RESEARCH REPORT

pork checkoff

ENVIRONMENT

Title: Implementing Mass Nutrient Balance Procedures on Swine Production Facilities. **NPB # 07-133**

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Date Submitted: March 11, 2010

Industry Summary:
It is often a challenge for an animal feeding operation to know when it has achieved environmental "sustainability". Typically, environmental sustainability is measured in terms of compliance with environmental regulations – receipt of appropriate permits, completeness of records, and implementation of some minimum set of best management practices. Such measures of regulatory compliance represent an indirect indicator of environmental sustainability focused on only one aspect of nutrient management on a swine farm.

Whole farm nutrient balance (WFNB) is a tool for defining the efficiency of nutrient utilization by the entire farm operation including animal and crop production components. Similar to a feed efficiency measure used by many pork producers (lbs of feed per lb of gain), WFNB provides an overall farm measure of nutrient use efficiency – one indicator of environmental sustainability.

The project team applied the principles of WFNB to 13 swine operations for two one-year periods (2006 and 2007). These farms ranged in size from 2,000 to 16,000 head finishing capacity with most farms being wean to finish or feeder pig to finish. The experiences and knowledge from these on-farm experiences are the basis of an educational resource for helping pork producers measure their nutrient efficiency and identify practices that can provide measurable environmental benefits.

On average, 1.5 lbs of nitrogen entered these farms from off-farm sources for every 1 lb of nitrogen leaving as managed outputs or products. From a phosphorus perspective, a very similar performance level was observed. These farms demonstrated significantly better nutrient efficiency over previous studies.

Feed was the single largest source on average of all nutrient inputs. Feed management decisions will typically have the largest single influence on nutrient efficiency of swine farms. Manure storage system selection and cropping system nutrient plan implementation were also observed to be important. However, improved crop nutrient planning by the 13 participating farms had little to no opportunity for additional improvements in farm's nutrient efficiency because of currently implemented practices. Factors such as animal density (head per acre) and farm size demonstrated limited to no value when trying to explain a farm's nutrient efficiency.

Scientific Abstract: This should be a scientific description limited to one page in length to describe your project and its results.

It is often a challenge for an animal feeding operation to know when it has achieved environmental "sustainability". Typically, environmental sustainability is measured in terms of compliance with environmental regulations – receipt of appropriate permits, completeness of records, and implementation of some minimum set of best management practices. Such measures of regulatory compliance represent an indirect indicator of environmental sustainability focused on only one aspect of nutrient management on a swine farm.

Whole farm nutrient balance (WFNB) is a tool for defining the efficiency of nutrient utilization by the entire farm operation including animal and crop production components. It is a mass balance approach for measuring nutrients entering and exiting the farm as managed products. Losses to the environment or accumulations within the farm are estimated by the difference of measured inputs and managed outputs.

The project team applied the principles of WFNB to 13 swine operations for two one-year periods (2006 and 2007). These farms ranged in size from 2,000 to 16,000 head finishing capacity with most farms being wean to finish or feeder pig to finish. The experiences and knowledge from these on-farm experiences were compared against existing nutrient practices and farm characteristics to identify the ability of these indicators to explain the observed variation in WFNB

On average, 1.5 lbs of nitrogen entered these farms from off-farm sources for every 1 lb of nitrogen leaving as managed outputs or products. From a phosphorus perspective, a very similar performance level was observed. These farms demonstrated significantly better nutrient management over previous studies that applied WFNB to animal feeding operations.

Feed was the single largest source of inputs on average (79 and 85% of all N and P inputs, respectively) of all inputs. The combination of feed nutrient concentration and feed utilization efficiency provided the best explanation of the variation observed for WFNB. Manure storage selection and cropping system nutrient plan implementation were important factors influencing WFNB. However, cropping system nutrient planning showed little value for future improvements on the 13 participating farms because of current practices which had eliminated most commercial fertilizer use. Animal density (animal population per unit of land) explains a very limited amount of the variation observed. Factors such as farm size have almost no influence on nutrient efficiency. The value of differentiating the need for regulatory permit or practice application based upon size was not supported by the results of this project.

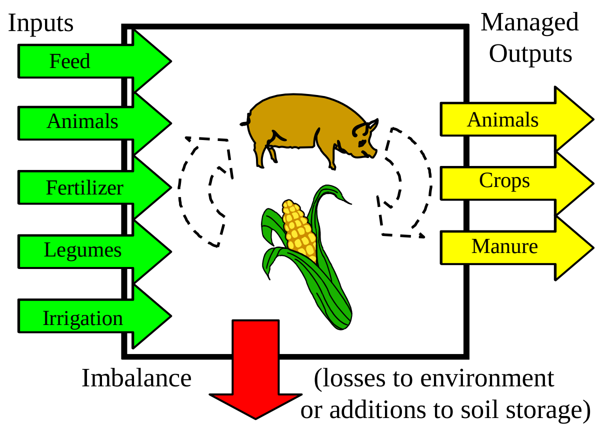
The results and experiences resulting from this project have been packaged into a series of web products accessible through the national eXtension web site for Animal Manure Management. The products include a series of 1) seven educational fact sheets summarizing Lessons Learned, 2) six tools including a spreadsheet calculator for estimating WFNB for pork systems, and 3) three archived seminars summarizing the lessons learned from this project.

Introduction: An overview of the researchable question and its importance to producers.

A Whole Farm Nutrient Balance (WFNB) is a comparison of the quantity of nutrients, typically nitrogen (N) and phosphorus (P) that enter (inputs) and exit (managed outputs) the farm gate (Figure 1). This measure can be visualized as a "Nutrient Yardstick". In many ways, it is similar to feed input/output efficiency for animal (lbs of feed per lb of gain). These indicators compare inputs used to achieve a useful output. Smaller ratios suggest better performance. **A WFNB describes the "whole farms" efficiency for utilizing nutrients and is an important indicator of a farm's environmental performance.**

Common sources of nutrients entering a farm (Inputs) include purchased animals, feeds, and fertilizers. Nitrogen fixed by legumes and N contained in irrigation water represent additional inputs. The Managed Outputs (useful products) include animals and crop sold and manure shipped to off-farm uses.

Figure 1. Whole Farm Nutrient Balance estimates nutrient use efficiency by comparing products entering (inputs) and exiting (managed outputs) the farm. Only products with an N or P component are included.



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If there are more Input nutrients than Managed Output nutrients, the difference is a nutrient Imbalance. This Imbalance represents nutrients that will be lost to the environment by both air and water pathways as well as those nutrients that accumulate on the farm (e.g. increased soil P levels). An Imbalance suggests a potential environmental risk.

This balance measures only those nutrients that cross the boundary of the farm and does not directly track nutrients flows within the farm. Using the feed to gain analogy, as a pork producer you are not too concerned about the efficiency of internal organs such as the gastrointestinal tract's ability to capture nutrients for the pig to utilize. However, you are aware that these internal processes affect the overall feed to gain ratio. Similarly, those internal processes (e.g. efficiency of utilization of manure in the cropping system) affects the quantity of nutrient inputs into the farm (e.g. purchased fertilizer inputs to the farm). Thus, a WFNB measure is reflective of multiple internal on-farm processes affecting nutrient efficiency.

WFNB also provides an indicator of the magnitude of direct nutrient losses (e.g. ammonia into the air or nitrate in the soil) and accumulations that add to a farm's environmental risk (e.g. P buildup in the soil). Regulatory agencies are increasingly asking questions about these losses and accumulations. WFNB provides a producer with a relatively simple method for understanding these losses and accumulations and a means of tracking management changes that produce environmental benefits.

Why is A Measure of WFNB Important?
Permitted livestock operations are being asked to provide annual reports to a permitting authority (state regulatory agency or EPA) that provide indirect indicators of nutrient plan implementation. Producers are also required to keep extensive records of planning procedures, plan implementation, sampling, and inspections. Again these records provide indirect indicators of environmental performance. Finally, all producers are

required to implement the same best management practices (BMP) whether they are producing pork in Nebraska, North Carolina, or Indiana. However, the effectiveness of these BMP is highly site and size specific.

WFNB provides a “potential” opportunity to set a common performance based goal for all livestock producers but allow individual producers latitude in determining how to reach that goal and a means of measuring an individual farm’s progress towards that goal. Setting environmental goals based upon a WFNB measure may give a producer greater flexibility and control in achieving an environmentally sustainable animal operation. It may also provide a simpler and more accurate means of documenting environmental performance.

It must be emphasized that WFNB only has the “potential” for achieving these goals. It has been used in policy implementation in Europe but has seen only limited application in the US. At this time WFNB is strictly a voluntary tool a producer may chose to use to track environmental performance.

What Decisions Might Result from Understanding WFNB?

