Maumee Watershed Alliance

partnerships for healthy rivers

Project Title:	Nutrient Loading Reduction through Phosphorus Recovery Demonstration Program
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Project End Date:	02/19/2024
Award Number:	NR223A750013G030

1. Project Summary

The overall project objective was to investigate and advance the use of technologies that can economically recover nutrients, primarily phosphorus (P2O5) from animal waste to levels that can support the transportation and distribution of the now recovered nutrients on farm fields that can be utilized for crop production, or potential resale. The solution evaluated included the use of low-cost dewatering of raw manure with a Kendensha Rotating Disc Separator (KDS) and the USDA patented QuickWash® suite of technologies, for phosphorus recovery. Final dewatering of the recovered P205 was conducted using an ESMIL Group JD series Dewatering Roller press provided by Ekoton, USA.

Manure nutrient levels vary between the type of livestock being grown & livestock production method. One of the most common methods in the Midwest is under-building deep pit storage, especially for swine production. The nutrient makeup of manure can also vary based on feed ration, amount of additional water getting into the waste storage system, or the use or lack thereof of phytase products.

Under typical swine production situations, the amount of phosphorus (P2O5) in the manure is the limiting factor as to how much manure is required to produce a typical corn/soybean crop rotation. If the livestock producer limits manure application to the required phosphorus levels for crop production, he will most likely need to supplement his crop nutrient program by applying the required additional nitrogen and potash. Some producers, especially in years past, have elected to apply additional swine manure to levels that now meet crop nitrogen needs, often resulting in an over application of P2O5.

Results from the completed program demonstrated the ability to recover up to 94.69% of available P2O5 through simple dewatering with supplemental polymer addition through use of a high molecular weight, mid-range cationic polymer. Further, slightly higher recovery (98.15%) was achieved with the QuickWash process and conventional dewatering of the raw manure at a reduced cost. Economics for both processes were developed which demonstrates these levels of P2O5 recovery at a cost comparable to conventional land application of manure. A sample of the QuickWash treated manure was also processed into pellets with favorable nutritional characteristics and is under review for a field trial evaluation of their effectiveness.

Interestingly though, it was also demonstrated that in conventional dewatering of raw swine manure, the majority of the ammonium (NH4) is still available (Appendix B, Figure 5.8). While outside of the scope of this program, using a second technology of the QuickWash suite, this ammonium was recovered in the form of ammonium sulfate, with a demonstrated recovery of 98.0% (Appendix B, Figure 5.19).

2. Project Goal and Objectives

The overall Goal for this Project was to evaluate a technology solution to help reduce the phosphorus load entering the Ohio Watersheds of St. Joseph, St. Marys, and the Upper Maumee.

The following specific Goals and Objectives were identified for this Program. Shown after each Objective is the key summary Table/Figure to support Objective completion.

Objective 1:
Demonstrate the ability to reduce Total Phosphorus (TP) a minimum of 80% over the course of an extended duration demonstration at a swine operation.

- An average reduction in Phosphorus (P_2O_5) from the Raw Manure of 98.15% was demonstrated (Table 5.8).

Objective 2:
Define the economics of a typical installation.

- An estimated consumable cost of $0.0089/gal treated was determined (Table 5.9).

Objective 3:
Determine the estimated value of the recovered products produced with the treatment process. Recovered products included dewatered manure and recovered phosphorus.

- An estimated value of $46.60 - $96.20/ton vs. $35.00/ton for untreated (Table 5.11).

Objective 4:
Confirm the acceptability of treated water to be used as a source of irrigation water by comparing the quality of the treated water against nutrient and irrigation water standards by comparing the treated water to currently used irrigation water at other farms in the St. Joseph, St. Marys, and Upper Maumee Watersheds.

- An evaluation of treated water against multiple agricultural streams was determined to be equivalent (Figure 5.20).

Objective 5:
Participate in a Project Closing Event.

- Multiple Outreach Events were held and a final closing event was held on October 23, 2023 (Section 6).

3. Project Background

The recent declaration by several Great Lakes States that the Western Basin of Lake Erie is considered impaired due to excessive nutrients (primarily phosphorus) highlights a significant challenge facing the Great Lakes. Despite years of progress at voluntarily trying to reduce overall phosphorus loads entering the Western Basin through concerted efforts, little noticeable progress has been made. While much of the emphasis is being placed on the challenges facing Lake Erie, the same consequences of excessive phosphorus loading impact many of the Great Lake States' waterways. It is widely recognized that the role agriculture plays in helping to reduce excessive phosphorus loading in the Great Lakes is significant. Considerable efforts towards sound land and manure management practices (Best Management Practices) have been made through programs such as Ohio's H2Ohio Initiative, but more needs to be done to make a lasting impact. Unlike traditional point source dischargers where infrastructure to support innovative technologies can be more economically employed, agricultural applications and practices must also consider the cost of technology to be widely adopted. Liquid manure management has traditionally consisted of land application of raw manure to fields around animal operations. With continued expansion and therefore, less land available, there is an increased need to find alternative methods of manure management. Technologies that can remove most of the phosphorus and a portion of other nutrients will allow the high-nutrient solids to be moved off-site more economically, and the remaining low-nutrient liquid can be better managed closer to the operations.

Originally developed by the USDA for application in poultry applications, QuickWash is used wherever the need exists to reduce phosphorus regardless of the source of the phosphorus. QuickWash has been successfully vetted through the WEF/WRF LIFT (Leaders Innovation Forum for Technology) Program. QuickWash results in the recovery of phosphorus in the form of amorphous calcium phosphate (ACP), which can be a valued natural fertilizer, and produces a treated water stream that is lower in phosphorus that can be used as an irrigation water source.

This project focused on demonstrating the ability of QuickWash to significantly recover the phosphorus in an application common to the targeted watersheds within the geographic area served by the Maumee Watershed Alliance. Originally, included in the original proposal were multiple sites. However, after year 1 of the program, a scope change was requested and accepted to allow for a more thorough and comprehensive evaluation in a deep-pit swine application. A model developed based around the USDA 2012 Census of Agriculture (Appendix C), estimated that approximately 9.1% of the total US levels of P2O5 in livestock manures were produced in the 2 primary states within the Maumee Watershed Alliance Region (Indiana and Ohio).

4. Project Methods

A high-level overview of the process followed for the evaluations conducted in this Program is summarized in Figure 4.1 below. Also shown are the location of the sample collection points used. Unless noted separately, all conclusions were based on third-party lab analysis (Brookside Labs, New Bremen, OH).

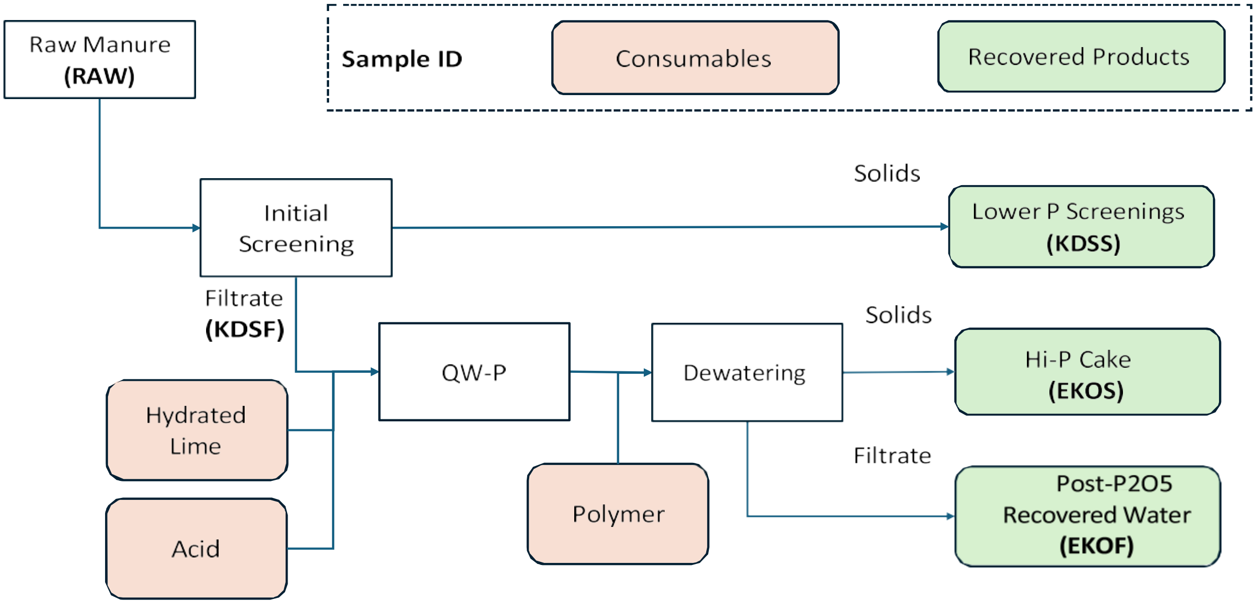


Figure 4.1: Process Overview

Raw manure (RAW) is initially screened to remove excessive solids, resulting in a lower P containing material (KDSS). The liquid from this process (KDSF) is then processed through the QuickWash (QW-P) technology and then dewatered. This results in a dewatered solids Hi-P Cake (EKOS) and a liquid treated stream (EKOF) containing reduced phospherous.

Appendix A is a summary of the technologies employed in this Program:

- Initial Screening: Kendensha Rotating Disc Separator (KDS)
- Phosphorus Recovery (QW-P): QuickWash® Phosphorus Recovery
- Dewatering: ESMIL JD series Dewatering Roller press (Ekoton)

5. Project Results

A detailed analysis of progress against the previously noted objectives in Section 2, is included in Appendix B. The following are excerpts from this detailed analysis, providing a summary of progress against the specific Objectives noted in Section 2. All references to Tables and Figures refer to their location within Appendix B.

Objective 1:
Demonstrate the ability to reduce Total Phosphorus (TP) a minimum of 80% over the course of an extended duration demonstration at a swine operation.

The majority of the effort of this program was focused on this objective. The relationship between TP and P2O5 is a constant value of 2.29 and for relevance to agricultural production, values associated with P2O5 were used. As part of the investigation, a detailed evaluation of the contribution of the key steps in the process summarized in Figure 4.1 was conducted. All evaluations were conducted based on data reported through third-party evaluations (Brookside Labs, New Bremen, OH) of samples provided on an approximate weekly basis throughout the time period of active testing. The following key observations and results were achieved.

Raw Manure Analysis

All comparisons were made relative to the characteristics of the Raw Manure coming directly out of the deep-pit storage used at the host farm. Over the 2-year period of this program, a total of 112 samples were collected and analyzed. The summary of key metrics is shown in Table 5.1.

Table 5.1: Key Raw Manure Characteristics – Deep-Pit Storage Manure Characteristics

Metric	Solids, %	P2O5	TP	NH4
Number of samples	112	112	112	112
Solids, %	7.05			
Std Dev, % Solids	2.105			
Avg, lb./1000 gal		45.30	19.80	23.88
Std Dev, lb./1000 gal		16.028	6.993	2.805

As noted previously, the Raw Manure was stored in a deep-pit configuration. During the course of this program, a separate evaluation, at different locations, was also conducted on analysis of swine manure stored in a shallow-pit configuration. These applications involve less under hog storage times (typically less than 3 days) and are flushed into a holding lagoon or other storage vessel on a regular basis. For comparison, the data in Table 5.2 is based on the same Key Raw Manure Characteristics as summarized in Table 5.1.

Table 5.2: Key Raw Manure Characteristics – Shallow-Pit Storage Configuration

Metric	% solids	P2O5	TP	NH4
Count	12	12	12	12
Solids, %	0.62			
Std Dev, % solids	0.119			
Avg, lb./1000 gal		0.90	0.40	6.76
Std Dev, lb./1000 gal		0.314	0.134	2.666

Comparing Tables 5.1 and 5.2, it is clear that the P2O5 levels are considerably different. This is due to the settling of particulate phosphorus in a shallow-pit storage configuration. Over time, the particulate phosphorus will settle into the sludge at the bottom of the storage vessel, commonly a lagoon. While the same effect occurs in a deep-pit configuration, in a deep-pit design, the volume of manure stored would be considerably less than a lagoon. As would be expected, the deeper into a deep pit that manure is sampled, it would be expected to have a higher concentration of solids, and consequently, a higher level of P2O5. This relationship is shown in Figure 5.1 in which the individual samples are plotted. Shown for comparison are the results of the 12 shallow-pit samples from Table 5.2.

