NUGIS: A NUTRIENT USE GEOGRAPHIC INFORMATION SYSTEM FOR THE U.S.

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ABSTRACT

Several critical contemporary agricultural issues involve the nutrient balance of U.S. cropland. Knowledge of the current status and temporal trends of nutrient balance can offer guidance in nutrient management education, serve as a basis for science-based guidance in marketing of fertilizers and nutrient management related services, and provide useful input to water quality and nitrous oxide emission modeling and to environmental policy development involving plant nutrients. The Nutrient Use Geographic Information System (NuGIS) creates county-level estimates of N, P and K applied to the soil in fertilizer and livestock manure, and removed by harvested agricultural crops. Geospatial techniques are used to estimate balances for 8-digit hydrologic units using the county-level data. The current version makes estimates for five years, coinciding with the USDA Census of Agriculture, from 1987 - 2007. A version that can be updated annually for non-Census years is under development. Model output and detailed methodology are available on line (http://www.ipni.net/nugis) through interactive thematic maps or as exportable tabular data. The analysis reveals areas of both highly positive and highly negative nutrient balances, and several weaknesses in data sets essential to the estimation process. The NuGIS model is being developed by the International Plant Nutrition Institute (IPNI) and PAQ Interactive.

INTRODUCTION

Agriculture and the context within which agriculture operates are experiencing remarkable changes. Many of those changes have the potential to impact nutrient balances for U.S. cropland. Global population growth and economic development make increasing productivity a high priority for all agricultural systems and suggest that nutrient removal in crop harvest is likely to continue to increase. 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, crop nutrient concentrations and nutrient use efficiency. Increased volatility in fertilizer and crop prices has altered farm fertilizer use decisions. And, government policy can cause shifts in many of these factors.

Our belief is that wise nutrient stewardship decisions in the future, ranging in scale from the field to the farm to the watershed to the region and to the policy arena, will be facilitated by a fact-based understanding of the current status and temporal trends of cropland nutrient balances. Such an understanding establishes the baseline from which the impact of future changes can be measured. The interactive nature of crop nutrition and associated nutrient use efficiencies suggests that a singular nutrient focus, whether the objective is production or environmentally driven, could be counterproductive. Therefore, NuGIS evaluates balances of all three primary nutrients. An additional motivation for the development of NuGIS was an observation that the increases in nutrient removal in crop harvest as crop yields have increased is often underappreciated.

METHODS AND THEIR CHALLENGES

The Basic NuGIS Model

The basic NuGIS model is a very simple field based partial nutrient balance algorithm as follows: Balance = Farm fertilizer nutrient used + Recoverable manure nutrient use + Biological fixation – Nutrient in harvested crops (IPNI, 2010). It is a partial balance because it does not take into account atmospheric deposition, nutrients in irrigation water, land application of biosolids, or several nutrient losses such as eroded soil, gaseous N emissions, or leaching. It also does 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. Future NuGIS versions will likely add additional components but current developmental focus has been only on the four factors mentioned.

NuGIS currently covers a 20-year period at 5-year intervals set by the years of the Census of Agriculture (COA). We felt a 20-year period was adequate to establish trends without taking us back to years when needed data were not accessible in electronic form. The spatial objective of NuGIS was USGS 8-digit hydrologic units (HUC) of which there are 2,150 in the U.S. This compares to 3,117 counties. The 8-digit HUC was chosen to accommodate watershed-based models and because we felt it was the highest level of spatial resolution possible with available aggregate data. NuGIS will output county level estimates but these are an intermediate step to the watershed unit.

Development of NuGIS has been more challenging than the basic algorithm at its core might suggest. The merging of disparate incomplete data sets having temporal structural changes and the use of data sets not intended for the specific purpose of estimating nutrient balance, contributed to the challenge. However, one of our objectives was to call attention to weaknesses in the databases essential to determining nutrient balances, whether at the farm level or in aggregate.

This summary of methods will not be detailed, as detailed methods are available online (http://www.ipni.net/nugis). The emphasis here will be on the methodology choices made and the reasons behind those choices.

Farm Fertilizer Nutrient Use

We use the commercial fertilizer sales data provided annually by the American Association of Plant Food Control Officials and The Fertilizer Institute (AAPFCO; Slater and Kirby, 2008) as the starting point in estimating fertilizer use. AAPFCO provides county-level data for approximately 72% of the counties in the 48 states. When county data were unavailable from AAPFCO, COA “Dollars spent on Fertilizer and Lime Products” was used to apportion state AAPFCO nutrients to individual counties. Not all fertilizer sold is used for farm purposes. We adapted USGS methodology used by Ruddy et al.(2006) to estimate farm use fertilizer sales for locations that did not already provide reliable farm use sales reports.

