

## NITROGEN, PHOSPHORUS AND POTASSIUM BALANCES ACROSS DAIRY FARM SIZES:

### DO LARGE DAIRIES IMPORT MORE NUTRIENTS THAN SMALL ONES?

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**Abstract:** *With the increase in dairy herd sizes across Wisconsin, the question of whether larger farms accumulate more phosphorus than smaller farms is being asked. To address this question and others, a mass balance of 13 dairy farms, ranging in herd size from 50 to 500 head and 4 cash grain operations was conducted in the Lower Fox River Basin (Outagamie and Brown Counties) over a two year period to determine the per-acre rate of nitrogen, phosphorus and potassium loading on farms in the watershed. Incoming sources of these nutrients were quantified from feed, fertilizer and livestock purchases, as well as natural sources of nitrogen (rainfall, legume credits). Economic nutrient export was calculated, as well as an estimate of environmental phosphorus losses.*

*The mass balance showed an average of 87 lb/ac nitrogen accumulation, 15 lb/ac phosphorus accumulation and 80 lb/ac potassium accumulation on dairy farms. Cash grain accumulation rates were -9, 3, and 23 lb/ac, respectively. Differences in cow populations did not change per acre phosphorus accumulations. Potassium accumulations increased as herd size and acreage increased.*

*Eleven of the 13 dairy farms had already implemented nitrogen based nutrient management plans. The study indicates phosphorus accumulations could be reduced by more than 90% by implementing a number of additional management practices, including switching to lower phosphorus protein supplements, growing rather than purchasing protein sources, reducing the amount of phosphorus in the dairy ration and reallocating manure across the farm to fields with the greatest phosphorus need.*

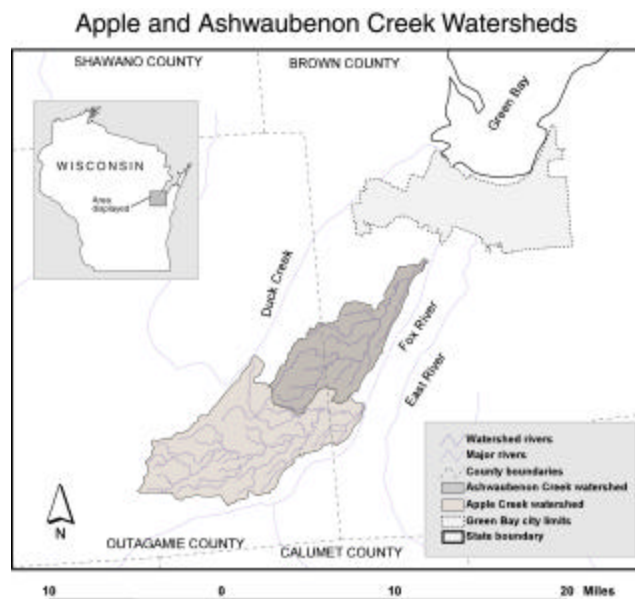
**INTRODUCTION:** The current approach to phosphorus management for water quality improvement focuses almost exclusively on fertilizer and manure phosphorus, without looking at the other sources (feed, protein supplements, purchased animals). At the same time that significant dollars have been invested in both structural practices (such as manure storage) and cropland management practices (nutrient management, conservation tillage), little attention has been paid to the actual impact of the changing structure of the dairy industry on phosphorus and potassium loading.

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To address these issues, a two-year mass balance was conducted with 13 dairy farms (ranging in size from 50 to 500 milking head) and 4 neighboring cash grain operations. All of the farms were located in the Apple-Ashwaubenon Creek watersheds in Outagamie and Brown Counties in Northeastern Wisconsin (Fig 1). This area was chosen for several reasons: for the variety of dairy farm sizes, similar soil types, and surface water quality concerns. Numerous studies (Robertson, 1996, WDNR, 1997, Johnson et al, 1994) show that greater than 50% of the phosphorus and sediment loading comes from the less than ten percent of the Fox-Wolf watershed closest to the Bay of Green Bay (East, Duck-Apple-Ashwaubenon and Plum Watersheds).



**Figure 1:** Map showing mass balance study area (shaded watersheds) and Duck and East River, which combined contribute ~50% of the TSS and P to Lower Green Bay. (Source: USGS).