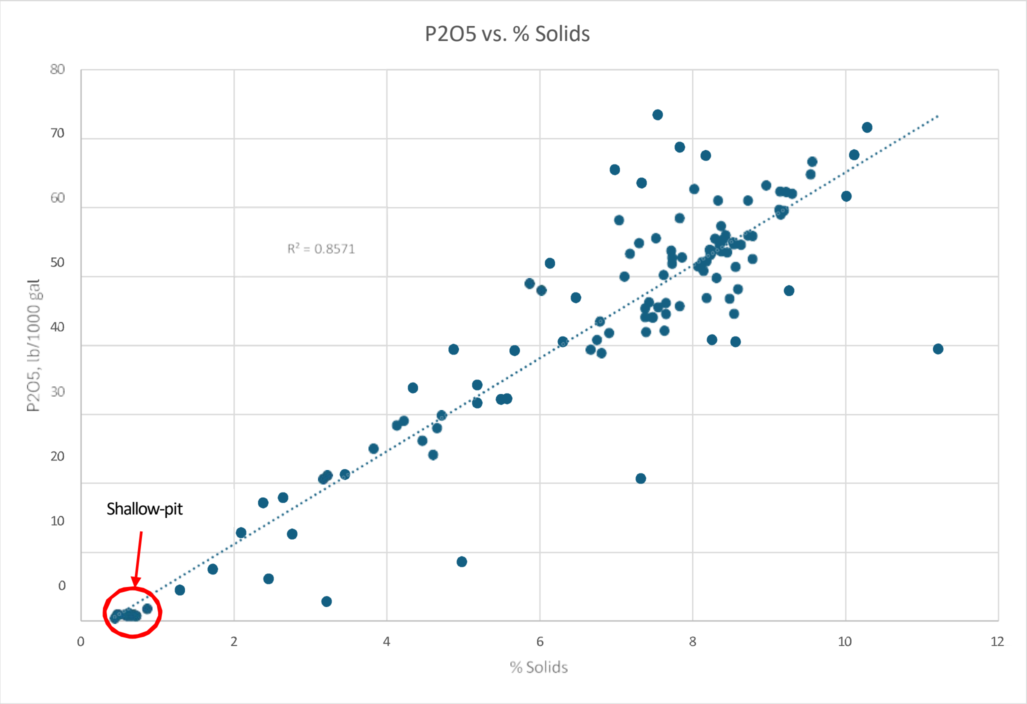


Figure 5.1: P2O5 and % Solids Relationship

The final observation worth noting is the relationship between P2O5 and NH4. As shown in Figure 5.2, while the P2O5 levels can vary widely (Table 5.1, standard deviation of 16.03lb/1000 gal or 35% of average), the level of NH4 remains constant with relatively "stable" levels (Table 5.1, standard deviation of 2.08 lb./1000 gal, or 12% of average). Also shown for comparison are the values measured for the shallow-pit applications. It is worth noting that the "peak" observed in the shallow-pit data is from an anaerobic lagoon application where gas production would be expected to be associated with higher NH4 values.

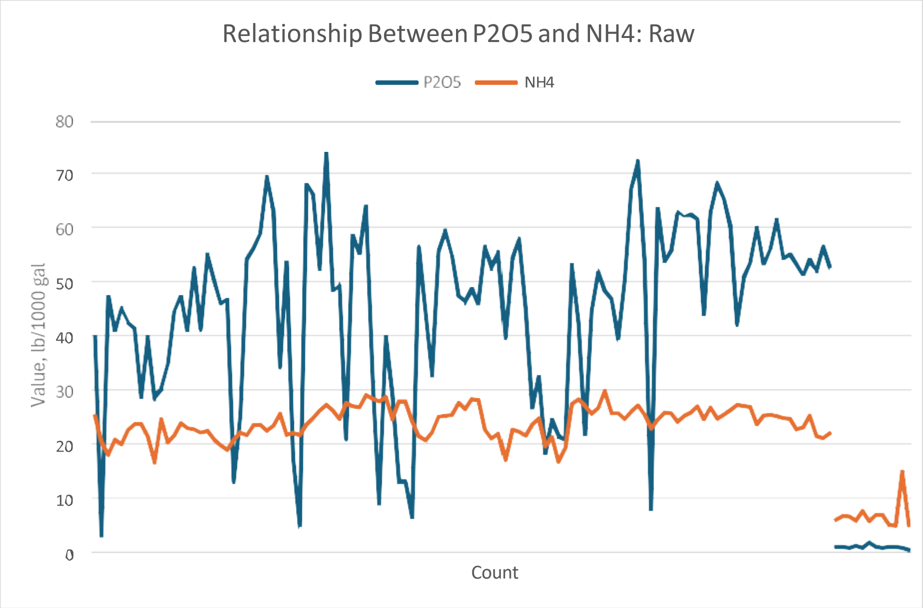


Figure 5.2: Relationship Between P2O5 and NH4

As noted above, a more detailed summary of the investigation into the various process steps is included in Appendix B. Table 5.8 from Appendix B summarizes the contribution of these steps to Objective 1. All results included use of polymer in dewatering with the Ekoton device:

Table 5.8: Summary of Influence of Consumables

Flow	n	Runs	Average P2O5, lb/1000gal	Average % solids	Average % reduction
KDSF direct to Ekoton (no QW-P)	15	1-15	10.00	1.58	72.18%
QW-P Hydrated Lime only	8	16-22	1.61	0.72	94.69%
QW-P Acid and Hydrated Lime	23	23-45	5.86	1.41	84.81%
2023 Full Treatment (Figure 4.1)	5	46-50	0.43	0.65	98.15%

This data shows the following observations:

- If no additional treatment were conducted, a P2O5 recovery of 72.18% is possible directly from the deep-pit storage through simple dewatering through the KDS, with no polymer usage, prior to dewatering in the Ekoton device, with polymer.
- If only hydrated lime were used to precipitate out soluble P2O5, a 94.69% recovery is possible after dewatering in the Ekoton device, with polymer.
- If both the acid hydrolysis and hydrated lime processes were used, it appears that an 84.81% recovery is possible. However, these studies were conducted using the same dosage of polymer to maximize solids capture, using the KDSF to Ekoton as the dosage used resulting in slightly less solids capture. The benefit of acid hydrolysis is shown by the increased level of P2O5 availability with a slightly higher solids content. Capturing the increased solids would reduce P2O5 further.
- The final runs conducted were focused on optimizing the polymer dosage to achieve a similar % solids to the hydrated lime only condition. This suggests that a maximum P2O5 recovery of 98.15% is possible when acid hydrolysis and hydrated lime addition are employed.

It is worth noting that the amount of acid hydrolysis used was minimized by focusing on only the degree of hydrolysis required to break the alkalinity of the manure. Using pH as the process control parameter, a target of pH 7.25 was used. This required the need to allow pH to drop approximately 0.5 pH units. While a noticeable increase in P2O5 was observed at this level of hydrolysis, further P2O5 may be available at more aggressive levels of acid hydrolysis if warranted, at an increased cost of acid.

Objective 2:
***Define the economics of a typical installation*.**

For purposes of defining a "typical installation," the following assumptions were made:

- Economics were based on the cost of consumables to achieve a defined level of P2O5 recovery. The cost of material transport to an off-taker for further processing was not considered as this can vary widely depending on the farm and off-take location.
- The level of nutrients was equivalent to the average Raw manure measured and summarized in Table 5.1.
- The process conditions used in the final assessment (98.15% P2O5 recovery) was desired.
- It was assumed that no economies of scale were factored in to reflect the high volume of consumables.

Pricing per consumable was based on actual costs from an Ohio Water Development Authority (OWDA) funded program completed in summer, 2021. A formal 2023 SNF quote on tote volumes of polymer for use in the Ekoton device was also used for polymer estimated costs. Table 5.9 is a summary of the estimated total consumable costs to treat 100,000 gallons of raw manure.

Table 5.9: Estimated Consumable Costs to Treat 100,000 Gallons of Raw Manure

Consumable	Units	Value	Weight	Units	$/lb	Total	Pricing Source
H2SO4, 5N	mL/gal	6	321.872	lb	$ 0.15	$ 48.28	OWDA 2020 pricing
Dolomitic Hydrated Lime	mL/gal	75	4934.211	lb	$ 0.12	$ 609.38	OWDA 2020 pricing
Polymer	ppm	500	50	gal	$ 4.73	$ 236.48	2023 SNF tote pricing
					Total	$ 894.14	
					$/gal	$ 0.0089	

Consumable costs are estimated to be $0.0089/gallon manure treated. This is in line with previously evaluated consumable cost estimates of $0.0063/gal treated and $0.0064/gal treated conducted through an Ohio Farm Bureau sponsored program (2020) and the above noted OWDA funded program (2021), without the use of final dewatering polymer costs. The significant reduction in the estimated costs for the dewatering phase using the Ekoton equipment and SNF polymer were well below the projected cost of $0.010/gal treated that was anticipated. Additional costs for power would need to be determined based on the cost of power in the site location plus the final scope of design for the individual application. Capital costs would also need to be estimated based on the treatment strategy to be employed, the volume of manure and frequency of treatment plus specific site equipment and site layout required. In general, based on multiple quotes provided for swine applications, the initial in-scope capital costs would run approximately $400K-$425K for a targeted recovery of P2O5 of 50% up to an estimated cost of

$500K - $525K for a maximum recovery of P2O5 as determined in this program for a facility treating 700K gal/year.

The final figure to consider in defining economics of a typical installation would be the labor requirement. In general, it is estimated that a full-time equivalent (FTE) of approximately 0.5 would be required to operate and maintain a facility treating 700K gal/year.

It is worth noting that the above cost estimates do not consider the value of the recovered nutrients.

__Objective 3:__

Determine the estimated value of the recovered products produced with the treatment process. Recovered products included dewatered manure and recovered phosphorus.

To determine the estimated value of the recovered products, it was decided to simply calculate the value of the recovered nutrients on the basis of the nutrient contribution against prevailing nutrient costs. For purposes of this estimate, the following assumptions were made:

1. There are 2 primary products produced through the process evaluated: a low P2O5 product (KDSS) and a high P2O5 product (EKOS).
2. Table 5.10 is a summary of the assumed prevailing nutrient costs.
3. It is worth noting that this analysis is considered conservative in that the potential values of recovered constituents, such as sulfur, calcium, or magnesium, are not considered. Nor is the value of the organic matter recovered.
4. It is also worth noting that the value of recovered ammonium as liquid ammonium sulfate was not considered. Additionally, the ammonia recovered may have value as an alternative to conventional fertilizer, such as green ammonia or even as a form of hydrogen feedstock.

Table 5.10: Cost Assumptions for Value Assessment of Recovered Products

Nutrient	***$/ton***	***Unit price***	**Unit**
P205	$ 800	$ 0.40	lb
K20	$ 465	$ 0.23	lb
Ammonia	$ 943	$ 0.47	lb

Based on the above assumptions, we would estimate a conservative value of the recovered nutrients as shown in Table 5.11. The values used are based on the summary of average results shown in Figures 5.15 and 5.18 (from Appendix B).

Table 5.11: Estimated Value Based on Nutrient Only Contribution (Value per Ton, $)

Nutrient	**RAW**	**KDSS**	**EKOS**	**EKOF**	***EKOS as Pellets (EKOS-P)***	***KDSS + EKOS+ EKOF***	***KDSS + EKOS- P + EKOF***
P2O5	$19.17	$6.88	$19.06	$0.22	$63.15	$26.16	$70.25
K20	$4.41	$0.96	$0.72	$2.38	$3.44	$4.06	$6.78
Ammonia	$11.43	$11.43	$1.29	$3.66	$4.09	$16.37	$19.17
Total	***$35.00***	**$19.27**	**$21.07**	**$6.25**	**$70.68**	***$46.60***	***$96.20***

As shown in Table 5.11, the conservative nutrient only estimated value ranges from \$46.60 - \$96.20 per ton depending on the degree of processing (i.e., pelletizing) of the high P2O5 material recovered. For comparison, the same calculated value on the RAW only material is \$35.00/ton.