1. A farm’s WFNB can be used to evaluate alternative nutrient strategies. For example by knowing the magnitude of the fertilizer input, the potential improvement in WFNB that might result from an improved manure use plan can be forecasted. Other nutrient strategies contributing to an improved WFNB can also be evaluated including manure export, alternative cropping systems, alternative feeding programs.
2. A farm’s WFNB provides a mechanism for comparing fertilizer vs. feed inputs, typically the two largest sources of nutrients. A recognition of which input is larger provides guidance as to which of those nutrient strategies that will be most effective for reducing an imbalance.
3. A farm’s WFNB can be compared to a larger set of farms to identify the relative farm’s performance.

Objectives:.

Phase I

A. Construct a whole farm nutrient balance (WFNB) and a swine facility nutrient balance (SFNB) for nitrogen and phosphorus for two Consent Agreement swine facilities (*dropped at NPB request)*,
B. Establish a data base of mass nutrient balance for 12 swine facilities in Nebraska, Iowa and Indiana *(originally proposed as 8 farms in Nebraska and Indiana)*.

Phase II

C. Evaluate the role of mass balance procedures for adjusting ammonia emissions factors for unique situations not addressed by original Consent Agreement farms *(reduced in scope due to lack of access to Consent Agreement Farms)*.
D. Utilize the data collected for WFNB to develop a new educational module for futue pork producer targeted educational initiatives *(expanded in scope*).

This proposal targeted the 2005 NPB Environmental Research Strategy #1 priority, "Conduct a model system mass balance evaluation". After receiving funding for this project, representatives of the National Pork Board asked that we not attempt to make our measurements on some of the Consent Agreement Farms. Thus our ability to validate estimates of ammonia emissions by nutrient balance methods was lost. As a result we focused on expanding the number of farms involved in WFNB measurement and expanding the scope of the educational products that resulted from the project.

Materials & Methods.

Identification of cooperators: Koelsch met with Nebraska Pork Producers Association Board of Directors in July 2006 to build understanding of project intent and identify potential cooperators. Personal visits were then made to 6 Nebraska swine operation and 8 Indiana farms in August - September 2006. Visits were also made with Smithfield representatives producing a list of 7 potential swine cooperators. From this group, 4 Nebraska farms, 4 Iowa farms, and 5 Indiana farms were selected for this study. Factors considered in selection included size (representative of common facility sizes), type of manure storage (lagoon vs. outdoor storage vs. deep pit), and ability to separate animal feed use and manure application land from what might be used by other livestock (if any) managed by the producer. Judgments were also upon the degree of cooperation that might be received by individual producers.

Joe Lally completed a second visit to each of the Nebraska and Indiana sites gaining a commitment from four Nebraska farms (1 deep pit facilities, 2 outdoor storage, and 1 anaerobic lagoon) and Indiana farms (2 deep pit and 2 anaerobic lagoon). In addition, four Smithfield farms in Iowa have agreed to participate

About the Participating Farms. Thirteen pork production facilities in Indiana, Iowa, and Nebraska were engaged in defining their whole farm nutrient balance (WFNB) for two one-year periods (2006 and 2007). The results of individual farms summarized in Table 1 (2006) and 2 (2007). These farms ranged in size from 2,000 to 16,000 head finishing capacity with most farms being wean to finish or feeder pig to finish. Two farms included sow facilities. Most farms included a crop production component ranging from 0 to more than 2000 acres. All but two farms were operated by individual families. Eight farms operated a contract swine operation, four were independent and one was an integrated operation.

Data Collection: Producer visits were made during December 2006 through February 2007 to collect farm specific data to create a WFNB for each of 13 farms for 2006. Data was analyzed during the spring or 2007. The project team met with all cooperators during late spring and summer of 2007, shared a draft of 2006 whole farm nutrient balance (see attachment 1) with each producer, and finalized the WFNB for all 13 farms. Issues of data accuracy and completeness were addressed during the visit and resolved. All farms have received a draft WFNB for 2006 and a final report if corrections were made similar to the report in Appendix B. The producer meetings were also used to introduce our plans for 2007 including a protocol for conducting a finishing house nutrient balance for estimating ammonia emissions (see Appendix C) We also reviewed procedures with the producers for the 2nd year of data collection. A similar meeting was held with all producers in late 2008 to complete collection of data for the 2007 WFNB visit directly with producers about individual questions. A final meeting was hosted with producers in early spring 2009 to provide a summary of results and lessons learned.

Supporting Producer Resources: The following resources were developed to help communicate the project's purpose, outcomes, and data collection requirements to the participating producers:

- Three fact sheets introducing the concepts of WFNB and FHNB as well as addressing potential producer questions about the project were developed to be used during visits with swine producers (see Appendix A).
- A data analysis tool (Excel Spreadsheet) was modified and updated for use with WFNB measurements by this project. The tool, originally developed for the Livestock and Poultry Environmental Steward curriculum, was reviewed for accuracy, ability to adapt to swine systems, and user friendliness (potential tool for use in education products promised for phase II project). Modifications were identified and completed. One remaining change will require a review of the recent literature for the nitrogen and phosphorus retention within feeder and finishing pigs and possible modification of those values. The current spreadsheet values are representative of the literature through 1995.
- An example report provided to producers using this spreadsheet tool is illustrated in Appendix B.
- A FHNB paper based worksheet was developed. The previously mention WFNB spreadsheet tool has since been adapted for a FHNB measurement with some changes to the nutrient inputs and outputs sections. FHNB will be conducted for analysis of all 13 farms for two turns of pigs from data collected in 2007- 2008. In addition, a series of supporting data and record sheets were developed for use by producers who will begin collecting data. Some of these record sheets were designed to also meet both project record needs as well as records required for Concentrated Animal Feeding Operation (CAFO) regulation compliance.
- On-farm manure, water, and feed sampling expectations by swine producers have been identified and shared with producers during a summer farm visit (May - June 2007).
- Two $500 payments (February and December of 2007) were completed to 13 producers to compensate for their time investment and costs of collecting necessary samples.

Results:

Objective: Establish a data base of mass nutrient balance for 12 swine facilities in Nebraska, Iowa and Indiana.

Table 1: 2006 Results

Farm	A-1	A-2	A-3	A-4	B-1	B-2	B-3	B-4	B-5	C-1	C-2	C-3	C-4
Swine Facility	2,200 hd feeder pig to finish	4,000 hd feeder pig to finish	4,000 hd feeder pig to finish	3,300 hd feeder pig to finish	3,400 hd, 1600 hd nursery, 550 sows - Farrow to finish	6,000 hd. wean to finish	16,000 hd wean to finish	3,400 hd feeder pig to finish	3,300 hd wean to finish	5700 hd feeder pig to finish + 500 sows	3,600 hd feeder pig to finish	12,000 hd feeder pig to finish	2,000 hd feeder pig to finish (gilt develop-ment)
Storage	Earthen basin	Deep pit	Concrete storage	Slurry Store	Deep Pit	Earthen basin	Deep pit	Anaerobic Lagoon	Deep pit	Anaerobic lagoon	Concrete storage	Deep pit	Anaerobic lagoon
Land & Crops	110 ac	426 ac	452 ac	173 ac	2177 ac	850 ac	980 ac	89 acres	400 ac	180 ac	None	540 acres	250 ac
Nitrogen Balance													
Animals	8,000	12,000	14,000	2,000	2,000	4,000	10,000	15,000	2,000	10,000	18,000	8,000	4,000
Feed	96,000	171,000	164,000	100,000	76,000	119,000	499,000	126,000	127,000	200,000	222,000	320,000	110,000
Fertilizer	0	11000	0	0	253000	23000	0	16000	0	16000	0	0	4000
Legumes	2000	16000	6000	3000	54000	23000	30000	0	12000	6000	0	0	21000
Irrigation	0	0	0	0	0	0	0	0	0	9000	0	10000	4000
Inputs	**107000**	**211000**	**185000**	**105000**	**386000**	**169000**	**539000**	**157000**	**141000**	**241000**	**240000**	**339000**	**143000**
Animals	38000	68000	65000	38000	37000	62000	194000	70000	39000	70000	77000	163000	25000
Crops	17000	72000	50000	14000	270000	59000	146000	11000	56000	17000	0	79000	66000
Manure3	13000	18000	0	17000	0	0	0	0	0	11000	79000	28000	0
Outputs	**68000**	**158000**	**115000**	**69000**	**306000**	**120000**	**340000**	**82000**	**95000**	**98000**	**156000**	**271000**	**91000**
Imbalance	**39000**	**53000**	**69000**	**35000**	**79000**	**48000**	**199000**	**75000**	**46000**	**144000**	**83000**	**68000**	**52000**
In/ Out Ratio	**1.6 to 1**	**1.3 to 1**	**1.6 to 1**	**1.5 to 1**	**1.3 to 1**	**1.4 to 1**	**1.6 to 1**	**1.9 to 1**	**1.5 to 1**	**2.5 to 1**	**1.5 to 1**	**1.3 to 1**	**1.6 to 1**
Phosphorus Balance													
Animals	1800	2800	3100	400	400	800	2300	3300	1000	2500	3900	1900	900
Feed	14500	25800	24800	15100	16200	15300	105100	24200	27000	45300	37600	70300	31100
Fertilizer	0	0	0	0	35100	0	0	2300	0	2400	0	0	4400
Inputs	**16300**	**28600**	**27900**	**15500**	**51800**	**16100**	**107400**	**29800**	**27000**	**50200**	**41500**	**72100**	**36400**
Animals	7500	13200	12700	7500	7200	12100	38100	13800	8000	13800	15100	32000	4800
Crops	2700	10200	8200	2000	39000	5900	20800	2200	8000	1700	0	15700	6200
Manure3	4900	4900	0	4500	0	0	0	0	0	2000	6400	5900	0
Outputs	**15100**	**28300**	**20900**	**14000**	**46200**	**18000**	**58900**	**16000**	**16000**	**17500**	**21500**	**53600**	**11000**
Imbalance	**1200**	**300**	**7000**	**1600**	**5600**	**-1900**	**48400**	**13800**	**12000**	**32700**	**20000**	**18500**	**25400**
In/Out Ratio	**1.1 to 1**	**1.0 to 1**	**1.3 to 1**	**1.1 to 1**	**1.1 to 1**	**0.9 to 1**	**1.8 to 1**	**1.9 to 1**	**1.7 to 1**	**2.9 to 1**	**1.9 to 1**	**1.3 to 1**	**3.3 to 1**