A problem when using AAPFCO fertilizer sales data to estimate fertilizer use is that the fertilizer may not be used in the same county in which it is sold. Also, fertilizer use is likely not constant across an entire county. To account for these factors in modeling fertilizer use spatially, we used a spatial interpolation method similar to that used when creating soil test maps. The ‘mean center’ of cropland in each county was attributed with the fertilizer sales data for that county. An inverse distance weighted interpolation method was then used to create an interpolated raster map of farm fertilizer nutrient use per total cropland acre across the lower 48-states.

Apparent aberrations do appear in AAPFCO sales data over time and space and have led to criticism of their application as surrogates for fertilizer use. These are most apparent where land use diversity is high such as in counties where cropland is intermingled with urban centers, extensive forests, mountains, or grasslands. We were aware of these issues so considered alternatives to using AAPFCO data. However, alternatives appeared to all have greater limitations than the procedure outlined above. One alternative was to rely completely on COA dollars spent on fertilizer and lime for county-level estimates. Problems with that approach include an assumption that fertilizer costs are the same across a state and that the N-P_2O_5-K_2O ratio is constant within each state. Both assumptions do not hold in many states. Another approach is to use USDA-ERS survey data on nutrient use for specific crops. The major limitation with this approach is the limited number of crops for which county-level data are available in any given year.

Recoverable Manure Nutrient Use

A combination of livestock inventory and sales data from the COA, and findings from previously published studies was used to estimate the annual volume of manure, nutrients excreted, and nutrients recoverable, by several different species of livestock, by county (Lander et al., 1998; Kellogg et al., 2000). 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. Potassium estimates were not reported by Kellogg et al., but were obtained at the state level from Chuck Lander (personal communication) and published in a bulletin by the Potash & Phosphate Institute (Appendix 6.3 in PPI/PPIC/FAR, 2002). Because data were available only at the state-level, all counties in a state received the same K recoverability coefficient.

A limitation of the current NuGIS model is that it does not reflect temporal changes in the P concentration of excreted manure due to changes in livestock feeding. As a consequence of the adoption of more rigorous nutrient management plans, producers have 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. (2008) 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. Such reductions in manure P content with time are not captured by NuGIS.

Biological 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.

Nutrients in Harvested Crops

The National Agricultural Statistics Service (NASS), COA, and the USDA-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. The majority of the crop production, harvested acres, and planted acres data comes from the "NASS Annual Ag Statistics Summary" datasets. When production data were not available from NASS summaries, other sources were investigated, including the COA, State NASS office publications and ERS Publications. 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 COA years of 1987, 1992, 1997, 2002, and 2007.

The 21 crops mentioned above account for an average of 95% of the COA harvested cropland acres for the U.S. When adjusted for double cropping, the value drops to 90%. However, for some states and counties the 21 crops account for much lower portions of harvested cropland. For example, we estimate that in California the 21 crops account for only about 55% of harvested cropland with some important agricultural counties dropping below 25%. To account for the nutrient removal represented by these missing crop acres, we calculated an "other crop" acreage at a county level by first subtracting the 21 crop acreage from the COA total harvested crop acreage, then adjusting for double cropping using state level estimates. Nutrient removal per acre for these other crop acres was an expert judgment based on the average removal per acre for the 21 crops and consideration of the likely crops making up the other crops category with the provision that the removal per acre could not exceed the state average removal for the 21 crops. These methods create considerable uncertainty in the predictions made for states such as California, Florida, Maine, Massachusetts, Oregon, Rhode Island, and Vermont, where the 21 crops represent less than 70% of the COA harvested cropland acreage.

One of the challenges we encountered in estimating nutrient removal was assembling reliable crop removal coefficients. For major crops like corn, soybeans and wheat, measured concentrations from research plots, quality surveys, field samples, and feed analysis were frequently lower than those reported in published fact sheets. This process resulted in the establishment of a research project at the University of Missouri to build and fill a national database of measured crop nutrient concentration data that will explore the potential for spatially dependent concentration data. Findings thus far have led to regionalized estimates of P in corn grain and for N, P and K in wheat. NuGIS utilizes removal coefficients based on data summaries whenever possible.