Objective 4:

Confirm the acceptability of treated water to be used as a source of irrigation water by comparing the quality of the treated water against nutrient and irrigation water standards by comparing the treated water to currently used irrigation water at other farms in the St. Joseph, St. Marys, and Upper Maumee Watersheds.

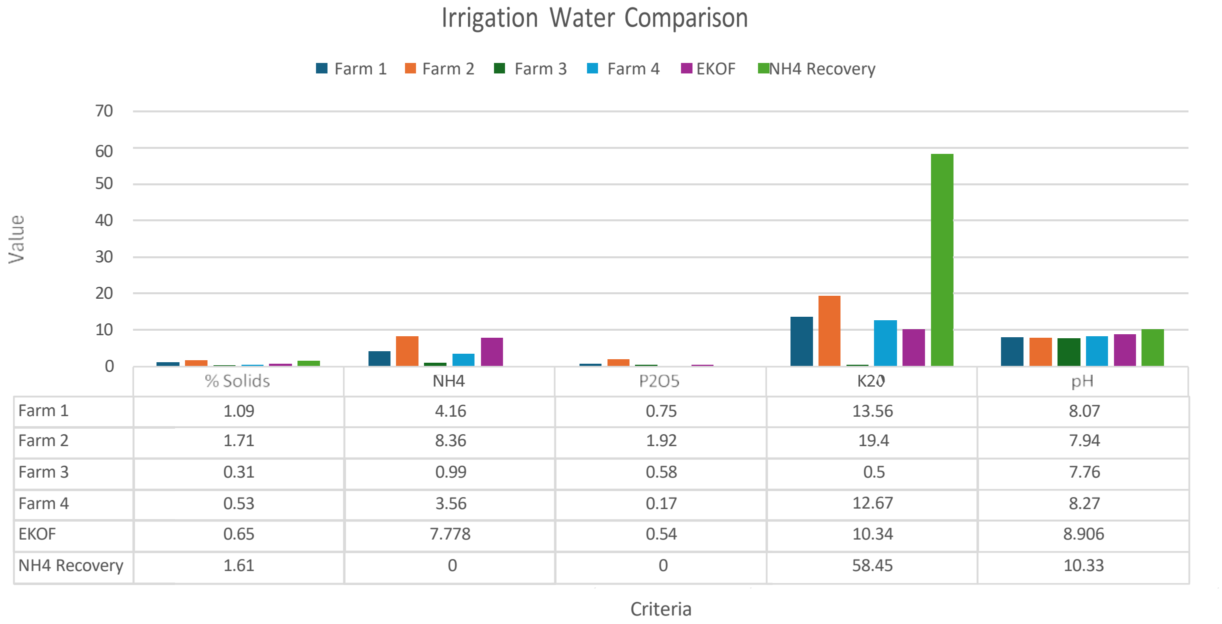
As noted previously, one of the benefits resulting from the treatment of swine manure in this program was a water with potential value after the recovery of P2O5. If only P2O5 is recovered, there will be a higher amount of NH4 in the water which may or may not need to be considered before use as irrigation water. In order to compare the quality of the water remaining after P2O5 recovery has occurred, samples were collected from local operations where the water remaining after production is used to support center pivot irrigation of a typical corn-soybean rotation. A total of 4 different farms were sampled and are described briefly in Table 5.12.

Table 5.12: Comparative Farm Producers Irrigation Water

Farm	Description
1	Multiple Dairy Operations discharging to single lagoon
2	Large single Dairy Operation
3	Large egg-breaking operation
4	Shallow pit swine operation

Samples were collected from each farm and third-party testing (Brookside Labs, New Bremen OH) conducted using a standard manure analysis used throughout this program. These are summarized in Figure 5.20 alongside analysis of the final confirmation run averages summarized in Appendix B as Figure 5.15 (EKOF). While outside of the scope of this program, also shown is the water quality analysis from the NH4 recovery shown in Figure 5.19. In that particular process, the use of a hydroxide is used to maintain the process pH above 9.2 to expedite the conversion of ammonium to ammonia for recovery. In this case, KOH was used to increase the available K20 in the potential irrigation water. The objective was to show that the level of K20 in the irrigation water can be influenced through recovery of ammonium.

	Units	Farm 1	Farm 2	Farm 3	Farm 4	EKOF	NH4 Recovery
% Solids	%	1.09	1.71	0.31	0.53	0.65	1.61
NH4	lb/1000gal	4.16	8.36	0.99	3.56	7.778	<0.010
P2O5	lb/1000gal	0.75	1.92	0.58	0.17	0.54	<0.001
K20	lb/1000gal	13.56	19.4	0.5	12.67	10.34	58.45
pH	SuS	8.07	7.94	7.76	8.27	8.906	10.33



	% Solids	NH4	P2O5	K20	pH
Farm 1	1.09	4.16	0.75	13.56	8.07
Farm 2	1.71	8.36	1.92	19.4	7.94
Farm 3	0.31	0.99	0.58	0.5	7.76
Farm 4	0.53	3.56	0.17	12.67	8.27
EKOF	0.65	7.778	0.54	10.34	8.906
NH4 Recovery	1.61	0	0	58.45	10.33

Figure 5.20: Irrigation Water Comparison

<u>Objective 5:</u>
Participate in a Project Closing Event.

Throughout the course of this program, numerous site visits and educational events were hosted. A Project Closing Event did occur on October 5, 2023, when Ohio EPA visited the site to recognize the shipment of material to an off-taker (Kurtz Brothers). During this visit, a thorough walk-thru and process overview discussion was held both at the site and at a separate conference room.

6. Project Outputs

Throughout the course of this program, numerous site visits and presentations were given. These are briefly detailed in the following sections:

Outreach Events

- August/September 2021: As the CIG project proposal was taking shape the Maumee Watershed Alliance (MWA), in cooperation with the Allen County Soil and Water Conservation District (ACSWCD), conducted two pre-project site-visits to Mercer County, Ohio, where the KDS and QuickWash® technologies were operating to introduce local and state government leadership, representatives from Indiana Farm Bureau and interested local livestock producers to the forthcoming project and the technologies that will be used. Attendee comments offered included:
    - After viewing the KDS / QuickWash technologies demonstrated, attendees commented that the concept looked promising, but were often commenting that the cost to acquire, operate and maintain would be a key factor in producer acceptance.
    - Comments were also noted that the use of geotextile bags being used did not seem practical and that a different final dewatering system would be needed.
    - Comments were also noted on the apparent need for secondary (post treatment) storage of the remaining liquid manure.
    - Attendees expressed their understanding that the producer would need to be prepared with a storage facility for both the KDS and QuickWash produced solids.
- Spring 2022: As the CIG project was getting underway, meetings with local livestock producers were held to inform them of the project and to seek their input regarding the project's goals, anticipated outcomes, and to gauge potential long-term farmer interest in the technologies being demonstrated. Perhaps the most important outcome of the farmer meetings was the opportunity for the project's leadership to hear directly from producers on how implementing technology such as this would impact their operation.
- March, 2023: The CIG project was also introduced to Fort Wayne (IN) City Utilities administrative and lab staff to make them aware of new efforts being evaluated by the agricultural community to improve water quality. During these meetings discussions focused on the feasibility of discharging the final liquid form of manure, with nearly all nutrients removed, into the Utilities' regional sewer system.
- March, 2022: Throughout the project the MWA and ACSWCD showcased the CIG project at several events, such as the annual Going Green for Ag event, with nearly 100 producers in attendance each year. The CIG project was the featured topic at the 2022 Going Green for Ag event held in March 2022. The CIG project was also featured during the annual Fort Wayne Farm Show, with nearly 30,000 participants, and the annual ACSWCD Soil Health Field Day, with over 150 growers in attendance (January 2023 and January 2024).
- July 19, 2022: Representatives from the MWA, ACSWCD and Rick Johnson from AES, gave an on-site presentation to the Indiana NRCS Leadership Team with approximately 30 in attendance.
- August 2022: MWA Board members and ACSWCD staff conducted on-site outreach meetings with representatives from the Indiana Conservation Partnership. The

Conservation Partnership is comprised of representatives from USDA-NRCS, Indiana State Department of Ag (ISDA), Purdue University, and the Indiana Association of Soil and Water Conservation Districts, as well as other state and local agency personnel.

- Summer / Fall, 2023: MWA Board members and ACSWCD staff showcased the CIG project and related technologies to Mark Smith, NRCS Western Lake Erie Tri-State Coordinator and Mark Fritz, CCA and NRCS Western Lake Erie Project Assistant.
- August 30, 2023: Rick Johnson gave a presentation on the CIG project and the technologies being used at the Manure Management and Field Spill Demonstration field day held in Adams County with approximately 75 people in attendance.
- October 5, 2023: Site visit from Ohio EPA. This visit was used to support the preparation of a proposal for a Federal EPA grant (through the Great Lakes Restoration Initiative administered through Ohio EPA) for a similar program to be conducted within Ohio in summer, 2024.

Presentations

- A poster was prepared and presented at the 78th SWCS International Annual Conference, August 6-9, 2023 in Des Moines, Iowa, titled *Western Lake Erie Basis – Manure Nutrient Recovery*, Paper ID: 172.
- A poster was prepared and presented at the 79th SWCS International Annual Conference, July 21- 24, 2024 in Myrtle Beach, South Carolina, titled *Western Lake Erie Basin – Manure Nutrient Recovery*, Paper ID: 253.
- An oral presentation was prepared and given at the 79th SWCS International Annual Conference, July 22, 2024 in Myrtle Beach, South Carolina, titled *Nutrient Loading Reduction through Phosphorus Recovery Demonstration Program.*

Project Outputs

- A total of 85 yards of materials (KDSS and EKOS) were delivered to multiple off-takers for further processing for planned field trials. Materials were primarily submitted to Kurtz Brothers (Cleveland, OH) for processing into enhanced materials used in their Regen Product Family, Lake Farms (Allen County, OH) for a small privately owned field trial and Riggenburg Nurseries for composting.

Next Steps

- As noted in Table 7.1 in the following section, and noted above under Project Outputs, materials have been provided to several off-takers for follow-on evaluation and small scale field trials. It is anticipated that results from these will be completed in the 2025 planting and harvesting seasons. Results from these will be used in associated field presentations and used to further develop the technology solution evaluated.
- Based on the results achieved and, in particular the relatively high ammonium levels observed, development of a second Conservation Innovation Grant (CIG, Classic) will be developed and proposed for further investigation of the recovery of ammonium in swine applications.
- In addition to the above noted second CIG proposal, based on input and interest from those who viewed the Demonstration Program, development of a separate Conservation Innovation On-Farm Demonstration Program will also be prepared for submission.

7. Project Impacts

The primary objective of this Program was to demonstrate the ability to recover a minimum of 80% of P2O5 from a deep-pit swine operation over an extended duration. As noted in Section 6, during the course of this program, a total of 85 yards of material was recovered with an approximate weight of 51 tons (each yard had previously been weighed to approximate 1200 lb./yard). These materials were shipped to various off-takers as identified in the submitted proposal for further evaluation and potential reuse evaluation. Each yard provided had a grab sample of the material analyzed prior to shipment. The estimated total volume of key nutrients recovered (P2O5, TN and K20), plus secondary nutrients which may have beneficial impact on soils (S, Ca, Mg) from these 85 yards are summarized in Table 7.1.