Table 2: 2007 Results

Farm	A-1	A-2	A-3	A-4	B-1	B-2	B-3	B-4	B-5	C-1	C-2	C-3	C-4
Swine Facility	2,200 hd feeder pig to finish	4,000 hd feeder pig to finish	4,000 hd feeder pig to finish	3,300 hd wean to finish	3,400 hd finish, 1600 hd nursery, 550 sow Farrow to finish	6,000 wean to finish	16,000 hd wean to finish	3,400 hd feeder pig to finish	3,300 hd wean to finish	1500 hd feeder pig to finish	3,600 hd feeder pig to finish	12,000 hd wean to finish	2,000 hd feeder pig to finish (gilt develop-ment)
Storage	Earthen basin	Deep pit	Concrete storage	Slurry store	Deep Pit	Earthen basin	Deep pit	Anaerobic Lagoon	Deep Pit	Earthen basin	Concrete storage	Deep pit	Anaerobic lagoon
Land & Crops	1106 ac	436 ac	452 ac	140 ac	2097 ac	970 ac	980 ac	89 acres	400 ac	180 ac	None	660 ac	350 ac
Nitrogen Balance													
Animals	6,000	13000	14000	2,000	2,000	4000	10,000	13,000	2,000	5,000		9,000	3,000
Feed	69,000	159000	162000	101,000	145000	162,000	526,000	135,000	123,000	34,000		353,000	93,000
Fertilizer	0	0	0	0	231000	37,000	0	14000	6000	10000		0	0
Legumes	0	18000	10000	5000	44000	24,000	36000	0	11000	0		0.000001	12000
Irrigation	0	0	0	0	0	0	0	0	0	5000		10,000	6000
Inputs	**75000**	**189000**	**186000**	**107000**	**422000**	**227,000**	**572000**	**162000**	**142000**	**55000**		**373,000**	**114,000**
Animals	31000	67000	63000	39000	58000	79,000	190000	56000	39000	24000		131000	16,000
Crops	16000	86000	52000	20000	199000	64,000	160000	13000	56000	0		97,000	58,000
Manure3	17000	17000	0	18000	0	0	0	23000	0	9000		0.000001	0
Outputs	**64000**	**171000**	**115000**	**78000**	**257000**	**143,000**	**350000**	**92000**	**95000**	**33000**		**228,000**	**75,000**
Imbalance	**11000**	**18000**	**72000**	**29000**	**165000**	**84,000**	**222000**	**70000**	**47000**	**22000**		**145,000**	**39,000**
In/ Out Ratio	**1.2 to 1**	**1.1 to 1**	**1.6 to 1**	**1.4 to 1**	**1.6 to 1**	**1.6 to 1**	**1.6 to 1**	**1.8 to 1**	**1.5 to 1**	**1.7 to 1**		**1.6 to 1**	**1.5 to 1**
Phosphorus Balance													
Animals	1300	2800	3200	400	400	900	2300	2900	500	1100		2,000	700
Feed	11900	27000	27000	16600	14200	16,500	100000	21200	23200	7700		57,900	23,100
Fertilizer	0	0	0	0	48400	5,000	0	0	100	0		0	0.000001
Inputs	**13200**	**29900**	**30200**	**17000**	**63000**	**22,400**	**102000**	**30000**	**23800**	**8800**		**59,900**	**23,700**
Animals	6100	13200	12300	7700	11300	15,500	37200	10900	7600	4700		25,600	3,200
Crops	3200	12200	7700	2800	28600	6,400	22300	2500	8300	0		19,200	10,300
Manure3	6400	3800	0	5700	0	0	0	800	0	2400		0.000001	0
Outputs	**15700**	**29200**	**20000**	**16100**	**39900**	**21,900**	**59500**	**14200**	**15900**	**7100**		**44,800**	**13,500**
Imbalance	**-2500**	**700**	**10200**	**900**	**23000**	**500**	**42800**	**15800**	**7900**	**1700**		**15,200**	**10,200**
In/Out Ratio	**0.8 to 1**	**1.0 to 1**	**1.5 to 1**	**1.1 to 1**	**1.6 to 1**	**1.0 to 1**	**1.7 to 1**	**2.1 to 1**	**1.5 to 1**	**1.2 to 1**		**1.3 to 1**	**1.8 to 1**

Objective: D. Utilize the data collected for WFNB to develop a new educational module for futue pork producer targeted educational initiatives.

The results of this project are accessible through a series of 19 web pages hosted on the national eXtension Animal Manure Management web site (http://www.extension.org/animal+manure+management). At the time of this report, the pages have not gone live as the peer review process is completed. When completed, all pages will be accessible from http://www.extension.org/ pages/Nutrient_Planning_on_Swine_Farms.

The specific educational products accessible from this site include:

WFNB for Pork Production - An Introduction

Lessons Learned (one to two page fact sheets)

Overview of Nutrient Management Lessons Learned
Impact of Farm Size on WFNB
Impact of Crop Nutrient Management Plans on WFNB
Pig Density Impacts on WFNB
Impact of Feed Management on WFNB
Type of Manure Storage vs. WFNB
Operational Changes Influence on WFNB

Tools

Whole Farm Nutrient Balance Calculator for Swine Farms
Introduction to Opportunities Checklist for My Farm's Whole Farm Nutrient Balance
Opportunities Checklist for Feed Management
Opportunities Checklist for Cropping System
Opportunities Checklist for Manure Export
Opportunities Checklist Manure Treatment, Storage, and Handling

Archived Workshop on WFNB (summarizes in video and audio format the above information)

Introduction to WFNB
Lessons Learned from 13 Commercial Swine Facilities
Introduction to WFNB Tools

Discussion:

Overview of WFNB Results

On average, 1.5 lbs of nitrogen entered these 13 farms from off-farm sources (Inputs) for every 1 lb of nitrogen leaving as managed outputs (Figure 2). This ratio ranged from 1.1 to 2.5 lbs input per 1lb managed outputs. Feed was the single largest source of inputs on average (79% of all inputs) followed by fertilizer (11%). Animals, legume fixed nitrogen, and nitrates in irrigation water accounted for the remaining 10%.

On average, phosphorus input to managed output ratio was 1.5 to 1 with a range of 0.8 - 3.3 lbs input to 1 lb managed output for the 25 farm-years of data collected (13 in 2006 and 12 in 2007). Again feed represented single largest off-farm source of phosphorus (85%) with fertilizer and animal accounting for the remaining phosphorus inputs.