What makes this area unique is the rapid growth of the dairy industry. While the number of dairy farms has been dropping across Wisconsin, cow numbers have remained fairly constant in Brown and Outagamie County (WASS, 1992-2000). As dairy farms close, their animals have been acquired by expanding dairies, several of which are located in or near the study area. Animal units grew from 3,000 to 11,000 in a nine square mile area in Apple/Ashwaubenon watersheds from 1990 to 2000. Evaluating the potential impact of this concentration was the impetus for doing a nitrogen, phosphorus and potassium mass balance of dairy farms of different sizes within the Lower Fox basin.

**Materials and Methods:** The goals of the mass balance were to determine if cow populations (milking head) or farm size (acres) made a significant impact on per-acre nutrient loading. Those portions of Apple and Ashwaubenon Creeks in Outagamie County were selected for this study, as water quality monitoring was planned in these watersheds during the study period and they contained a variety of dairy farms ranging from 40 to 1400 milking head. After grouping by size, eighteen dairy farms and six cash grain operations were randomly selected and contacted. After removing those not interested in participating and those who were undergoing significant changes in farm size or cow populations (>20% during the study period), data collection began with the 17 target farms.

Farms were broken down into the following categories: Cash Grain (minimal to no livestock), Small Dairy (milking <100 head), Expanded Dairy (between 100 and 300 head), Modern Large Dairy (>300 head). While there were several dairies with more than 600 head on the original list, most of these were either planning or undergoing an expansion during the study period.

The mass balance method chosen was a “driveway” or yardstick measuring model. The goal with this method is to measure all nutrients entering or leaving the farm. All nutrients entering the farm (feed, fertilizer, nitrogen fixation, precipitation and other inputs) were entered into a Microsoft Excel spreadsheet. Nutrients leaving the farm (crops sold, milk, meat, animal losses) were documented and subtracted from the inputs. Environmental phosphorus losses were estimated using water quality monitoring data from neighboring watersheds and sediment delivery estimates provided by local conservation agencies.

Nutrients that cycled on the farm (manure applications, crops harvested for feed) during the study period were ignored, as these should remain fairly constant from year to year. Some nutrient flows (such as nitrogen fixation) were estimated from available data.

Calendar years 1997 and 1998 were chosen for the study, as both years and the prior growing season’s yields were not significantly impacted by adverse weather conditions. Multiple interviews were conducted with each farmer, reviewing their tax, purchasing and sales records. This data were then compared to the records from the feed, seed, and farm product suppliers. Whenever possible, actual laboratory analysis was used rather than book values for purchased feeds for the dairy herd.

**Results and Discussion:** As expected, total imports of nitrogen, phosphorus and potassium exceeded total exports. The 17 study farms documented an annual excess of 1.4 million pounds of nitrogen, 117,000 pounds of phosphorus and 586,000 lbs of potassium. While the excesses were high overall, deficits were noted on individual fields on every farm except one, while two farms recorded a total overall nutrient deficit for at least one nutrient during one of the two study years.

The initial data analysis takes the total pounds of excess nutrient and divides that number by the acres on the farm. This calculation generates a lb/ac excess (or, in the case of a negative number, a deficit), which initially makes comparing farms of similar size and management simple and straightforward. As shown in Table 1, there is some variation between farm types in all three nutrients, although all dairy farms are relatively close to the all dairy farm mean for P and K.

**Table 1:** N, P and K accumulations (net loading) per acre for the study farms.  
“Farm Years” is the number of observations in each category.