Table 7.1: Estimated Beneficial Nutrients Recovered (Total Recovered Nutrients, lb)

Off-taker	Yds	Weight Tons	P205	TN	K20	S	Ca	Mg
KBI	75	45.0	1143.9	674.1	177.3	149.4	372.6	555.3
Lake Farms	9	5.4	137.3	80.9	21.3	17.9	44.7	66.6
Riggenburg	1	0.6	15.3	9.0	2.4	2.0	5.0	7.4
Total	85	51	1296.4	764.0	200.9	169.3	422.3	629.3

Further, from the analysis of the material shipped summarized in Appendix D:

- The average moisture content was 79.36%
- The average pH was 8.13
- The average P205 that was plant available was 82.77%
- The materials shipped are currently in the early stages of field trials to demonstrate the impact on crop enhancement / growth performance

Appendix C is a reprint of Table 1 in the original proposal submission which provided an estimate of manure volume produced within the geographic region of the Maumee Watershed Alliance based on the 2017 USDA Agricultural Census and actual P205 composition provided by the Mercer County (OH) SWCD of 1689 tons per year. If the results demonstrated in Table 5.8 were achieved (98.15% P205 Recovery) in 25% of this estimated tonnage of P205 (from Appendix C), a total of over 410 tons of P205 could be recovered. Appendix D is a detailed summary of the Shipment Analysis Results from the materials sampled prior to shipment.

Appendices

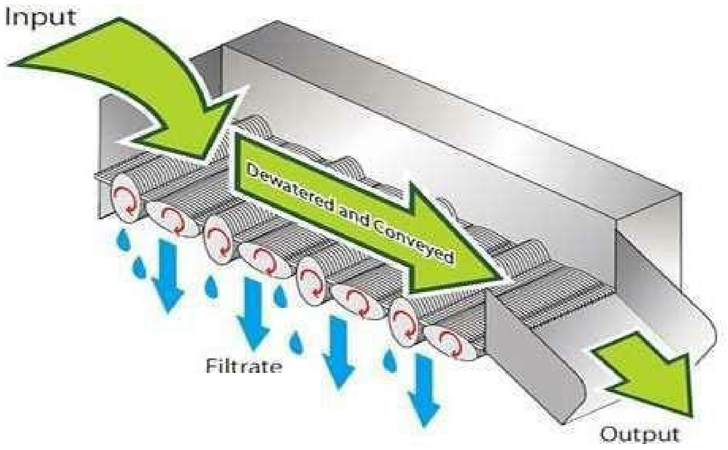
Appendix	Description
A	Technology Descriptions • Kendensha Rotating Disc Separator • QuickWash® Phosphorus Recovery • Ekoton Dewatering
B	Detailed Program Testing Results
C	Table 1 Reprint from Original Program Submittal
D	Sample Shipment Analysis

Appendix A: Brief Technologies Description

The following provide a brief summary of the various technologies employed in the course of this program.

Kendensha Rotating Disc Separator

The Kendensha Rotating Disc Separator (KDS) is produced by Kendensha Co, Ltd. Figure A.1 is an image of the Separator provided by Kendensha. A product stream to be dewatered enters the dewatering platform where lobed plates rotate allowing the entrained water to drain. The solids remaining are conveyed along the inclined body to the discharge chute. The liquid (filtrate) that comes out of the solution is collected under the platform for disposal or reuse. Because of its unique design, the unit is self-cleaning, and no backflushing is required. The end result is an efficient compact design with very low energy requirements.



(KDSS)

Figure A.1: KDS Multi-disc Roller Separator

The degree of dewaterability for a particular stream can be controlled by a concentration plate which is located above the discharge chute. By controlling the amount of pressure on this plate (through means of a pneumatic cylinder or physical weight), increased dewatering can result.

To improve the overall dewatering capability of the Separator, it is common to use a polymer in the input stream to maximize dewaterability. Numerous case studies have been completed where polymers were not required to achieve dewatered solids content of 20%+. With an installed base of over 1300 units as of March 2024 (primarily in Japan and Asia), the KDS Separator has demonstrated its ability to meet the demanding requirements of a wide range of industries. Figure A.2 is a summary of the installed base provided by Kendensha as of September 2022.

Of particular relevance to this proposal are the results of 3 separate streams dewatered during a shorter duration pilot conducted in spring 2018 in Mercer County, OH. This pilot was conducted to demonstrate the ability of the KDS Separator to successfully dewater swine manure, dairy manure and a DAF Float (produced through a free electron, ionized dissolved air floatation device being installed at the Celina Water Treatment Plant). Images of all 3 streams are shown in Figure A.3.

The KDS unit evaluated in Mercer County has been used in multiple program pilots within Ohio to evaluate the ability of QuickWash to recover phosphorus in side stream applications. For these evaluations, dewatering was conducted using the KDS in a thickening mode (no pressure plate load) with solids content of 10-14% being achieved in municipal applications. The KDS unit was also employed in a 2019 field program and was able to consistently result in a cake solid of up to 20% in a dairy pilot, without the use of polymers.

Category	**Installed Base**	**% of Total**
Livestock	224	30.7
Industrial Wastewater	80	11.0
Domestic Wastewater	124	17.0
Recycling Wastewater	54	7.4
Food Related Wastewater	163	22.3
Civil Works	85	11.6
Total	***730***	***100***

Figure A.2: KDS Installed Base Summary

Swine Manure Dairy Manure DAF Float

Figure A.3: KDS Short Term Pilot Images – Mercer County

QuickWash Technology

QuickWash is a technology based on a suite of patents issued to the USDA and exclusively licensed to Renewable Nutrients (Renewable). Applied Environmental Solutions (AES) is the exclusive commercialization partner for Renewable and brings a broad base of experience in the water / wastewater markets. The QuickWash technology has successfully been vetted through the Water Environment & Reuse Federation (WE&RF) Leaders Innovation Forum for Technology (LIFT) Technology Scan Process and is further identified as one of the 10 technologies vetted through the H2Ohio Technology Assessment Program (TAP) that has potential to significantly impact the reduction of soluble phosphorus entering the Western Lake Erie Basin. The QuickWash phosphorus recovery technology (QW-P) consists of 2 main steps of operation:

> *Step 1 Solubilization*: In this step, phosphorus contained in the stream to be treated is solubilized, through the use of acid hydrolysis, resulting in a lowered pH. This results in the water-soluble phosphorus (primarily orthophosphate) moving from the solids to the liquid stream. The degree of solubilization has ranged from 50-95% in bench testing at USDA depending on the particular stream and pH achieved. Following solubilization, the remaining solids contain lower total phosphorus (TP) and have the potential to be land-applied given the lower phosphorus loading.
>
> *Step 2 Precipitation*: In this step, the water-soluble phosphorus is precipitated through the addition of hydrated lime, producing an amorphous calcium phosphate (ACP) material. The resulting liquid now contains a negligible amount of phosphorus, and the ACP produced represents a usable secondary product with commercial value.

These steps are summarized in the high-level process flow diagram shown in Figure A.4:

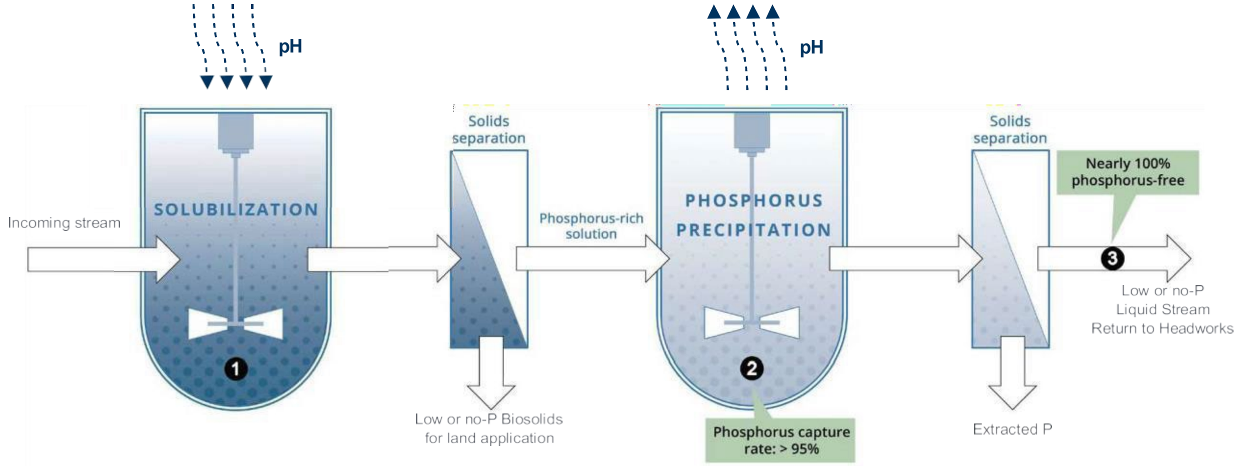


Figure A.4: High level process flow

The degree of solubilization in Step 1 varies from stream to stream and is dependent on influent (to the process) alkalinity and the unique characteristics of the overall influent composition. Further, in a municipal or industrial setting, when considering a relatively high industrial waste stream composition (i.e., if Significant Industrial Users, SIU's are involved), the actual percentage of phosphorus available can also vary. The degree of solubility desired is also influenced by the cost of solubilization and/or the desired characteristics of the resulting biosolids.

Once the phosphorus is solubilized following step 1, hydrated lime is introduced to precipitate out the phosphorus in the form of ACP. The degree of precipitation is driven primarily by the amount and type of lime introduced and mixing efficiencies. The recovered phosphorus produced through the QW-P process is classified as amorphous calcium phosphate (ACP) and is more soluble than the crystalline calcium phosphates commonly used today (such as hydroxylapatite). Up to 99% of the P_2O_5 in recovered amorphorus calcium phosphate is plant available.

ESMIL JD series Dewatering Roller press (Ekoton)

The JD Dewatering Roller press is distributed within the US by Ekoton, USA. Multi-roller dehydrators are an excellent solution for the dewatering of sludge with a concentration of suspended matters of up to 150,000 mg/l for medium and small-productivity wastewater treatment facilities as well as for industrial facilities. The dewatered sludge (cake) has a solids content of 15-30%, depending on the properties and composition of the sludge.

The dehydrator's design prevents clogging of the main dewatering unit, therefore there is no need for washing water. The equipment is compact and can be easily placed in restricted space conditions. It operates automatically, is simple to maintain and it does not require regular staff presence. It is economical; electricity, reagent and other resources consumed in the dehydrating operation is lower than at any other dewatering equipment. High wear resistance of the rollers provides reliable operation of the main dewatering unit up to 30,000 hours.

Figure A.9 is an overview of the Ekoton JD Press.

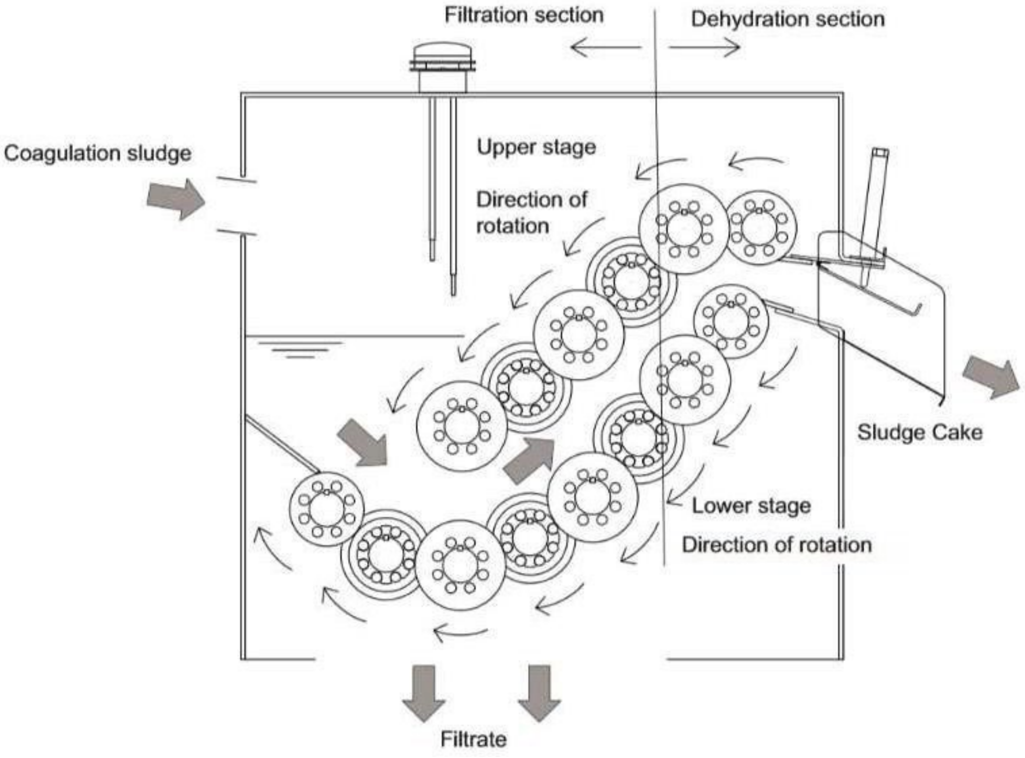


Figure A.9: Ekoton Overview

Influent sludge is fed to the inlet of the dosing chamber by an influent sludge pump. To prevent emergency spills from the flocculation chamber, the dosing chamber is equipped with a vertical emergency overflow pipeline. The sludge from the dosing chamber enters the flocculation chamber via the overflow window.