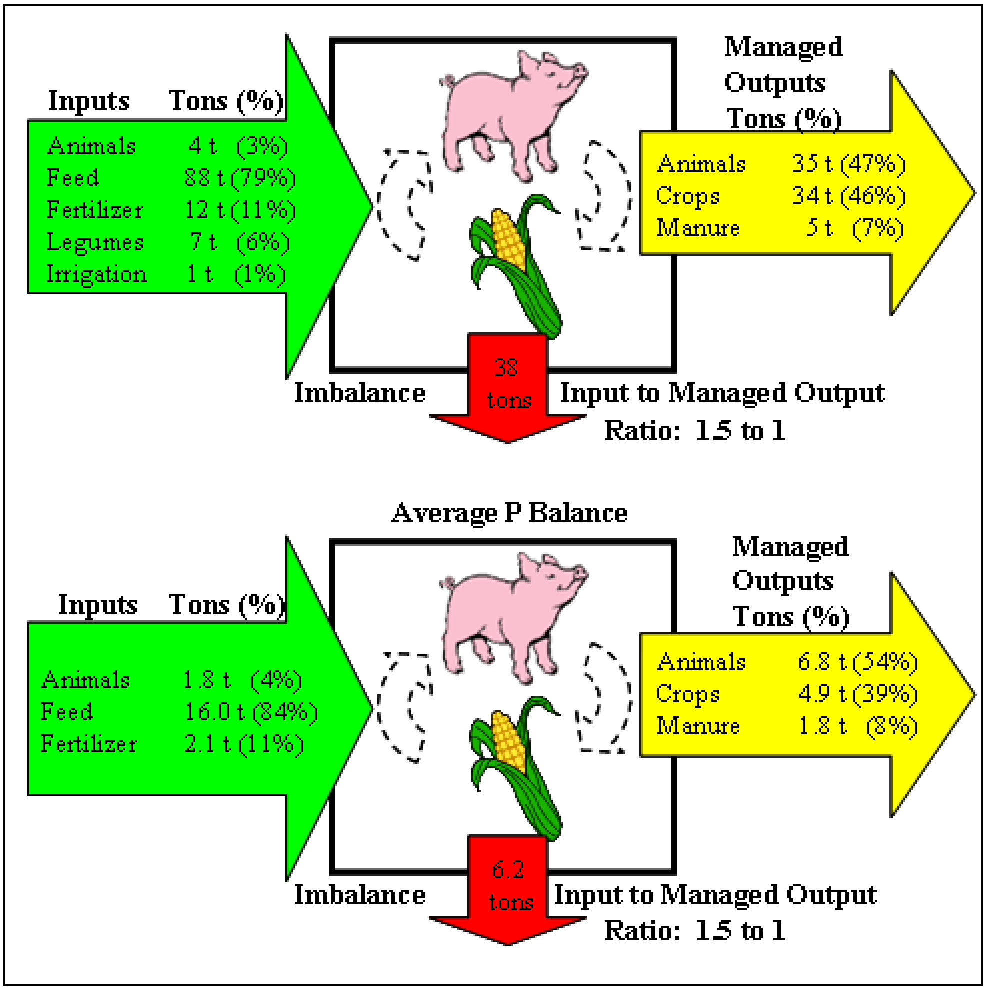


Figure 2. Average whole farm nutrient balance for 13 corn belt farms for 2006 and 2007.

Critical Control Points
An analysis of several critical control points have been reviewed from the results of WFNB for these 13 farms. Based upon these reviews it is our conclusion that the following factors are the most critical control points for avoiding excess accumulations of nutrients on farm or losses from farms:

Phosphorus in purchased feeds.
Type of manure storage system.
Implementation of manure nutrient management plan.

The results also suggest that some additional factors will influence WFNB and the resulting accumulation of and loses from farms:

Crude protein (and nitrogen) in purchased feeds.
Density of animals to land base.

Finally the results provide insights that the following factors have little or no influence on WFNB and the resulting accumulation of and losses from farms:

Farm pig capacity or size.

Comparison to Other Species
The WFNB has been applied primarily to dairy farms in previous research. Spears et al. (2003) conducted whole-farm nitrogen balances on 41 Western dairy farms. On average 2.8 lbs of Nitrogen entered the farm for every pound leaving as a managed output. Castillo et al. (2000) estimated whole-farm nitrogen balances from European dairy farms to range from 1.2 - 2.3 to 1. Studies conducted prior to most nutrient management planning efforts also revealed relatively high whole farm imbalances. Fox (et al, 1994) reported whole farm balances for five dairies that ranged from 2.6 - 4.2 to1 (nitrogen) and 2.4 – 4 to 1 (phosphorus). Koelsch (2005) reviewed whole farm nutrient balances on 33 beef finishing and swine farms from 1996. Nitrogen balance ranged from 0.8 - 4.0 to 1 and phosphorus balance from 0.5 – 4.8 to 1.

WFNB values observed in previous research was significantly higher that observed with the 13 swine farms. This may be explained in part of the degree of implementation of nutrient plans, the utilization of feeding technologies such as phytase, and the degree of integration of animal and crop production into the same farm. In general, the results of the swine operations that participated in this study suggest significantly better nutrient management over previous studies.

WFNB vs. Swine Facility Size

Farm Size is often used as a basis for determining which animal production facilities will be regulated and to what degree. For swine operations, a threshold of 2400 pig capacity (finishing and reproductive herd) often triggers the requirement of a federal permit under Concentrated Animal Feeding Operations rules of the National Pollution Discharge Elimination System program. However, for the 13 farms involved in this study of Whole Farm Nutrient Balance (WFNB), size proved to be a poor indicator of the efficiency of nutrient utilization or potential for nutrient losses from the farm.

Size of the pig operation does not explain the variability in WFNB as illustrated by the flat regression lines in Figure 3 for both N and P balances. Based upon an analysis of WFNB, three farms experience N or P whole farm balance ratios of 2 to 1 or greater. They included a 2000-head and a 3,400-head finisher, as well as a 6,200 sow and finish facility. The data does not support the need to only regulate the larger facilities.

Figure 3: Whole farm N and P balance for 13 swine farms vs size of pork production unit.

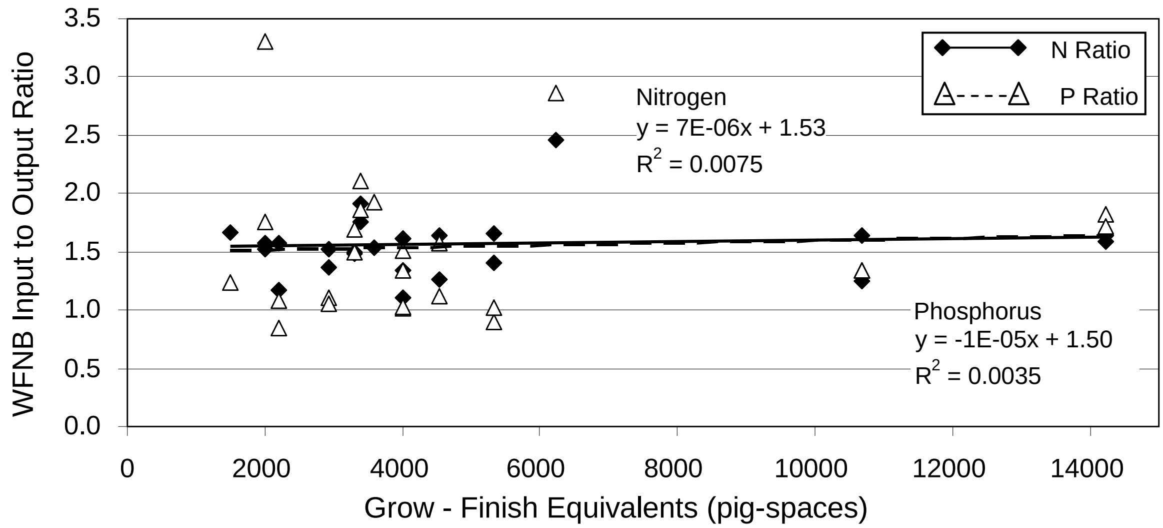
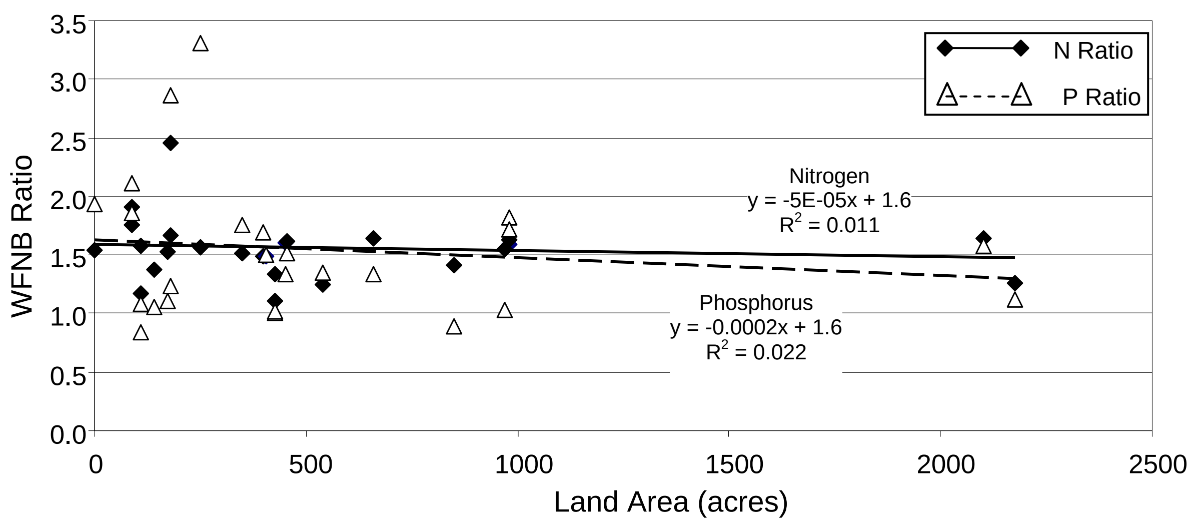


Figure 4: Whole farm N and P balance for 13 swine farms vs crop production land base.