RESULTS AND DISCUSSION

The methodology of NuGIS will likely continue to undergo changes in the years ahead as its output is scrutinized at a localized scale, its methods are more thoroughly vetted, and improvements are made in the input datasets. IPNI plans to maintain NuGIS with periodic updates and improvements as new data become available. The output of NuGIS is perhaps best evaluated via the online interactive thematic maps where input layers and calculated output can be viewed with panning capability at user selected resolution and using either county or watershed boundaries. In this article, we will share only national trends and offer a few examples of the differences among states.

Nutrient removal in crop harvest for the U.S. has increased dramatically from 1987 to 2007 for all three nutrients with N and P climbing about 35% and K about 26% (Figure 1). This occurred while total cropland acres declined from 443 million acres in 1987 to 410 million acres in 2007. Since farm fertilizer use experienced a smaller increase, nutrient removal to use ratios also increased during this same period with K showing the largest increase and N the smallest (Figure 1).

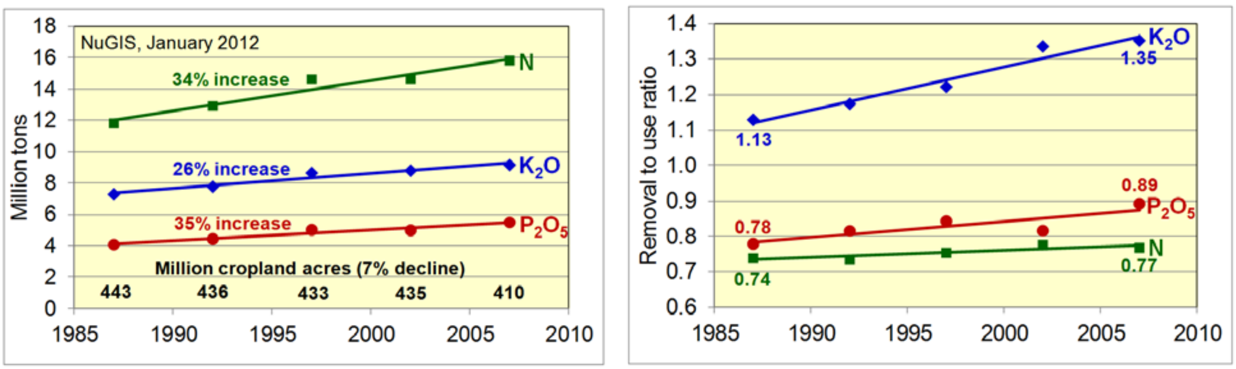

Figure 1. Nutrient removal in crop harvest and nutrient removal to use ratios for the U.S. over a 20-year period (NuGIS, January 2012).

Care needs to be used in interpreting national figures on nutrient balance due to the great variability existing among regions within the U.S. Table 1 illustrates the diversity in nutrient budgets and the resulting balances among states.

Table 1. N and P budgets for four states and the U.S. in 2007 (NuGIS, January 2012).

						Balance*	
State	Nutrient	Fertilizer	Recoverable manure	N fixation	Harvest removal	R/U	Cropland A
			Thousand tons				lb/A
Florida	N	167	13	4.5	102	0.55	56
	P_2O_5	56	13		33	0.47	25
Illinois	N	1,018	21	727	1,531	0.87	19
	P_2O_5	332	37		567	1.54	-16
N. Carolina	N	187	94	75	197	0.55	61
	P_2O_5	101	148		69	0.28	70
S. Dakota	N	450	17	333	679	0.85	13
	P_2O_5	212	29		219	0.91	2
U.S.	**N**	**12,594**	**1,405**	**6,643**	**15,847**	**0.77**	**23**
	P_2O_5	**4,337**	**1,809**		**5,484**	**0.89**	**3**

*Balance = Farm fertilizer + Recoverable manure + N fixation – Harvest removal; R/U = ratio of harvest removal to nutrient use; Cropland A = net balance on a per acre of cropland basis.

Summary: 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 the South Atlantic Gulf, New England and California watershed regions.
- Much of the Corn Belt has negative P balances and the entire western half of the country has highly negative K balances.
- Removal to use ratios appear unsustainably high in some regions and unsustainably low in others calling for intensive monitoring of soil fertility and more intensive nutrient management with greater adoption of 4R Nutrient Stewardship.
- Substantial uncertainty exists in such aggregate data and points to a need for farm level measurement of nutrient balance and removal to use ratios as a basis for indicating progress in nutrient management.

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