In the flocculation chamber influent sludge and chemicals are mixed together with an electric agitator causing them to form flocs. Chemically conditioned sludge then enters the main unit. The unit is equipped with filtering rollers arranged in two tiers (6 on the upper tier and 8 on the lower tier). In total there are fourteen filtering rollers (driven by seven gearmotors with chain transmission systems) of which four, closer to the outlet, are in the dehydration zone, the rest ten – in the filtration zone.

Each filtering roller consists of thick resin discs, small thin stainless-steel discs, and large thin stainless-steel discs. These filtering rollers are constructed for easy overhaul and reassembly maintenance is quick and easy. Slits are formed between neighboring discs so that only water drains out. The larger discs of the filtering roller engage with the smaller discs of the neighboring filtering roller causing the slits to be constantly clean.

Appendix B: Detailed Project Summary

The following discussion includes a detailed analysis supporting the numerous studies conducted and the high-level program summary provided under Section 5.

Objective 1:
Demonstrate the ability to reduce Total Phosphorus (TP) a minimum of 80% over the course of an extended duration demonstration at a swine operation.

Raw Manure
All comparisons were made relative to the characteristics of the Raw Manure coming directly out of the deep-pit storage used at the host farm. Over the 2-year period of this program, a total of 112 samples were collected and analyzed. The summary of results is shown in Table 5.1.

Table 5.1: Key Raw Manure Characteristics – Deep-Pit Storage Configuration

Metric	**Solids, %**	**P2O5**	**TP**	**NH4**
Number of samples	112	112	112	112
Solids, %	7.05			
Std Dev, % Solids	2.105			
Avg, lb./1000 gal		45.30	19.80	23.88
Std Dev, lb./1000 gal		16.028	6.993	2.805

As noted previously, the Raw Manure was stored in a deep-pit configuration. During the course of this program, a separate evaluation, at different locations, was also conducted on analysis of swine manure stored in a shallow-pit configuration. These applications involve less under hog storage times (typically less than 3 days) and are flushed into a holding lagoon or other storage vessel on a regular basis. For comparison, the data in Table 5.2 is based on the same Key Raw Manure Characteristics as summarized in Table 5.1.

Table 5.2: Key Raw Manure Characteristics – Shallow-Pit Storage Configuration

Metric	**% solids**	**P2O5**	**TP**	**NH4**
Count	12	12	12	12
Solids, %	0.62			
Std Dev, % solids	0.119			
Avg, lb./1000 gal		0.90	0.40	6.76
Std Dev, lb./1000 gal		0.314	0.134	2.666

Comparing Tables 5.1 and 5.2, it is clear that the P2O5 levels are considerably different. This is largely due to the settling of particulate phosphorus in a shallow-pit storage configuration. Over time, the particulate phosphorus will settle into the sludge at the bottom of the storage vessel, usually a lagoon. While the same effect occurs in a deep-pit configuration, in a deep-pit design, the volume of manure stored would be considerably less than a lagoon, for instance. As would be expected, the deeper into a deep pit that manure is sampled, it would be expected to have a higher concentration of solids, and consequently, a higher level of P2O5. This relationship is shown in Figure 5.1 in which the individual samples are plotted. Shown for comparison are the results of the twelve shallow-pit samples from Table 5.2.

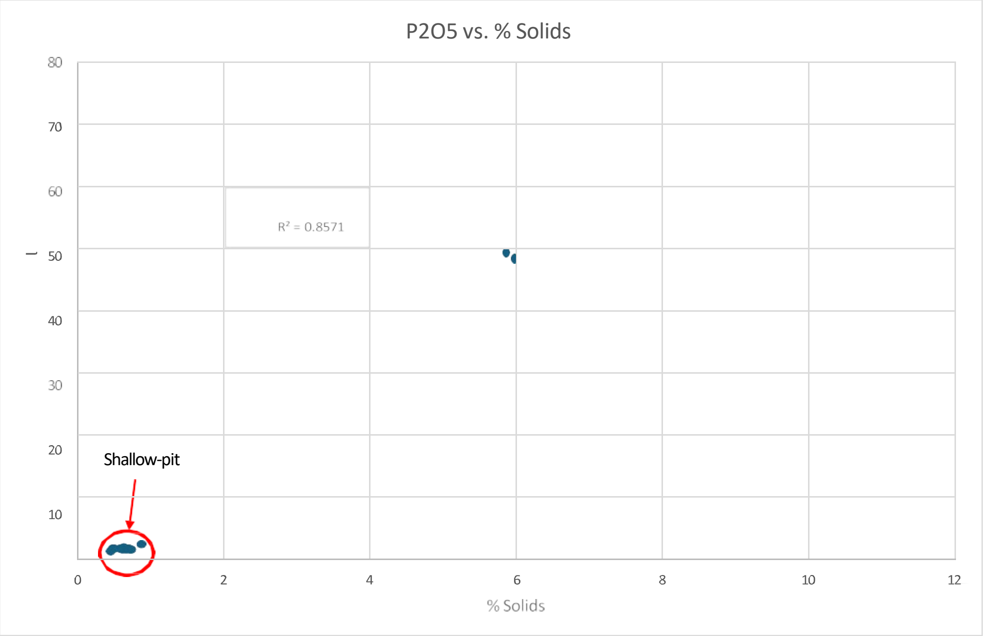


Figure 5.1: P2O5 and % Solids Relationship

The final observation worth noting is the relationship between P2O5 and NH4. As shown in Figure 5.2, while the P2O5 levels can vary widely (Table 5.1, standard deviation of 16.03lb/1000 gal or 35% of average), the level of NH4 remains fairly constant with relatively "stable" levels (Table 5.1, standard deviation of 2.08 lb./1000 gal, or 12% of average). Also shown for comparison are the values measured for the shallow-pit applications. It is worth noting that the "peak" observed in the shallow-pit data is from an anaerobic lagoon application where gas production would be expected to be associated with higher NH4 values.

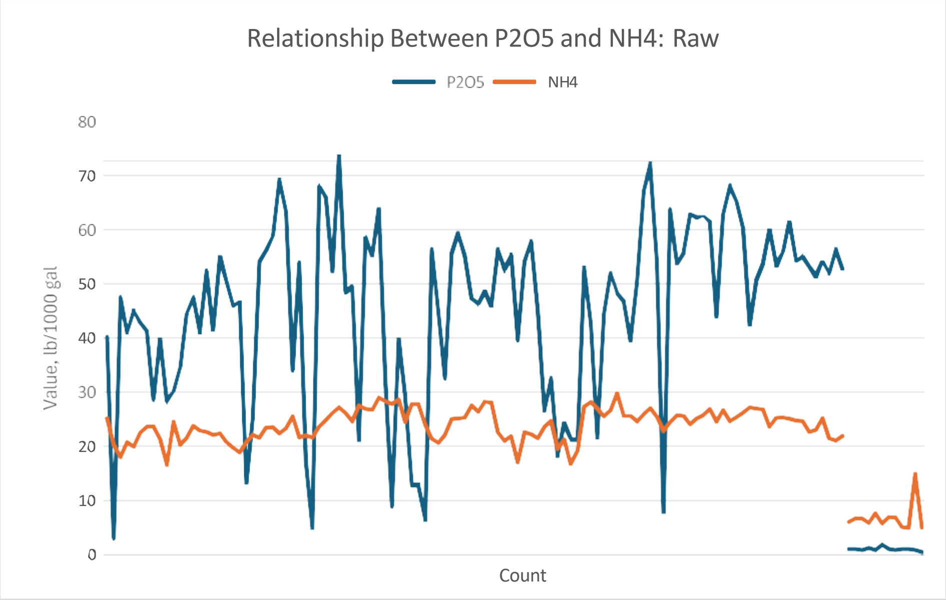


Figure 5.2: Relationship Between P2O5 and NH4

KDS Solids (KDSS)

The purpose of inclusion of the KDS in the overall process is to provide some initial screening of solids from the incoming Raw manure. Additionally, this also provides a potentially useful lower cost product for use in applications where a lower P2O5 reduction is acceptable. Table 5.3 is a summary of key characteristics measured of the solids that come off of the KDS unit. It is worth noting that the measurement units (lb./ton) reflect a lower moisture content compared to a Raw sample.

Table 5.3: KDSS Key KDSS Characteristics

	% solids	P2O5, lb/ton	NH4, lb/ton
Count	58	58	58
Average	20.00	18.92	5.07
St Dev	1.678	4.314	0.593

Figure 5.3 is a comparison showing the KDSS P2O5 levels obtained relative to the Raw Manure, and Figure 5.4 shows the same summary for NH4.