Access to a larger land base has often been associated with better utilization of manure nutrients. However, producers have found options for managing manure in situations where the land base is insufficient. Figure 4 suggests that one farm with no land base is managing nutrients as efficiently as producers with much larger land bases. This illustration also demonstrates that access to greater land areas does not result in improved utilization of nutrients.

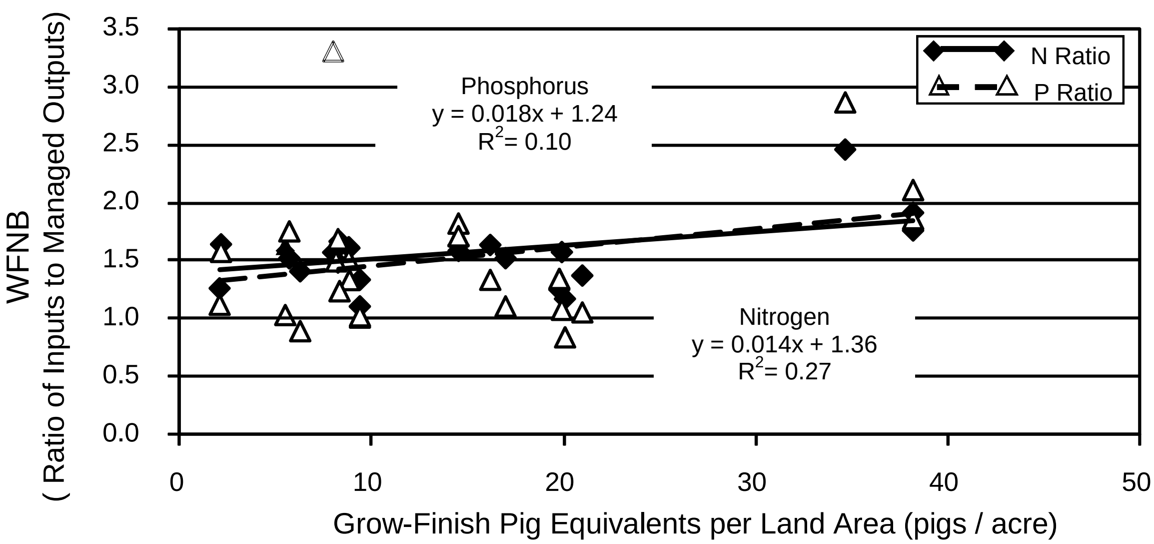
Manure export was used by seven of the 13 producers in one or more years as a means of accessing land base that they do not own or manage. Others employed diets low in crude protein or phosphorus to partially compensate for limited land access. These modifications to the overall farm's management of nutrients resulted in a level of WFNB that does not change with the size of the land base owned or managed by the participating producers.

WFNB vs. Pig Density

The relationship between the numbers of pigs raised on a swine farm to the numbers of acres to support this production unit is often called animal density. This measurement has been used in the past to relate the estimated amount of manure and nutrient production from pigs to the amount of land that can utilize these nutrients for productive purposes i.e., crop production. However, using this measurement may give erroneous results because of the great variety of pork systems that are operative. A whole farm nutrient balance (WFNB) study was conducted for two years (2006-2007) on 13 swine farms in the Midwest US. For more information about the farms involved in this study go to Overview of Nutrient Management Lessons Learned. Following are some observations from this study concerning the relationship of pig density to WFNB.

The relationship of pig density (grow-finish pig capacity per acre of available land area that can receive manure applications for crop production) to the WFNB for nitrogen (N) and phosphorus (P) as a ratio of N or P inputs to managed outputs was analyzed for the 13 swine farms during the two year study. Figure 5 shows the results of this relationship. There was a very weak conclusive effect or relationship of pig density per acre of land area on both N and P balance.

Figure 5: Whole farm nutrient balance for 13 swine farms vs. animal density.



Therefore, this measurement alone is not effective in describing potential impacts on nutrient balance of a specific farm and should not be used. Other potential components of the farm can temper a potential influence of pig density Including storage system type, feed program, degree of crop nutrient management plan implementation, and export of manure. As noted in Figure 5, there was considerable variation in the relationship of pig density to N and P balance with more variation in P balance than N balance. This reinforces the need to evaluate each specific farm independently for N and P balance considering the unique characteristics of the farm management, resources and other factors that can impact nutrient flow. A spreadsheet is available (link to Calculating My Farm's Whole Farm Nutrient Balance) to determine the WFNB on any specific producer's swine farm.

Pig density (pig capacity per acre land) is not a very effective indicator alone for N and P balance on a pork production unit. Many other aspects of the farm must be considered and evaluated to determined direct impact on N and P balance.

WFNB vs. Feed Management

Feeding swine is the highest economic cost (65 to 70%) for the pork operation. In addition, the formulation and utilization of the nutrients in the ration by pigs has a major influence on the excretion of nutrients and potentially the balance of the nutrients on a farm. If there is a large amount of nitrogen (N) and phosphorus (P) purchased and imported on the farm compared to the amount of N and P exported off the farm (sale of pigs and crops) then there will be a large nutrient imbalance and a potential threat to water pollution. Following are some observations from this study related to the feeding programs of the farms and feed management.

Average N and P inputs on the 13 swine farms from feed purchases made up 79% of the total N inputs and 85% of the P inputs for the two year period (Table 3). The range of N inputs from feed was 20 to 95% and the range of P inputs from feed was 23 to 100% for the farms over the two year period. A majority of purchased feed inputs for the farms ranged from 77 to 95% for N and 71 to 100% for P. Farms with lower N and inputs from purchased feed utilized corn grown on the farm versus the purchase of corn for most or all of fed rations. A more common practice is to sell corn grown on the farm and purchased a complete ration including corn from a feed mill. The average ratio of N and P inputs to managed outputs averaged 1.5 for each. However, the range of ratios of N and P inputs to outputs were 1.1 to 2.5 and 0.8 to 2.9, respectively.

Table 3. Average Whole Farm Nutrient Balance for 13 swine farms over 2 years.

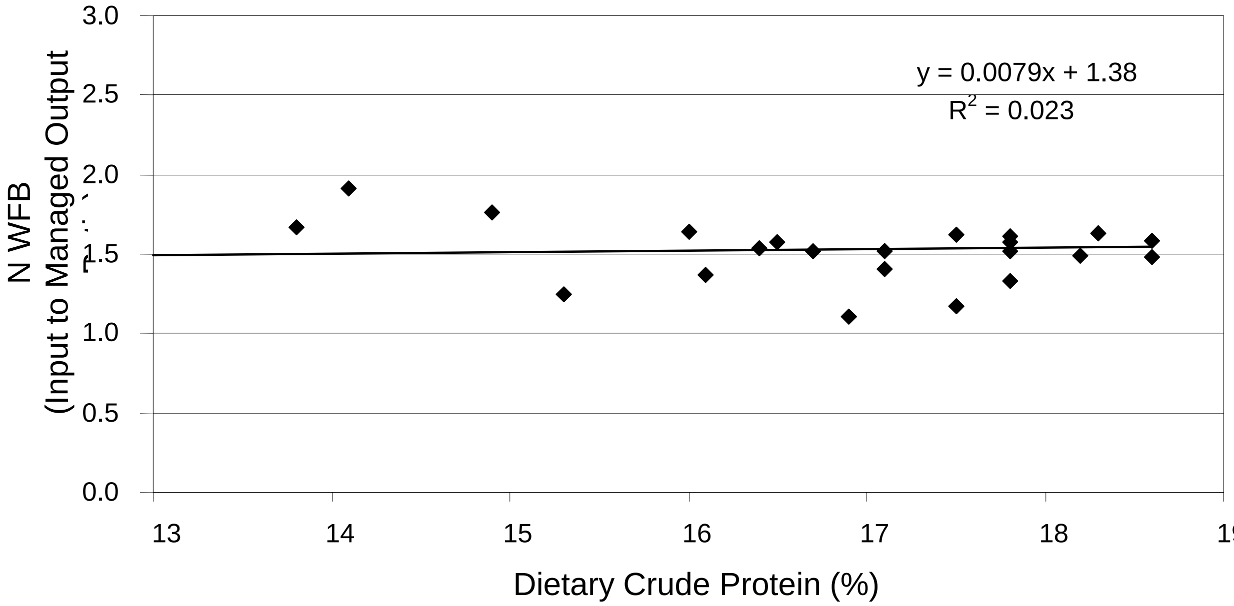
	Average Inputs, Outputs, or Balance (lbs/year)	Portion of Total Inputs or Outputs (%)
Nitrogen Balance		
Nitrogen Inputs		
Animals	7,700	3%
Feed	175,700	79%
Fertilizer	24,800	11%
Legumes	13,300	6%
Irrigation	1,800	1%
Total Inputs	**223,500**	**100%**
Nitrogen Managed Outputs		
Animals	69,600	47%
Crops	67,100	46%
Manure[1]	10,000	7%
Managed Outputs	**146,800**	**100%**
Imbalance	**76,600**	
Input/ Output Ratio: 1.5 to 1		
Phosphorus Balance		
Phosphorus Inputs		
Animals	1,700	4%
Feed	31,900	84%
Fertilizer	4,200	11%
Inputs	**37,800**	**100%**
Phosphorus Managed Outputs		
Animals	13,600	54%
Crops	9,800	39%
Manure[1]	1,900	8%
Managed Outputs	**24,800**	**100%**
Imbalance	**12,400**	
Input/ Output Ratio : 1.5 to 1		

[1] Manure exported from farm.

