 digit code identifies the Watershed. To build a regional dataset from a watershed dataset the data were separated into groups using the first 2 digits of the HUC code. Nutrient balance Values for each watershed were then summed for each 2 digit Region code.

Balance Calculations

Balances were calculated as a ratio of removal to use (sometimes referred to as "recovery efficiency by balance") and as lbs of nutrient /planted acre.

The Removal to Use ratio equation for N was: (Total N Removed by Harvested Crops) / (Fertilizer N + Recoverable Manure N + Legume N Fixation)

The Removal to Use ratio equation used for P was: (Total P_2O_5 Removed by Harvested Crops) / (Fertilizer P_2O_5 + Recoverable Manure P_2O_5)

The Removal to Use ratio equation used for K was identical in form to that used for P, except for substituting K_2O in place of P_2O_5.

The lbs of nutrient /planted acre balance equation used for N was: ((Fertilizer N + Recoverable Manure N + Legume N Fixation) - (Total N Removed by Harvested Crops)) / Planted Acres of Crops

The lbs of nutrient/planted acre balance equation used for P was: ((Fertilizer P_2O_5 + Recoverable Manure P_2O_5) - (Total P_2O_5 Removed by Harvested Crops)) / Planted Acres of Crops

The lbs of nutrient/planted acre balance equation used for K was identical in form to that used for P, except for substituting K_2O in place of P_2O_5.

Incorporating Land Use into Maps

The balances and statistics generated by NuGIS are directly related to agriculture. The county maps display balances and statistics for a county, but do not effectively convey the extent of agriculture within that county. For example, compare a county in Illinois with a county in Nevada. Both counties may have similar values for nutrient balances, but the county in Illinois has much more land used for agriculture. However, on the map the county in Nevada will stand out more than the county in Illinois, due to the larger geographic size of the county in Nevada. To counter this effect, we used a land use map, placed on top of the county balance map, to mask out all areas not identified as having an agricultural land use. This method is effective and appropriate because the NuGIS balances and statistics relate directly to nutrient inputs to, or nutrient removal from, agricultural land.

Land use / land cover datasets were obtained from the USGS "Land Cover Institute" website (http://landcover.usgs.gov/). Two spatial datasets were immediately available: the 1992 enhanced National Land Cover Dataset (NLCD-e1992) and the 2001 National Land Cover Dataset (NLCD2001). Both of these datasets are made up of 30-meter by 30-meter blocks that cover the entire contiguous U.S. Each block is assigned a numeric code that corresponds to the dominant land use and land cover within that 30-meter block.

Agricultural land uses were defined as any areas defined in the land cover dataset as "Orchards, Vineyards, other", "Pasture/Hay", "Row Crops", "Small Grains", or "Fallow". Blocks in the Land Cover Datasets that match these definitions have the codes: 61, 62, 81, 82, 83, & 84 respectively. These definitions are the same as those used in other studies.

To create the masking layer, any blocks representing agricultural land use are set as transparent, while all other blocks are set as opaque (white). This mask was then placed over other layers. We used the 1992 mask for 1987, 1992, and 1997 data and the 2001 mask for the 2002 and 2007 data.

When this masking layer is placed over another layer, such as the county nitrogen balances, color from the nitrogen budget layer will only be visible in areas defined as having agricultural land uses. Our application of land cover data differs from that of some other studies. We did not apply any data to specific land use blocks, or calculate any statistics from the land use layer. We only used the land use layer as a visual mask to provide a more accurate visual representation of agricultural lands. All balances and statistics were calculated at the county level, and not for land use blocks.

SYSTEMATIC ERRORS AND UNCERTAINTY

One of the objectives of the NuGIS project was to develop a nutrient use assessment process with complete transparency that would reveal any weaknesses in input data or the process itself. Along the way many conscious decisions were made concerning procedural steps that weighed potential error against data availability and cost. We hope that this exercise will illustrate where weaknesses exist so that as time passes improved input data will become available and the process itself can be improved. Here we list the major issues adding uncertainty to the nutrient balance estimates.