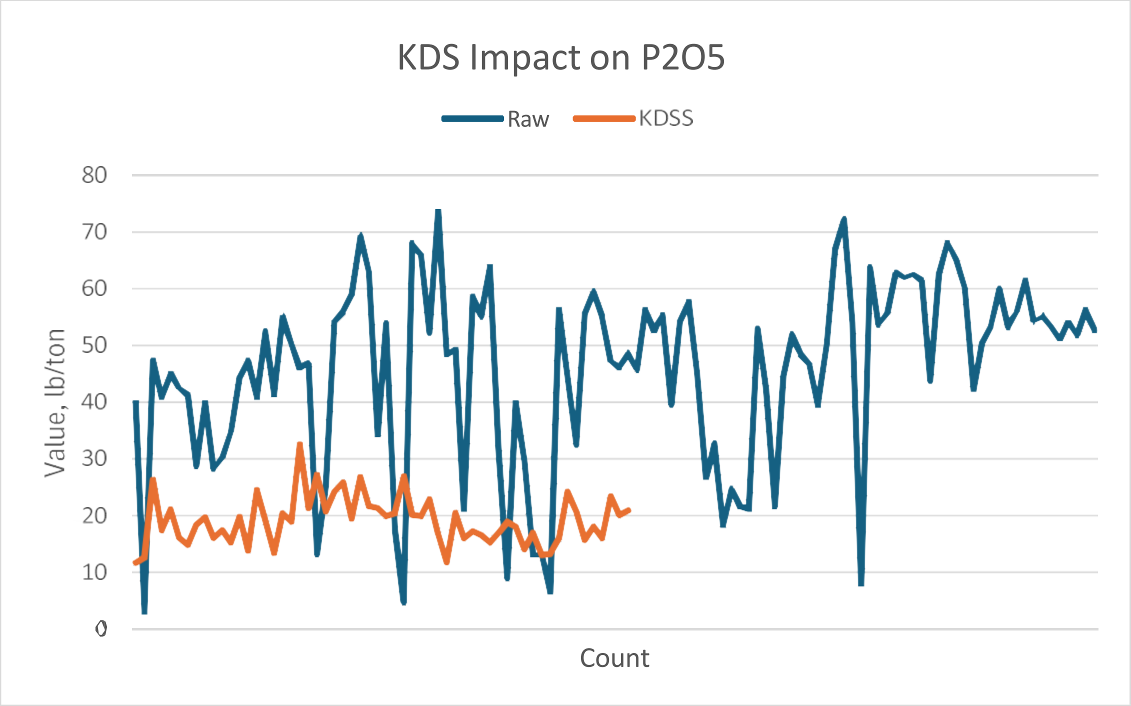


Figure 5.3: Comparison Between Raw and KDSS P2O5

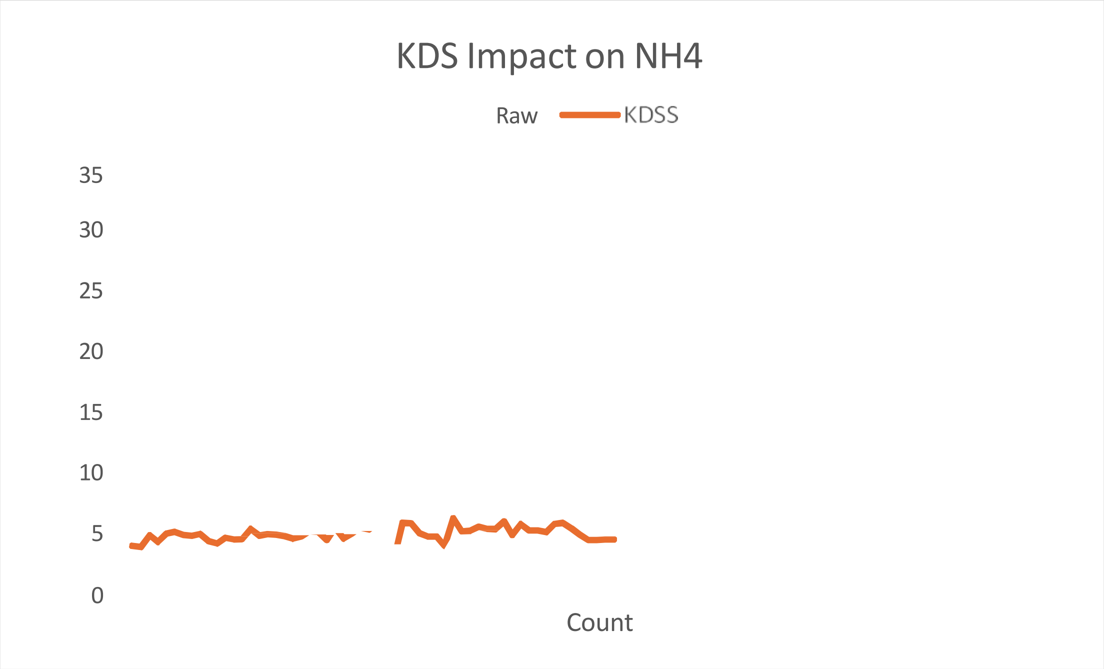


Figure 5.4: Comparison Between Raw and KDSS NH4

As can be seen, there appears to be a marked reduction in both P2O5 and NH4 contained in the KDSS samples. It must be remembered that the values summarized in Table 5.4 are using different units of measure: Raw in lb./1000 gal and KDSS in lb./ton.

Table 5.4: Raw vs KDSS

	P205 Raw	**P205 KDSS**	**NH4 Raw**	**NH4 KDSS**
Units	lb/1000 gal	lb/ton	lb/1000 gal	lb/ton
Avg	45.30	18.92	23.90	5.07
St Dev	16.028	4.314	2.811	0.593
SD % of Avg	35.4%	22.8%	11.8%	11.7%

Despite the difference in units, it is obvious from Figures 5.3 and 5.4, and from Table 5.4, that variability reduces making process evaluations more predictable. Additionally, while variability, as a percent of average seems relatively consistent for NH4, the lower average value, not accounting for units, suggests that a higher percentage of the liquid fraction (KDSF) will contain the bulk of the ammonium.

KDS Filtrate (KDSF)

As the solids from the incoming Raw Manure are screened out, the liquid fraction is collected, and this becomes the influent to the QuickWash Phosphorus Technology (QW-P). While the KDSS material will contain some P2O5 and NH4, it is envisioned that the majority of the soluble nutrients will reside in the filtrate. Figures 5.5, 5.6 and 5.7 confirm this. These compare the results of KDSF analysis against the same characteristic as the Raw dataset.

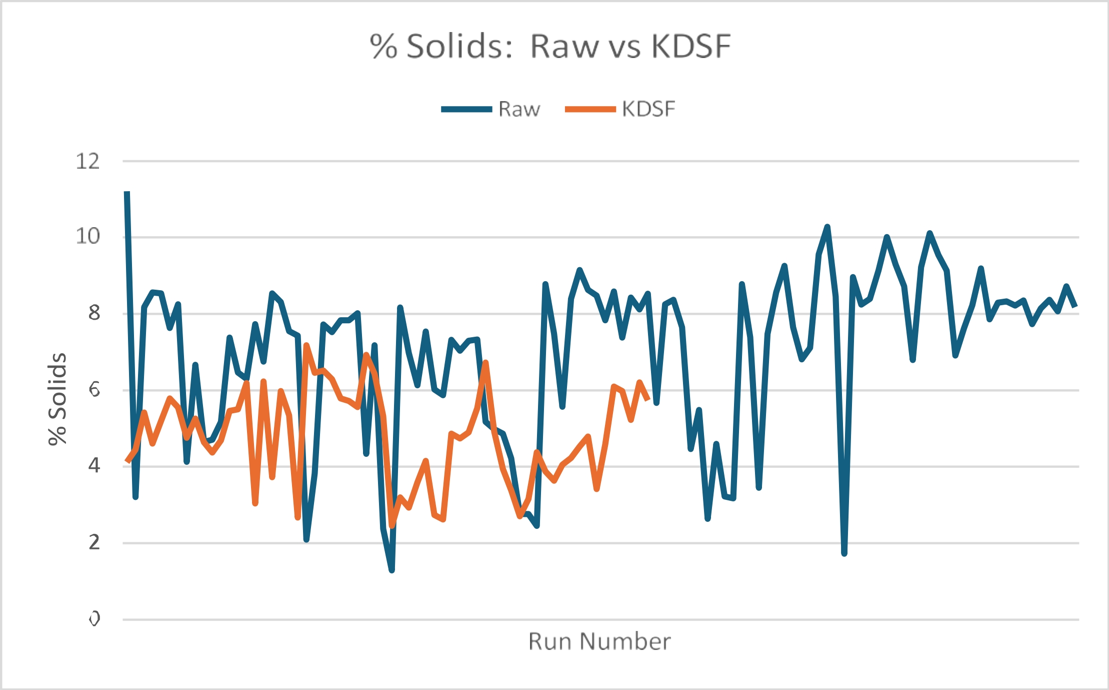


Figure 5.5: Percent Solids, KDSF vs Raw

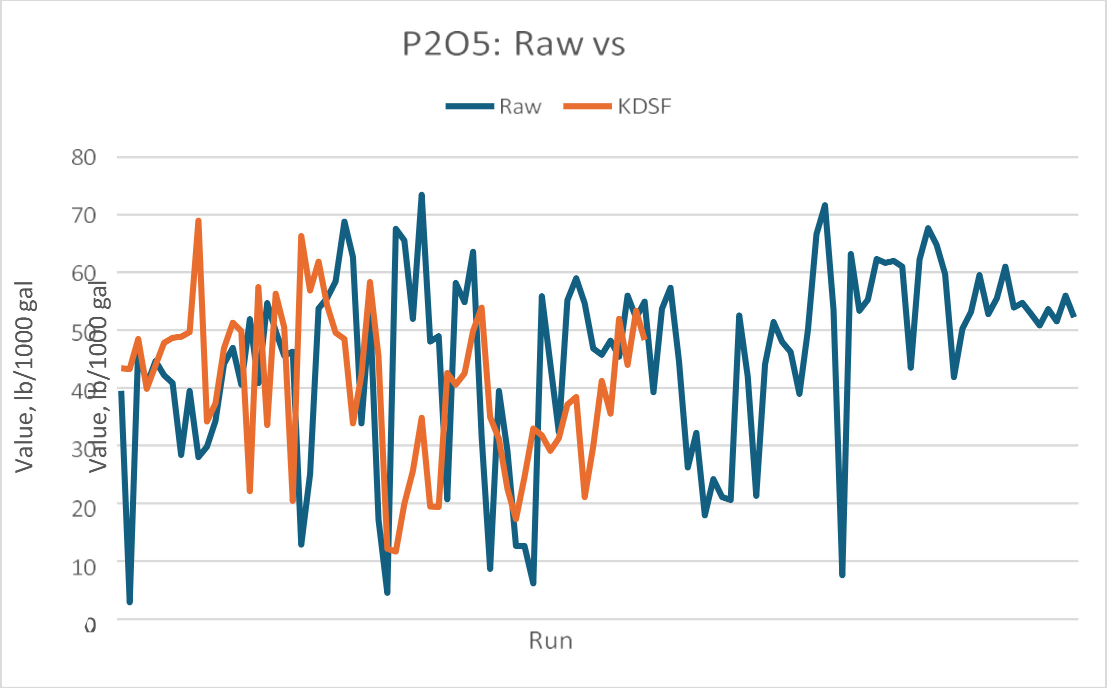


Figure 5.6: P2O5, KDSF vs Raw

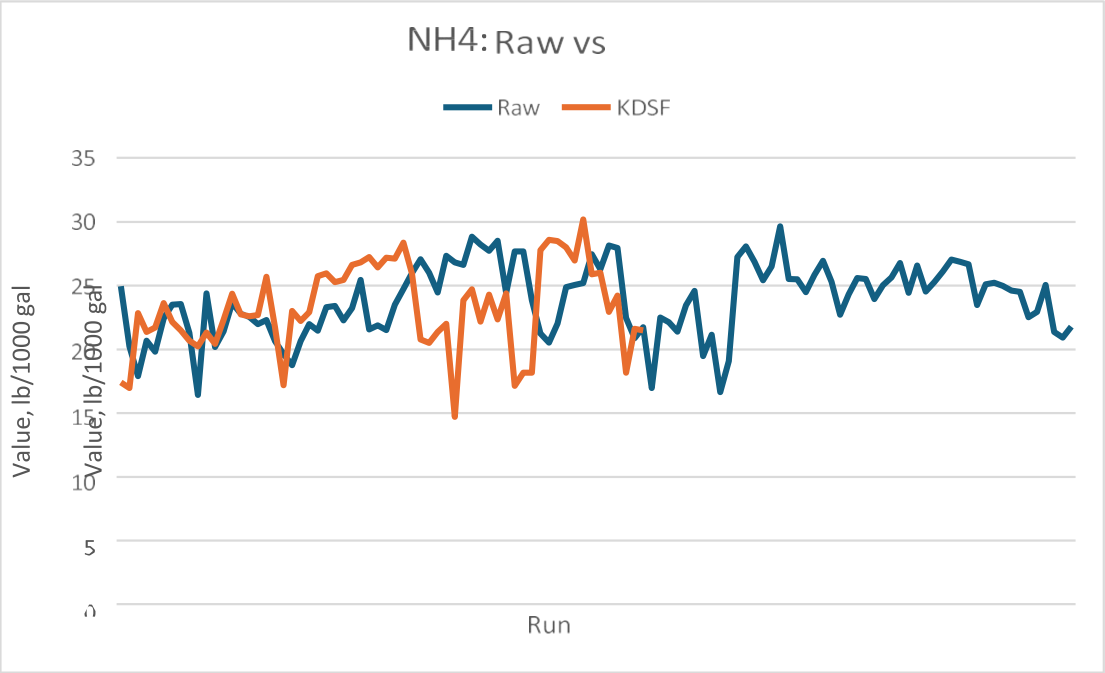


Figure 5.7: NH4, KDSF vs Raw

As noted under the discussion of the KDSS material, no polymer was used in order to keep overall operational costs low for the producer/farmer. As noted in the summary of Table 5.4, the units for the KDSS solids and Raw samples are different (lb./ton vs lb./1000gal, respectively). In the case of the KDSF, the units are the same as the Raw sample, so a direct comparison can be made. The summary of KDSF is shown in Table 5.5.