Diet Composition

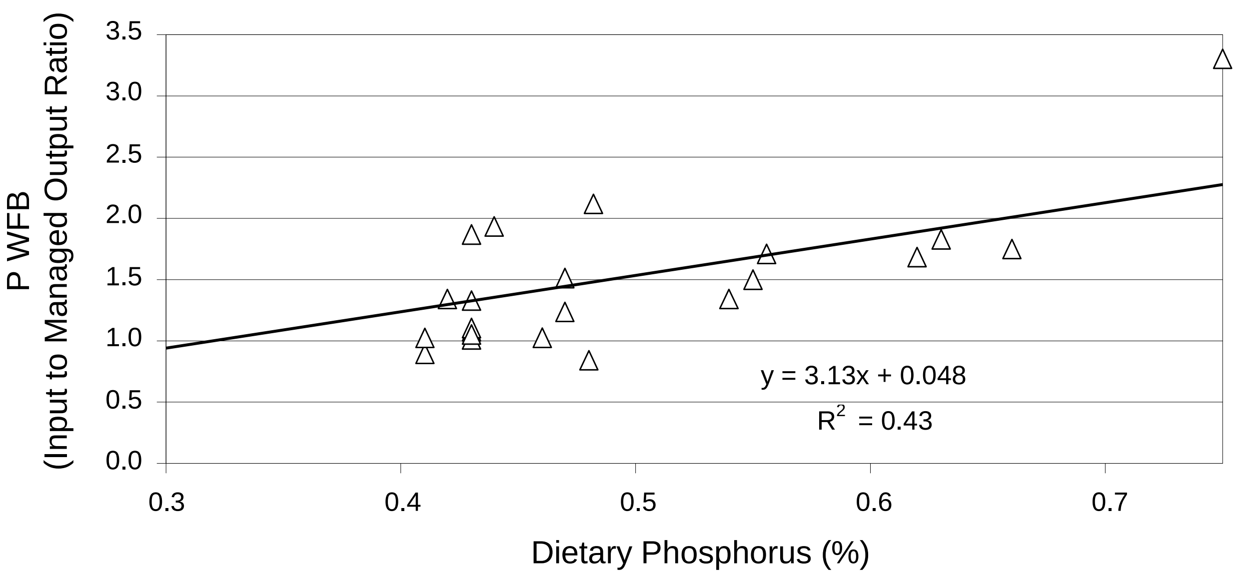
The average dietary crude protein and P levels were measured for the diets over the entire feeding periods of the pigs. Figures 6 and 7 show the relationship of the dietary crude protein and total dietary P levels to the WFNB ratio of N and P inputs to outputs on the pork operations.

Figure 6: Whole farm N balance for 13 swine farms vs. dietary crude protein level.



Average dietary protein levels ranged from 13.8 to 18.6% across all operations. Average dietary total P levels ranged from 0.4 to 0.75%. There was no impact of dietary crude protein level on the ratio of N inputs to outputs which was surprising. Apparently, even though it was anticipated that the increased crude protein in the diet would increase N excretion and an imbalance in the N ratio, there are other circumstances that over-shadowed any direct impact of crude protein level on N ratio. Potentially, there may have been significant differences on N losses to the environment due to ammonia emissions or leaching and runoff N losses which may have influenced these results.

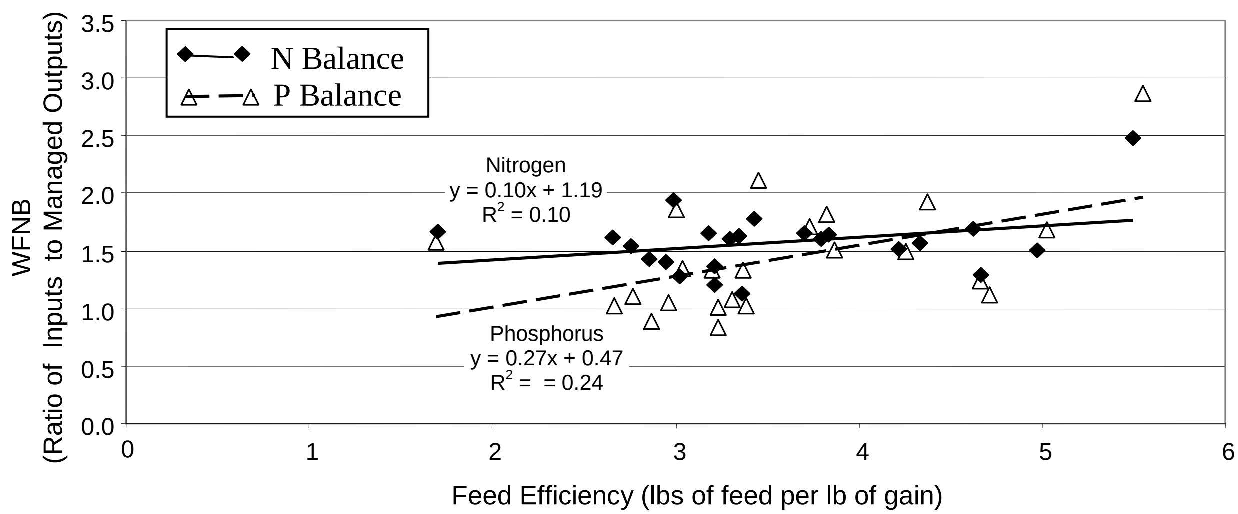
Figure 7: Whole farm P balance for 13 swine farms vs. dietary phosphorus level.



There was an indication of an increase in the WFNB ratio of P inputs to outputs as affected by increases in total P in the diet. The very high (0.75%) P diet content of one farm was because it was a gilt development operation which requires higher dietary P levels for gilt development and longevity of the breeding herd. Although other P inputs from purchased fertilizer can have an impact on the ratio of P inputs to outputs, it is clear that total dietary P is a major factor impacting this ratio. Therefore, any means of improving the availability and utilization of P in the pig through the use of phytase or choosing more biologically available P sources and a reduction of inorganic P in the diet will impact the excretion of P and the WFNB ratio of P inputs to outputs on a pork operation.

The comparison of feed efficiency with WFNB further suggests the importance of feed management decisions, especially for phosphorus (Figure 8). Lower feed required per pound of gain was associated with farms with better whole farm nutrient balances. For phosphorus management, the combination of dietary concentration (Figure 6 and 7) and feed efficiency (Figure 8) explains more than half of the variability observed in Whole Farm Phosphorus Balance.

Figure 8. Impact of feed utilization efficiency on Whole Farm Nutrient Balance. Farrow to finish and gilt finisher results (4 data points) were removed from data set.



Practical Applications: Comparing the total dietary P levels in a swine farm with the ratio of P inputs to outputs reveals that a reduced total dietary P resulted in lower P ratios. For example, a finisher operation that had an average 0.62% total dietary P level across the feeding period the first year was reduced to 0.55% total dietary P the second year and resulted in a change in the ratio of P inputs to outputs from 1.9 the first year to 1.7 the second year. Another example showed that the reduction of the total dietary P for a gilt development farm was from 0.75% total dietary P the first year to 0.66% total dietary P the second year plus no purchase of P fertilizer resulted in the P ratio dropping from 3.3 to 1.8 in one year.

An estimate can be made to determine the potential benefits of reducing the dietary total P level in the diet. Table 4 summarizes an example exercise for one farm. For example, if a 4000 head capacity feeder pig to finish operation with 440 acres in a corn and soybean rotation (Farm A2) currently has a 0.46% total dietary P level. When comparing a lower (0.4% P –dietary P if phytase is used) and a higher dietary P level (0.60% - dietary P if phytase is not used), the WFNB ranges from a low of 0.9 to 1 to a high of 1.3 to 1 for phosphorus. When the average crude protein levels changed from 16.9% (current practice) to 15.5% or 14.0% (diets based upon crystalline amino acid inclusion) with this farm, the N balance was reduced and the N ratio for inputs to outputs were reduced from 1.1 to 1.0 and 0.95, respectively. These changes may result in a need for additional N and P purchased fertilizer to meet the needs of the corn/soybean rotation for this 440 acre swine farm no longer met by the nutrients in excreted manure.