Fertilizer use

<u>Border issues with AAPFCO data</u>. The AAPFCO data, used as the primary source for county fertilizer nutrient use, is in reality sales data and uncertainty exists as to whether fertilizer is used in the same county as the point of sale. Though this causes uncertainty for specific county estimates, clusters of counties should be affected less and the comingling of county data done to create the 8-digit HUC maps should help as well.

<u>Lack of nutrient-specific Ag Census expenditures</u>. AAPFCO data were available for only 70-75% of the counties. When it was not available Ag Census data on fertilizer and lime sales were used to parcel the state AAPFCO data out to county levels. This procedure results in assuming the same N:P:K use ratio for an entire state. This is perhaps a reasonable assumption in some states, but it is problematic where gradients in soil supply of specific nutrients occur across a state or where regional differences exist within a state in crops grown. For example, in South Dakota where county level AAPFCO data are not available, from east to west across the state, soil K levels climb dramatically and cropping systems shift from row crops to small grains. In this case, apportioning nutrient use according to Ag Census sales data underestimates K use in the east and overestimates it in the west. The Ag Census would be much more useful for this purpose if it reported sales by nutrient.

<u>Separating farm from non-farm use</u>. The Ruddy farm to non-farm coefficients we used were developed based on fertilizer mixture use relationships from 1987-2001. As new fertilizer materials enter the market and fertilizer practices change in homes, professional turf, and on farms, these coefficients could also change. A direct reporting system would be advantageous.

Recoverable manure nutrients

Considerable variability exists in estimates of manure nutrient recoverability. We used the Kellogg et al. (2000) approach partly because it was well documented. A more direct systematic estimation technique driven by livestock animal units at a county level would likely result in improved accuracy. The nutrient content of manure may exhibit some temporal trends as feeding and livestock management systems change with time. Our approach did not account for such changes.

N fixation

We assumed that N fixation was equal to the N removed in the harvested portion of the major leguminous crops: soybean, alfalfa, and peanut. Implicit in this assumption is that the partial N balance of these crops is zero (N fixed - N removed = 0). This appears well supported for soybeans as Salvagiotti et al. (2008) in an extensive review of the literature reported an average partial N balance for soybeans not receiving N fertilizer of -4 kg/ha. It also is likely a reasonable assumption for peanuts. However, Peterson and Russelle (1991) in a review of alfalfa production in the U.S. Corn Belt states estimated N fixation by alfalfa at 61 lb/ton of hay and our N removal coefficient is 51 lb N/ton or 84% of their figure. Thus, we may be underestimating N fixation by alfalfa in our procedure.

Crop removal

Spatial or temporal variation in crop coefficients. NuGIS uses a fixed set of nutrient concentrations for the harvested portion of crops. The levels assumed are typical of those published by Land Grant Universities with some cross checking to feed analysis data when it is available. These coefficients need updating for many crops and should probably not be treated as constants across the entire country. For example, there is some evidence that corn grain P concentrations are higher in the northeast U.S. than in the western Corn Belt. Also, it is possible that changes in cultural practices and genetics could alter the nutrient concentration in harvested crops. Unfortunately, at this time there is no systematic method for accounting for such differences.

Estimates for specialty crops. We estimate that the 21 crops in NuGIS capture 95% or greater of crop nutrient removal for 41 of the 48 states; 90% or greater for 44 states. The four states dropping below 90% for at least one nutrient were Arizona, California, Florida, and Georgia (**Table 6.1**). The crops included in the PPI set of 80 that were not included in the NuGIS 21 but were significant in the particular state are also shown in table 6.1. Since production data for these specialty crops were not consistently available for the time periods needed, nutrient removal for them could not be explicitly included in NuGIS, thus our approach of dividing the 21-crop total by a state coefficient to approximate total removal for the state. At least a couple sources of error are incurred with this procedure. First, it forces missing crop removal to be split among all counties in the state. Considering the distribution of many specialty crop growing areas within states, this clearly introduces an error. Secondly, by using the same state coefficients for the entire 20-year span of NuGIS, we implied that the specialty crop acreages remained the same as they were in the 1998-2000 period when PPI did their intensive specialty crop evaluation, and that the yields of specialty crops changed at the same rate as the average of the 21 major crops. Again, both implied assumptions could have introduced error into the removal estimates.

Portion of nutrient removal reported in the PPI 80 crops represented by the 21 crops in NuGIS for the four states dropping below 90% and the crops missed by NuGIS.