Table 5.5: KDSF Key Characteristics

	Lb/1000gal P205	**Lb/1000gal NH4**	**% Solids**
RAW	45.30	23.88	7.05
KDSF	40.13	23.25	4.82
% Reduction	11.4%	2.6%	31.7%

As shown in Figure 5.8, the impact of the KDS process on nutrient reduction, without use of a polymer was relatively minor, but did provide a more reasonable reduction in the percent solids.

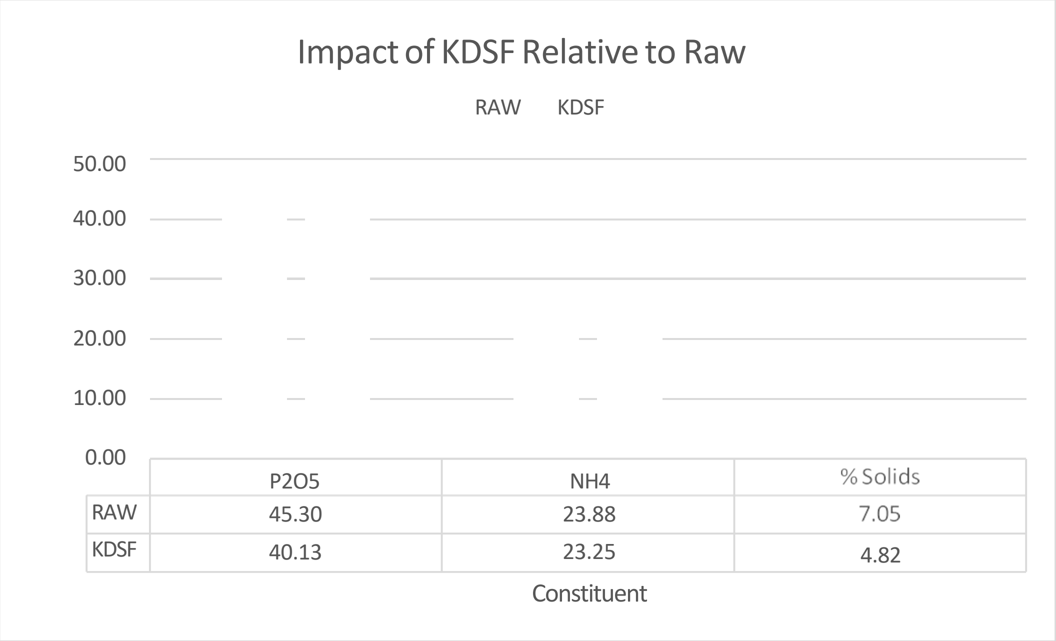


Figure 5.8: Impact of KDS on Filtrate Nutrients Relative to RAW

As noted above, this data is based on no polymer usage. The potential advantage of a carefully selected flocculent is the possible binding together of solid particulates, which have been shown to be directly correlated to P2O5 levels (Figure 5.1) resulting in a decrease in P2O5 in the filtrate (KDSF) and a corresponding increase in the P2O5 content of the solids (KDSS). To investigate this, jar testing of a number of flocculants was undertaken and the most effective one identified was a high molecular weight, mid-range cationic polymer provided by SNF.

Once determined, a series of batch tests were run where the dosage of polymer used ranged from 100ppm up to 750ppm. The polymer was added after the Raw sample had been collected so that a direct comparison to the same Raw sample could be evaluated. After being added, samples were taken of both KDSF and KDSS after approximately 15-20 minutes of mixing. Table 5.6 summarizes the data developed for the filtrate (KDSF) and solids produced (KDSS).

Table 5.6: Polymer Impact on KDS Effectiveness

Polymer dosage	Filtrate, lbs/1000 gal Count	Filtrate, lbs/1000 gal P205 reduction	Filtrate, lbs/1000 gal P205	Filtrate, lbs/1000 gal K20	Filtrate, lbs/1000 gal NH4	$/gal polymer
0	27	12.8%	35.48	19.02	22.78	$ -
100	5	25.0%	33.77	20.30	24.45	$ 0.0016
500	38	40.0%	31.95	16.80	21.25	$ 0.0078
650	5	68.7%	13.02	14.92	15.97	$ 0.0101
750	1	98.1%	0.73	12.09	18.88	$ 0.0117
Polymer dosage	**Solids, lbs/ton Count**	**Solids, lbs/ton P205**	**Solids, lbs/ton NH4**	**Solids, lbs/ton K20**	**Solids, lbs/ton Incremental P205**	**Solids, lbs/ton $/incr P205**
0	22	17.46	5.26	4.20	0	0
100	4	18.02	6.21	4.71	0.56	$ 0.0029
500	37	23.89	4.93	3.84	6.42	$ 0.0012
650	5	25.23	4.53	3.80	7.77	$ 0.0013
750	1	29.02	3.86	3.44	11.56	$ 0.0010

The key data from Table 5.6 is plotted in Figure 5.9 (KDSF) and Figure 5.10 (KDSS).

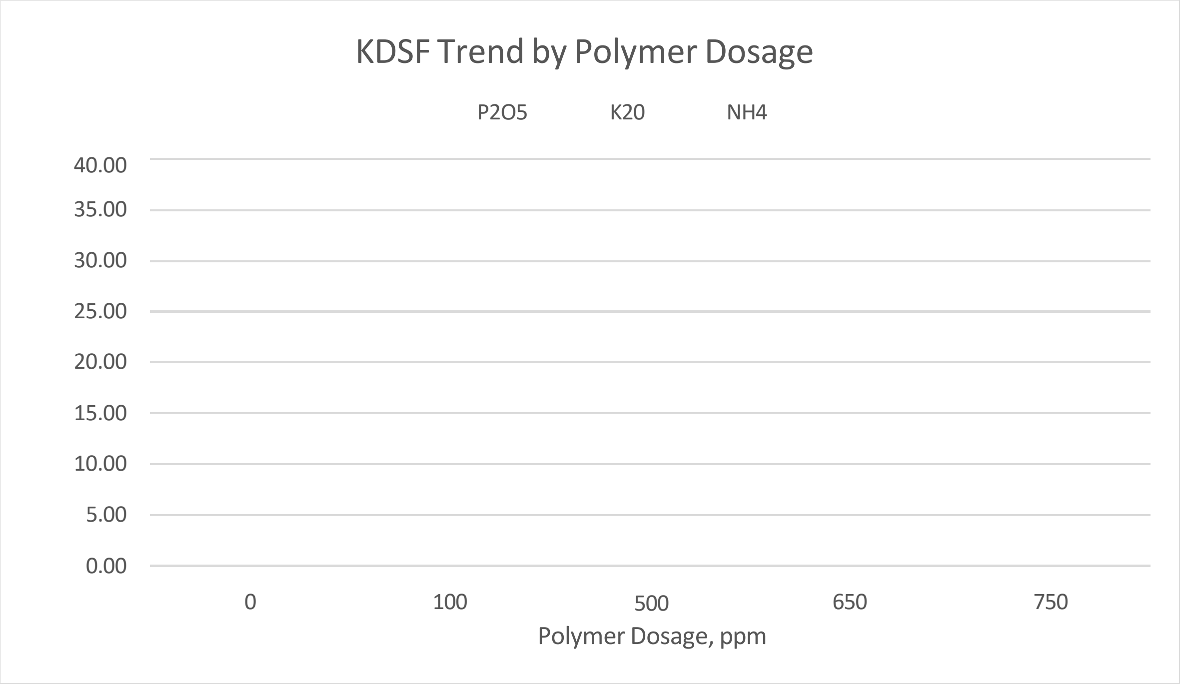


Figure 5.9: Influence of Polymer on KDSF Nutrient Levels

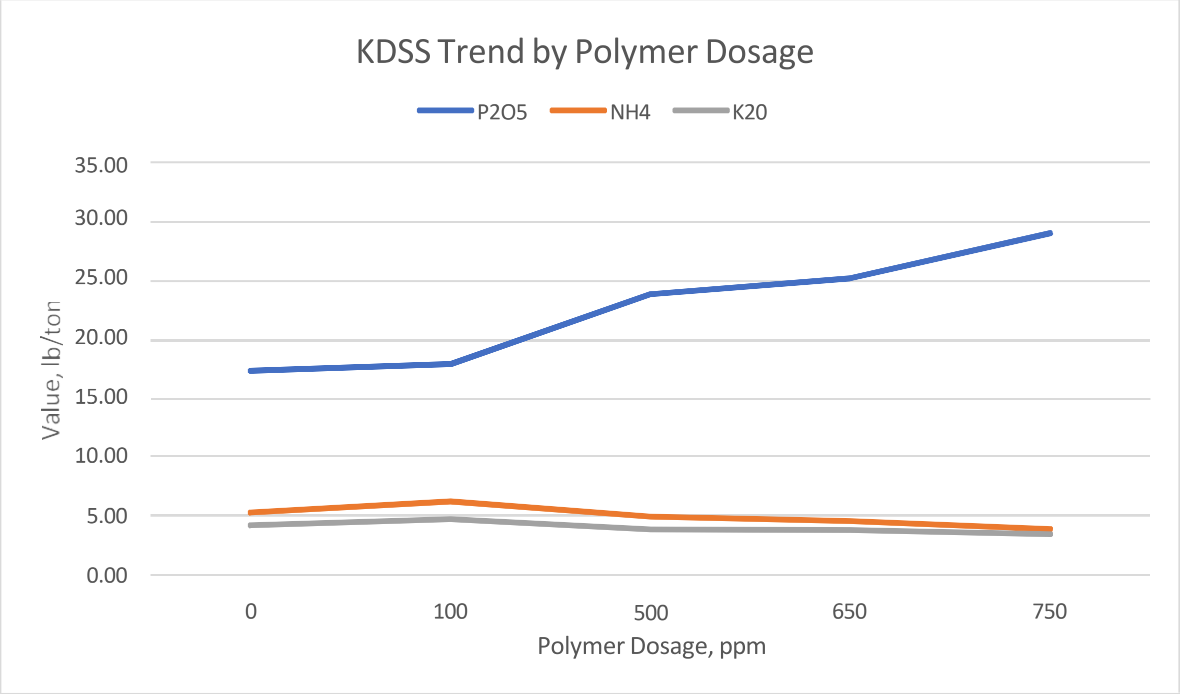


Figure 5.10: Influence of Polymer on KDSS Nutrient Levels

The data from Table 5.6 and Figure 5.9 and Figure 5.10 show that for P2O5 reduction, reductions as high as 98% may be possible at the highest dosage of 750ppm / gallon of polymer addition, which would also result in an increase in the P2O5 contained in the solids of approximately 66%.

While these are encouraging results, additional investigation would be required in order to ensure that in the solids portion, the available P2O5 to support plant growth is not compromised. Additionally, the 750ppm data point is a single data point only and additional data to confirm the results would be warranted.