Table 4. Cases of impact of diet change on Farm A2 whole farm nutrient balance.

	Current ration	Change 1	Change 2
% Dietary Crude Protein	16.9%	15.5%	14.0%
N Imbalance (lbs./yr)	18,300	5,100	-9,000
N ratio*	1.11 to 1	1.03 to 1	0.95 to 1
% Dietary Phosphorus	0.46%	0.40%	0.60%
P balance	700	-2,900	8,800
P ratio*	1.02 to 1	0.90 to 1	1.30 to 1

*Ratio is N or P inputs to N or P managed outputs

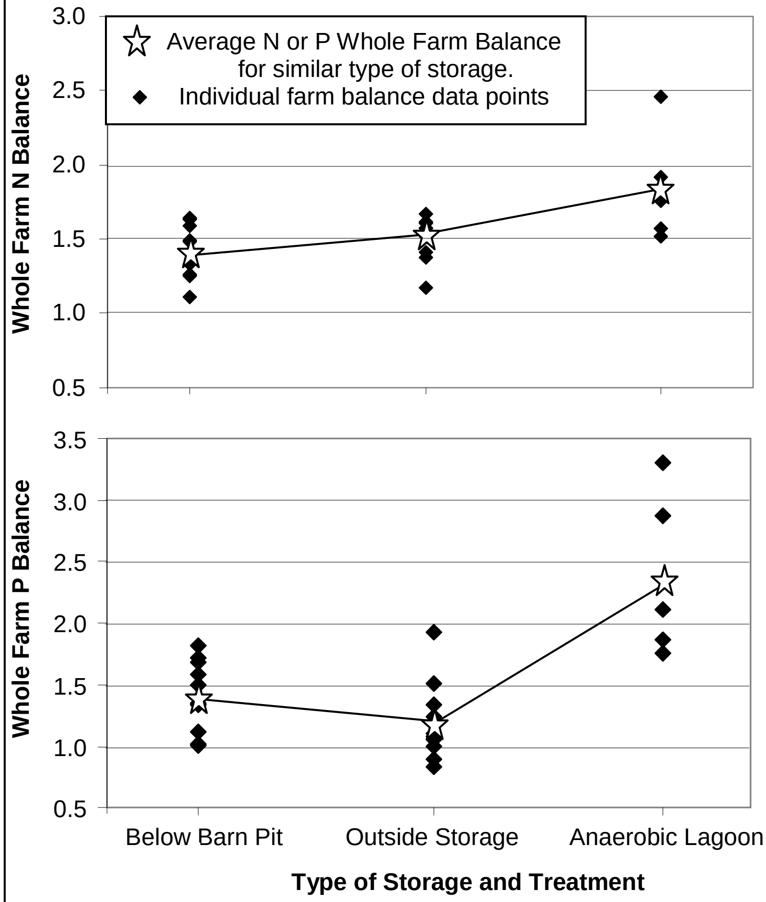
Summary: Changing the formulation of pig rations can have a significant impact on the excretion of nutrients and the WFNB of a farm especially phosphorus. Choice of feed ingredients and/or the use of additives that enhance availability of nutrients in the ration can help reduce nutrient excretion and reduce nutrient imbalances on the farm.

Type of Manure Storage

Selection of manure storage type has a significant influence on the Whole Farm Nutrient Balance (WFNB). This decision locks the farm into a level of "accessible" nutrients over the life of the storage. Thus selection of storage type will have a long term impact of the nutrient value (or lack of) from manure. In addition, nitrogen not accessible from an anaerobic lagoon system is likely lost into the environment adding to the environmental risk. Inaccessible phosphorus from an anaerobic lagoon system generally presents less of an environmental risk but can be a significant lost opportunity for reducing farm fertilizer costs

Farms with a below barn pit storage demonstrated the best nitrogen balance(1.4 to 1 average). Slightly higher nitrogen imbalances (1.5 to 1) were observed for exterior manure storage (earthen basins and formed manure storages). Anaerobic lagoons (combined treatment and storage functions) exhibited the largest imbalance on average (1.8 to 1). The differences suggest that additional nitrogen is being lost from anaerobic lagoons, most likely as ammonia lost to the atmosphere (assumed, not measured). The potential also exists for some leaching of ammonia from soil lined earthen structures. High ammonia losses are commonly associated with associated with anaerobic lagoons. In fact many lagoons have been installed for the purpose of "disposing" of nitrogen.

Figure 9. Whole Farm N Balance vs. Type of Storage



Phosphorus balance is reasonably similar for below barn pit (1.4 to 1) and exterior storages (1.2 to 1). With reasonable agitation equipment, most phosphorus is removed annually from these storage types for land application. However, anaerobic lagoons exhibit a higher phosphorus imbalance (2.3 to 1). The difference is likely a result of phosphorus settling to the bottom of the lagoon and not recovered during pumping. This unrecovered phosphorus represents a significant lost opportunity for the farm resulting in the need to purchase larger amounts of commercial fertilizer phosphorus for crop management.

Table 5. Average fertilizer inputs relative to total nutrient inputs and whole farm imbalance for 13 swine farms.

	Average Nutrient Inputs, Outputs, or Balance (lbs/year)	Portion of Total Inputs (%)
Nitrogen Balance		
Fertilizer Inputs	24,800	11%
Total Inputs	226,200	
Imbalance	79,300	
Phosphorus Balance		
Fertilizer	4,200	11%
Total Inputs	38,300	
Imbalance	13,000	

WFNB vs. Implementation of Nutrient Management Plans

The recent focus of animal manure management regulations has been to encourage implementation of a Nutrient Management Plan (NMP). The intent of an NMP is to encourage more efficient utilization of manure as an offset of purchased commercial fertilizers for meeting crop nutrient requirements. The environmental benefit of a NMP is limited by the amount of commercial fertilizer that can be displaced. The purpose of this summary is to identify the value of NMP implementation on the thirteen farms involved in this summary. In 2006, all farms suggested that they had a NMP in place and had at least implemented the plan in part.

Current Fertilizer Contribution

Fertilizer represents a small portion of the nutrients entering the 13 case study farms. On average only 11% of the nitrogen and phosphorus arriving on farm was as fertilizer. Fertilizer also represented 31% and 32% of the whole farm's N and P imbalance respectively. Thus, if manure is available to replace all of the fertilizer use, likely not possible on all farms, the farm's imbalance would only partially be addressed.

Figure 10. Comparison of whole farm nitrogen balance with nitrogen fertilizer use per acre

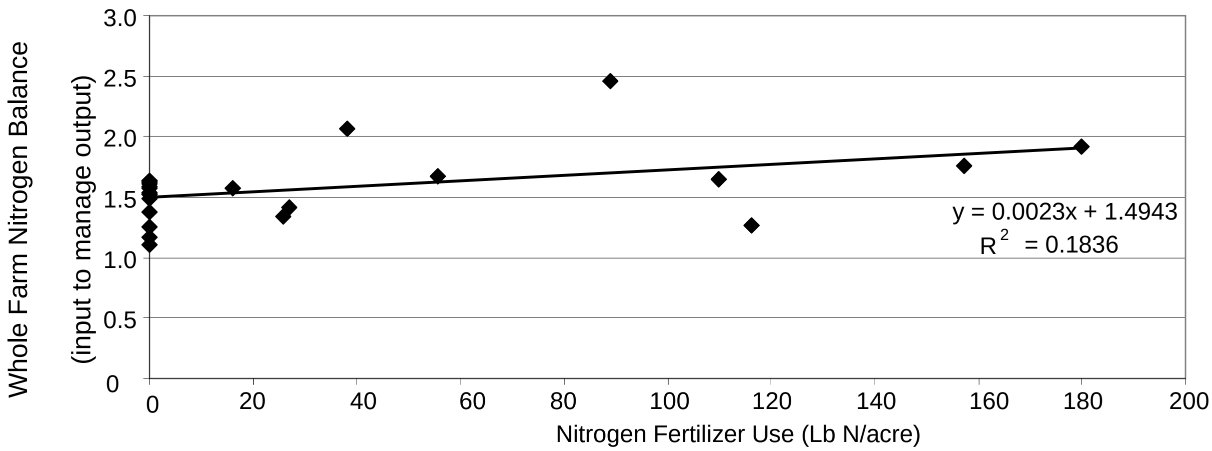
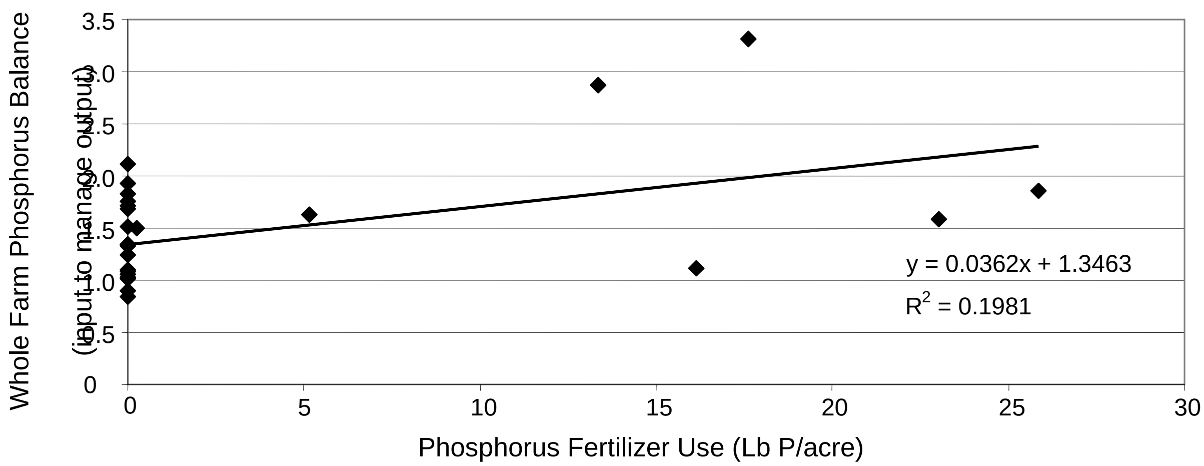