State	% represented by 21 NuGIS crops			Crops missed by the NuGIS 21 that were included in the PPI 80 *(parentheses hold the % of total 80-crop K removal represented by that crop)*
	N	P	K	
Arizona	93	93	86	Broccoli, cantaloupe(2), carrots, cauliflower, grapefruit, grapes-table, honeydew melons, lemons, lettuce(7), onions, tangerines, watermelon
California	76	73	63	Almonds(5), apples, artichokes, asparagus, avocados, broccoli, Brussels sprouts, cabbage, cantaloupe, carrots(2), cauliflower, celery, cucumbers, dates, figs, garlic, grapefruit, grapes-table(7), honeydew melons, kiwifruit, lemons, lettuce(3), mushrooms, oats, olives, onions, peaches, pears, peppers, pistachios, prunes, pumpkins, radishes, raspberries, snap beans, spinach, squash, strawberries(1), stone fruit, sweet potatoes, tangerines, tomatoes(6), walnut, watermelon
Florida	78	78	79	Cabbage, cucumbers, eggplant, grapefruit(4), limes, other fruits and veg.(2), pecans, peppers(2), radishes, snap beans(2), squash, strawberries, tomatoes(1), watermelon, wood(6)*
Georgia	72	74	66	Cabbage, cantaloupe, cucumbers, grapes-table, oats, onions, other fruits and veg.(2), peaches, pecans, peppers, rye, snap beans, sorghum silage, sweet potatoes, tomatoes, watermelon, wood (28)

*Wood represented 11% of N removal in Florida.

Partial balance

Our nutrient balance estimates are <u>partial</u> balances. They do not take into account atmospheric deposition, application of biosolids to ag lands, or nutrients contained in irrigation water (fertilizer nutrients used in fertigation are, however, included in our nutrient balance estimates). They do not take into account nutrient losses (soil erosion, leaching, gaseous losses) from agroecosystems other than crop removal. And, they do not directly account for soil nutrient content changes either from soil organic matter mineralization or immobilization or changes in inorganic levels from either surface soils or subsoils. Therefore, care should be exercised in how the NuGIS balance estimates are interpreted.

APPLICATIONS OF NUGIS AND CONCLUSIONS

Nutrient balances are important to farmers and to society as indicators of sustainability. Current status offers insights into both production and environmental consequences of existing practices and temporal trends in balances provide a vision of the future unless change occurs. Due to the interactive nature of nutrients in crops, soils, and ecosystems in general, evaluation of balances of multiple crop nutrients has advantages over a singular nutrient focus.

We see the final NuGIS as having several applications. These include:

- Offering guidance in nutrient management education.
- A basis for science-based guidance in marketing of fertilizers and nutrient management related services.
- A useful tool for integrating nutrient balances in water quality and nitrous oxide emission modeling.
- Factual spatial and temporal input into environmental policy development involving plant nutrients.

As discussed earlier, weaknesses exist in our current capacity to accurately evaluate nutrient balances at appropriate resolution. These include incomplete information concerning crop nutrient removal coefficients, lack of Agricultural Census data for specific nutrient use expenditures, and missing county level fertilizer sales data in the AAPFCO database. We hope the transparency of this preliminary NuGIS will motivate changes in nutrient data collection mechanisms that will lead to improved estimates of nutrient balances and cycling.

This spatial and temporal analysis of partial nutrient balances in the U.S. leads to the following general observations.

- Crop nutrient removal in the U.S. is increasing faster than nutrient use.
- Great variation exists across the country in major nutrient (N, P, K) balances.
- The most positive P balances are found in New England, the South Atlantic Gulf, and California. The most negative P balances are found in the Corn Belt and Northern Great Plains.
- Most of the Corn Belt has negative P balances and many of these same watersheds appear also to have negative K balances.
- Removal to use ratios appear unsustainably high in some regions and unsustainably low in others making intensive monitoring of soil fertility a critically important management practice.
- Where trends for high partial balances of N and/or P are observed, and/or low removal to use ratios are noted, it may also be important to monitor surface and groundwater water quality to identify opportunities for special management considerations to help remedy any unacceptable risks of potential water quality impairment.

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