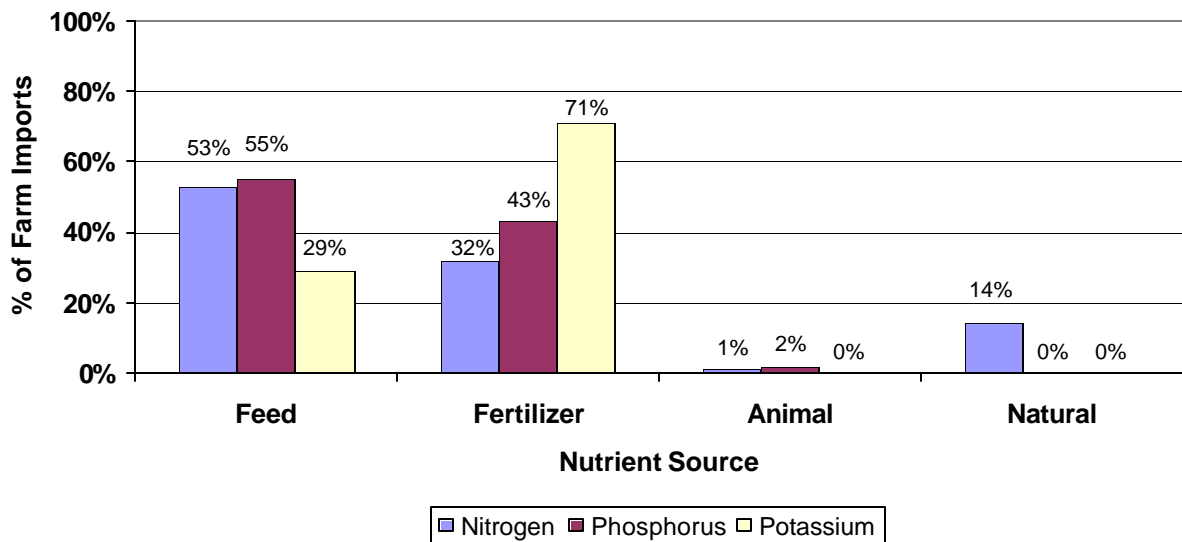
	<b>Farm Years (Observations)</b>	<b>N Mean</b>	<b>P Mean</b>	<b>K Mean</b>
<b>Lb/ac/yr: cash grain farms</b>	8	-9	3	23
<b>Lb/ac/yr: all dairy farms</b>	26	87	15	80
<b>Lb/ac/yr: dairies &lt;100 cows</b>	12	80	16	97
<b>Lb/ha/yr: dairies &gt;100 &lt;300</b>	8	63	10	46
<b>Lb/ha/yr: large dairies</b>	6	133	21	93
<b>Lb/cow/yr: all dairy farms</b>	26	124	21	106

The extremes on the low end of the All Farm average of each nutrient can be attributed to one cash grain farm that has implemented a “draw down” strategy. In this case, the farm is implementing the spirit and the letter of nutrient management planning by only applying those nutrients that the crop will remove in the current growing season. Fertilizer rates are reduced by the soil-test determined soil contribution. By applying less than crop removal, this particular farm hopes to draw down soil phosphorus and potassium levels, reducing the potential for environmental degradation.

Crop removal of phosphorus and potassium in excess of nutrient additions can only continue for the short term, at which point nutrient additions should more closely equal removal rates. This farm’s unique approach is a model which larger Wisconsin Department of Natural Resources CAFO-permitted operations in the Lower Fox Basin are being encouraged to follow as a condition of their WPDES (Wisconsin Pollution Discharge Elimination System) permits.

Low nitrogen numbers on the cash grain farms are the direct result of crop rotation and taking advantage of on-farm nitrogen sources. These on-farm sources (rhizobially fixed nitrogen from legume crops) have the potential to contribute significant amounts of nitrogen to the following crop.

**Where are the Nutrients Coming From?** As noted in Table 2, *Feed* is the dominant source for nitrogen and phosphorus imported onto the dairy farm, while fertilizer is dominant only for potassium. Since most of the farms had already reduced fertilizer and manure rates under their nutrient management plan, the mass balance identified feed sources as the next target for reductions.

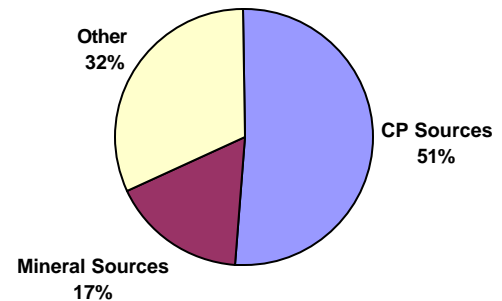


**Figure 2:** Sources of Nutrients and the percentage from each source.

If we hope to achieve phosphorus loading reductions, the mass balance indicates that we must look not only at fertilizer, but feed purchases as well. When feed purchases are examined in more detail (Fig 3), we see that more than 50% of the imported feed phosphorus comes with the crude protein supplements (cottonseed meal, soybean meal, etc). Previous dairy farm mass balances done in the Lower Fox Basin show much lower per acre phosphorus loading, but the farms in these studies were also using home-grown protein sources.