Figure 11. Comparison of whole farm phosphorus balance with phosphorus fertilizer use per acre



The nutrient analysis of finishing swine manure from deep pit and earthen basin facilities typically can be applied to a corn/soybean rotation at rates that meet the corn's nitrogen needs and supplies sufficient phosphorus for the two-year rotation from one manure application. Many of the participating producers utilize dep pit manure as their only crop nutrient source. However, for some operations that feed with diets containing synthetic amino acids and or phytase as feed additives, additional commercial fertilizer may be necessary to meet crop nutrient requirements.

Nitrogen and phosphorus commercial fertilizers were not used for 15 and 19 of the 25 crop years, respectively, for which farm data was shared (see Figure 10 and 11). In these situations, further efforts to develop or implement an NMP would produce few additional on-farm environmental improvements. Of those farms that used no phosphorus fertilizer, WFNB ranged from a ration of less than 1.0 to 1 (farm is exporting more P than importing) to greater than 2.0 to 1 (farm is accumulating more than 1 lb of excess P for every lb of P exported). Thus, a nutrient management plan that eliminates all commercial fertilizer use does not eliminate the risk of excess nutrients.

Commercially purchased fertilizer contributes to an increasing imbalance as illustrated by Figures 10 and 11. As fertilizer use per acre increased, WFNB ratio also increased. However, other factors contributed to the imbalance as suggested by the variation of the individual farm values from the straight line.

Operational Changes Influence on WFNB

Whole Farm Nutrient Balance (WFNB) is a comparison of the quantity of nutrients, typically nitrogen (N) and phosphorus (P), that enter (inputs) and exit (outputs) the farm gate. The purpose of this summary is to discuss impact on WFNB resulting from significant individual farm changes during the 2-year study period on two of the participating farms. The farms were dynamic to the extent that market conditions, labor availability, production system design, animal health and management were experiencing change.

Farm C4

Additional acres and crop rotation changes were observed on Farm C4 from 2006 to 2007. This farm changed from all legume crop (soybean/alfalfa) production to less than half the acres in legumes with corn being added to the rotation. In addition, an increase in total acres occurred. The WFNB nitrogen ratio was reduced from 1.6:1 and changed to 1.5:1, while the phoshorus ratio went from 3.3:1 down to 1.8:1. See Table 6.

Table 6. Whole Farm Nutrient Balance for farm C4. This farm added corn (2007) to a legume dominated rotation (2006) and reduced P in ration thus improving nutrient balance between 2006 and 2007.

	N ratio	P ratio	Dietary P Concentration	% legumes
2006	1.6	3.3	0.75%	100%
2007	1.5	1.8	0.66%	55%

The combination of these changes produced significant improvements in the whole farm P balance for C4. First, switching from legumes to a legume/corn rotation contributed to an increase in the total phosphorus removal from this farm from 6,200 lbs. P to 10,300 lbs. P as crops. This change also reduced legume fixed nitrogen inputs to the farm by 9000 lbs from 2006 to 2007 or more than 15% of the nitrogen imbalance experienced in 2006.

Second, this farm added 185 acres of corn production while reducing N and P fertilizer purchases by 4,000 and 4,400 lbs respectively from 2006 to 2007. Improvements in the crediting of manure nutrients and residual soil nutrients (manure management plan) were necessary to achieve these changes. The acres available for manure applications also increased.

Finally, the feed ration design also changed with the phosphorus content dropping from 0.75% in 2006 to 0.66% in 2007, the single biggest contributor to the improvement in P balance. The combination of the three changes produced significant improvements in the whole farm P balance.

Farm C1

Farm C1's decision to change an anaerobic lagoon (storage and treatment function) into an earthen basin (storage function only) is another example of a system design change that occurred over the course of this project. This signaled a significant improvement in the phosphorus ratio from 2.9:1 to 1.2:1, which reflects the premise of lagoons being designed to store phosphorus over a long period of time (years) compared to a basin's ability to utilize phosphorus annually. The added value of the manure from the earthen basin was the motivation driving this change.

Table 7. Change in management of the storage from an anaerobic lagoon to a earthen basin produced a significant improvement in whole farm nutrient balance for Farm C1.

	N ratio	P ratio	Storage
2006	2.5	2.9	Anaerobic Lagoon
2007	1.7	1.2	Earthen Basin

Farm B5

Because multiple factors influence WFNB, the influence of fertilizer purchases can often best be viewed by considering a case study farm where only one factor (commercial fertilizer use) is allowed to vary. Farm B5 used no commercial fertilizer in their current NMP. Two scenarios are illustrated in Table 8 where less efficient crediting of manure nutrients to meet crop nutrients is assumed. These scenarios cause the WFNB ratio to increase. For this farm (and most others), full implementation of an NMP produces a favorable WFNB. However, the magnitude of the WFNB imbalance is often greater than the ability of the NMP to correct. Thus additional nutrient management measures may be necessary.

Table 8. Impact of modifying implementation of NMP on WFNB for a case study farm. B5 swine farm (3,300 head finish capacity and 400 crop acres) is altered to assume 0 and 50% of crop nutrient requirements originate from manure. Manure supplies all crop nutrients currently.

	Current Situation - Full Credit to Manure	Scenario 1 - Half Credit for Manure	Scenario 2 - No Credit for Manure
Nitrogen Rate (lbs/ac)	0	100	200
Fertilizer Input (lbs N)	0	20,000	40,000
Whole Farm N Imbalance	46,000	66,000	86,000
WFNB Nitrogen Ratio	1.5 to 1	1.7 to 1	1.9 to 1
Phosphorus Rate (lbs/ac)	0	25	50
Fertilizer Input (lbs N)	0	10,000	20,000
Whole Farm N Imbalance	12,000	22,000	32,000
WFNB Phosphorus Ratio	1.7 to 1	2.4 to 1	3.0 to 1

Impact of Diet on Fertilizer Replacement

A preferred dietary nutrient level should be considered to avoid both an excess and a deficit of nutrients within a farm. This preferred level varies with farm. A reduction of dietary nutrient levels may not always be beneficial to a farm that has already reduced or eliminate purchased fertilizer through implementation of an NMP. Deep pit and earthen basin facilities should carefully monitor manure N and P during dietary changes to insure that manure will provide adequate crop nutrition.

Table 9 reflects the impact of changing the dietary nutrient concentrations on WFNB. A change of Farm A2 diet from 16.9% to 14.0% crude protein or from 0.46% to 0.40% P creates a negative balance. In other words, the farm is mining nutrients for export most likely from soil nutrient reservoirs. Such conditions are not sustainable and will eventually need to be offset by purchases of crop fertilizer. For this farm, reducing dietary crude protein to 14% and phosphorus to 0.4% would leave produce a nutrient shortage, likely requiring the farm to import commercial fertilizers to meet crop needs. The lowest possible dietary concentration is not always the best choice.

Table 9. Impact of diet change on available nutrients for meeting crop fertilizer needs for farm A2.

	Current ration	Change 1	Change 2
% Dietary Crude Protein	16.9%	15.5%	14.0%
N Imbalance (lbs./yr)	18,300	5,100	-9,000
% Dietary Phosphorus	0.46%	0.40%	0.60%
P balance	700	-2,900	8,800

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