Surprisingly enough, direct phosphorus supplementation accounts for a relatively small (17%) percentage of the feed phosphorus imports. All 13 dairies were feeding ~0.52% P during the study.

### Sources of Feed Phosphorus



**Figure 3:** Percentage of feed phosphorus from direct mineral supplementation (dicalcium phosphate), and crude protein sources. Together, these two comprise 68% of feed phosphorus imports and 36% of total farm phosphorus imports.

**Does the number of cows or number of acres influence accumulations?** Farm size for the dairy operations ranged from 153 to 1090 acres, with an overall average of 551 acres in size. This compares to an average Outagamie County farm size of 179 acres (WASS, 1999). When both the dairy and cash grain farms in this study are combined, the average drops to 544 acres. The average for the study group is intentionally higher than the county average, as the goal was to include a wide range of dairy herd sizes, while the majority of dairy farms are <100 head. Cow populations on the dairy farms in the dataset ranged from 50 to 500 milking head, with a mean of 168.9 in the study, or an average of 3.8 acres per milking cow on study farms.

Regression analysis showed that both cow populations and farm size impacted nitrogen and potassium loading, but had no influence on phosphorus loading. The reason for this can be attributed to the fact that during the data collection process, it was observed that the larger the farm (both cows and acres), the more aware farmers were of phosphorus issues.

**SUMMARY and CONCLUSIONS:** The whole-farm (driveway style) mass balance can be a useful tool for farmers who are trying to improve their nutrient utilization to reduce the potential for environmental losses, excessive nutrient loading of cropland, and protect farm business profitability.

The strength of the mass balance lies in the ability to help farmers pinpoint not only the sources of nutrients entering the farm, but to then use the information gathered to help reduce losses. By identifying the total lb from each source, areas for reduction and/or reallocation can be pinpointed and explored in depth. Adding a time component could conceivably help farmers change phosphorus and nitrogen inputs from seasons with high potential for losses to seasons when the potential is less.

Post-project interviews with participating farmers echoed a few common themes. These were:

1. **Where am I applying/feeding too much?** Once farmers saw that there was an excess, the natural reaction was to try to find out where that was.
2. **How do I compare to other farmers?** Their natural curiosity usually got the best of them, and this question opened many doors for discussing how management differed between farms.
3. **Is my well in danger?** This was the most common question when the topic of nitrogen loading came up. With the heavy clay soils in the project area and the high rates of denitrification seen in fields, actual contamination concerns are fairly minor. This would not be the case in a karst or sandy area, however.

In this study, the vast majority (>98%) of the phosphorus was entering in feed and fertilizer. Since most study farms were under a nitrogen based nutrient management plan, this indicates that fertilizer reductions alone are not going to eliminate excess loading of phosphorus. Farm managers must examine the source of phosphorus entering the farm in feed and begin looking at ways to cut back if environmental goals are to be met. Increasing phosphorus and potassium exports should also be enhanced on farms with excess loadings

From a phosphorus perspective, there is no statistically valid relationship between farm size, cow populations and per acre loading of phosphorus. While the amount of phosphorus imported increases as acres and cow populations increase, it appears that the larger farms are more tightly managing their phosphorus.

The final question asked if this analysis indicated any new or unexplored methods to reduce phosphorus in surface water. Evaluating protein sources by their Crude Protein : Phosphorus ratios may become a tool used both by nutritionists and by farmers to implement comprehensive nutrient management planning. Choosing a protein source with lower phosphorus content (higher CP:P ratio) would make it easier for the farmer to bring total dairy ratio phosphorus down to 0.38%.

**Management Recommendations:** Net phosphorus loading could be reduced to less than 4½ lb/ac/yr on all of the study farms if they would implement four management practices. As a strategy, implementation of all four could have a profound impact on phosphorus loading concerns. The management factors recommended are:

1. Reduce the dietary phosphorus in the dairy ration to 0.38% or less.
2. Grow part or all of their protein sources (soybeans) rather than purchase.
3. Improve manure allocation by looking at both phosphorus and nitrogen
4. Reduce corn starter fertilizer rates and/or the percentage of phosphorus in the fertilizer. (i.e. from a 9-23-30 to a 9-15-30)
5. Consider potassium loading reductions if forages are testing high in potassium.

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