Ekoton Solids (EKOS)

The last step in the recovery of P2O5 shown in Figure 5.1 is to treat the KDSF using acid hydrolysis followed by the precipitation of the resulting soluble phosphorus with hydrated lime. This stream is then processed through use of the Ekoton dewatering device where the dewatered solids are rich in P2O5 (EKOS). The results of this phase of the process are summarized in Table 5.7 and Figure 5.11:

Table 5.7: EKOS Summary

Count	% solids 50	P205 Lb/ton 50	NH4 Lb/ton 50
Average	24.24	44.24	3.99
St Dev	4.148	8.030	0.765

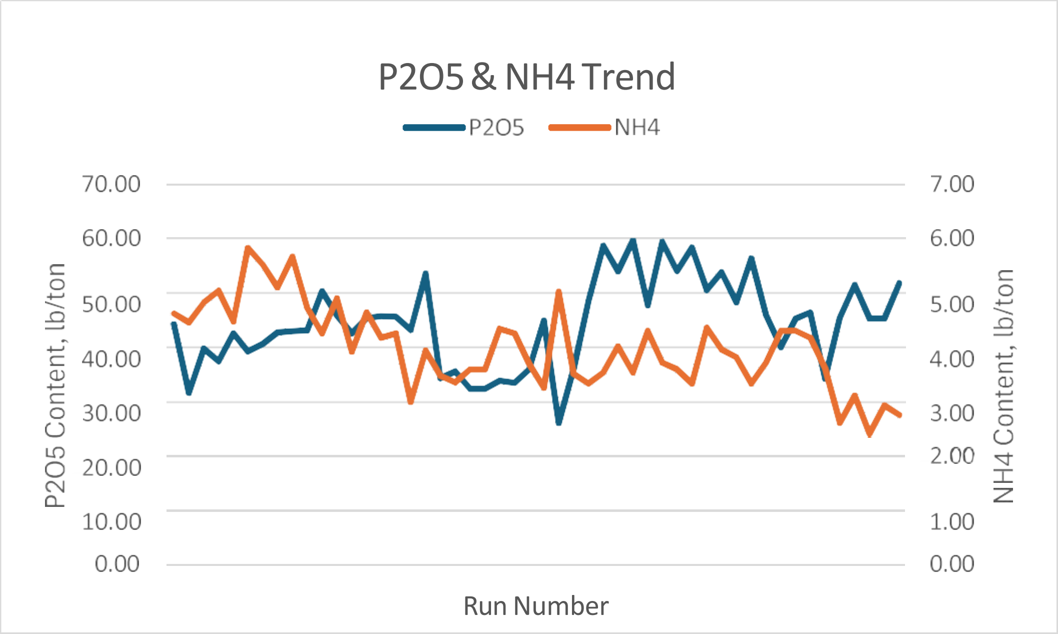


Figure 5.11: KDSF P2O5 and NH4 Trends

Figure 5.11 shows the relationship expected that as P2O5 levels increase (due to increased dewatering efficiency), the relative level of NH4 decreases slightly.

The result of this step is a higher phosphorus "stackable" cake that has the relationship shown in Figures 5.12 and 5.13.

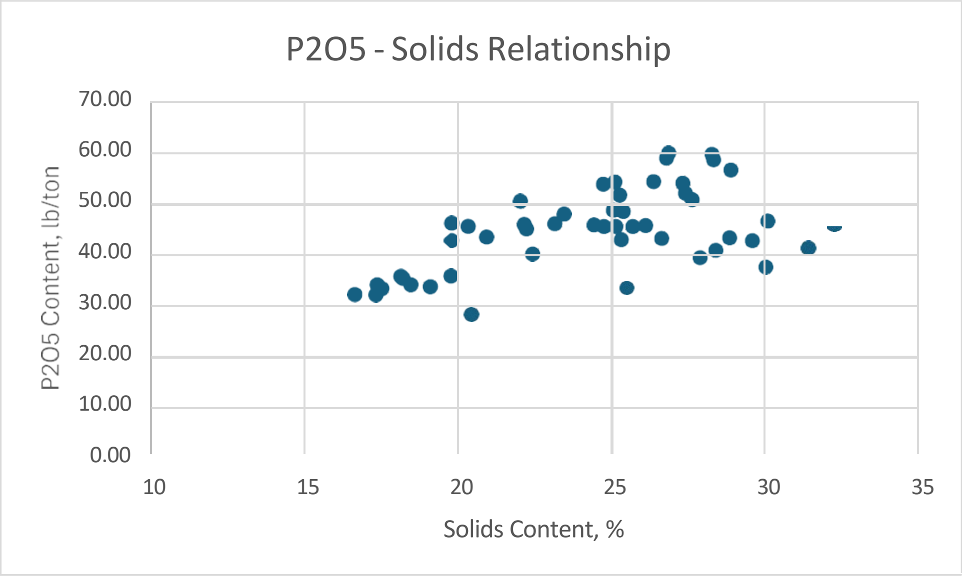


Figure 5.12: KDSF P2O5 – Solids Relationship

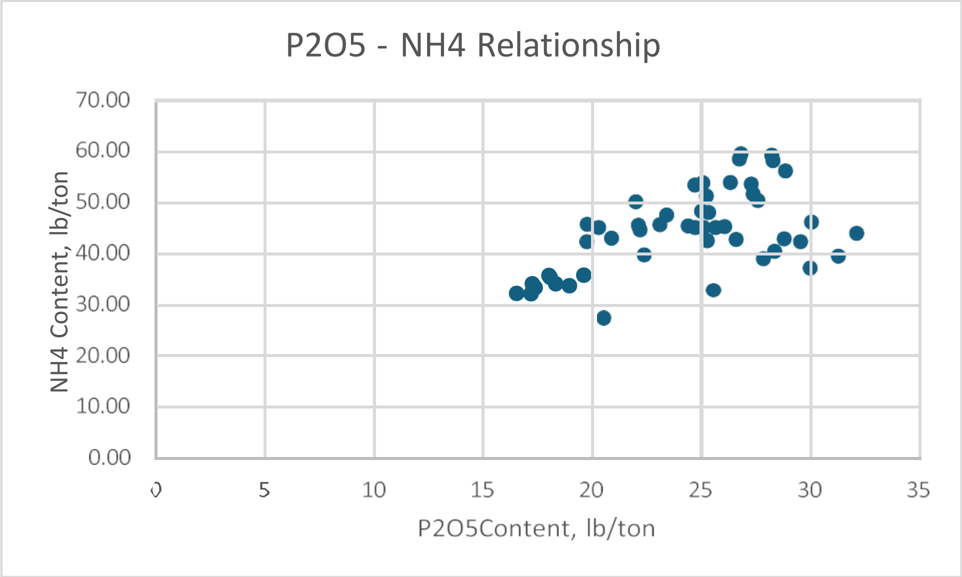


Figure 5.13: KDSF NH4 – Solids Relationship

These relationships further show that the drier the cake product is from this process, the higher the P2O5, and the lower the NH4 levels.

Ekoton Filtrate (EKOF)

After the dewatering step to remove the soluble phosphorus, the remaining filtrate (EKOF) is what remains for either discharge or further processing for additional constituent recovery, such as NH4. Figure 5.14 is a summary of P2O5 and NH4 trends from this evaluation.

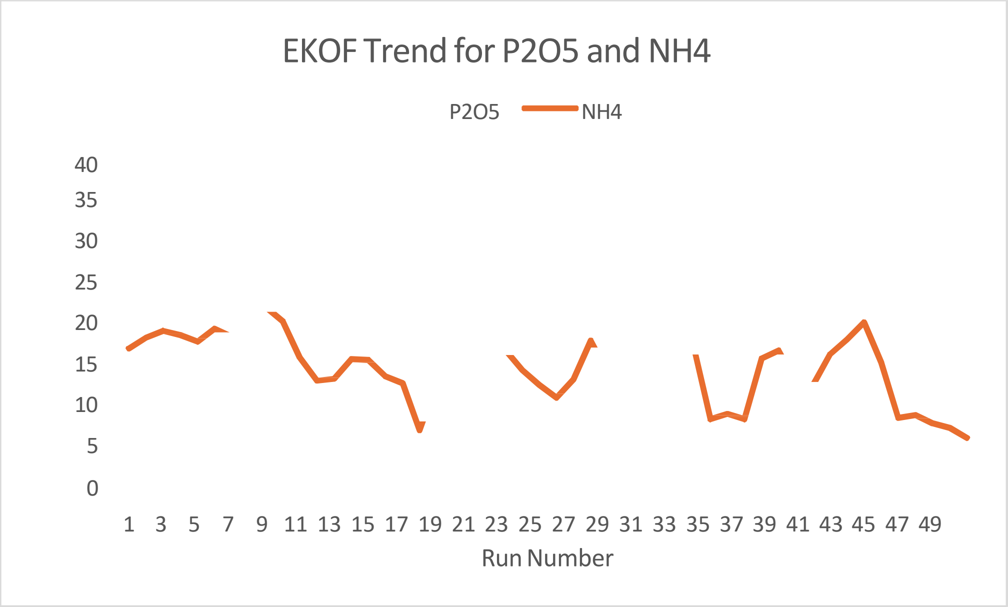


Figure 5.14: P2O5 and NH4 Trends on EKOF

While there appears to be a significant amount of "noise" in the P2O5 values, these are the results of several evaluations conducted to determine the impact of the use of acid hydrolysis and hydrated lime usage. These numerous studies included the following:

- KDSF directly to dewatering (no additional treatment)
- KDSF with hydrated lime addition only
- KDSF with both acid hydrolysis and hydrated lime addition
- Final runs with optimized conditions

Table 5.8 is a summary of these studies and the impact on key constituents.

Table 5.8: Summary of Influence of Consumables

Flow	**n**	**Runs**	**Average P2O5, lb/1000gal**	**Average % solids**	**Average % reduction**
KDSF direct to Ekoton (no QW-P)	15	1-15	10.00	1.58	72.18%
QW-P Hydrated Lime only	8	16-22	1.61	0.72	94.69%
QW-P Acid and HydratedLime	23	23-45	5.86	1.41	84.81%
2023 Full Treatment (Figure 4.1)	5	46-50	0.43	0.65	98.15%

This data shows the following observations:

- If no additional treatment were conducted, a P2O5 recovery of 72.18% is possible directly from the deep-pit storage through simple dewatering through the KDS with no polymer usage.
- If only hydrated lime were used to precipitate out soluble P2O5, a 94.69% recovery is possible.
- If both the acid hydrolysis and hydrated lime processes were used, it appears that an 84.81% recovery is possible. However, these studies were conducted using the same dosage of polymer to maximize solids capture, using the KDSF to Ekoton as the dosage

used resulting in slightly less solids capture. The benefit of acid hydrolysis is shown by the increased level of P2O5 availability with a slightly higher solids content. Capturing the increased solids should reduce P2O5 further.

- The final runs conducted were focused on optimizing the polymer dosage to achieve a similar % solids to the lime only condition. This suggests that a maximum P2O5 recovery of 98.15% is possible when acid hydrolysis and hydrated lime addition are employed.

It is worth noting that the amount of acid hydrolysis used was minimized by focusing on only the degree of hydrolysis required in order to break the alkalinity of the manure. Using pH as the process control parameter, a target of pH 7.0 – 7.5 was used. This required the need to allow pH to drop approximately 0.5 pH units. While a noticeable increase in P2O5 was observed at this level of hydrolysis, further available P2O5 may be available at more aggressive levels of acid hydrolysis if warranted - at an increased cost of acid.

<u>Objective 2:</u>

Define the economics of a typical installation.

For purposes of defining a "typical installation," the following assumptions were made:

- Economics were based on the cost of consumables to achieve a defined level of P2O5 recovery. The cost of material transport to an off-taker for further processing was not considered as this can vary widely depending on the farm and off-take location.
- The level of nutrients was equivalent to the average Raw manure measured and summarized in Table 5.1.
- The process conditions used in the final assessment (98.15% P2O5 recovery) was desired.
- It was assumed that no economies of scale were factored in to reflect the higher volume of consumables.

Pricing per consumable was based on actual costs from an Ohio Water Development Authority (OWDA) funded program completed in summer, 2021. A formal 2023 SNF quote on tote volumes of polymer for use in the Ekoton device was also used for polymer estimated costs. Table 5.9 is a summary of the estimated total consumable costs to treat each 100,000 gallons of raw manure.

Table 5.9: Estimated Consumable Costs to Treat 100,000 Gallons of Raw Manure

Consumable	Units	Value	Weight	Units	$/lb	Total	Pricing Source
H2SO4, 5N	mL/gal	6	321.872	lb	$ 0.15	$ 48.28	OWDA 2020 pricing
Dolomitic Hydrated Lime	mL/gal	75	4934.211	lb	$ 0.12	$ 609.38	OWDA 2020 pricing
Polymer	ppm	500	50	gal	$ 4.73	$ 236.48	2023 SNF tote pricing
					Total	$ 894.14	
					$/gal	$ 0.0089	

Consumable costs are estimated to be $0.0089/gallon manure treated. This is in line with previously evaluated consumable cost estimates of $0.0063/gal treated and $0.0064/gal treated conducted through an Ohio Farm Bureau sponsored program (2020) and the above noted OWDA funded program (2021), without the use of final dewatering polymer costs Significant reduction in the estimated costs for the dewatering phase using the Ekoton equipment and SNF polymer were well below the projected cost of $0.010/gal treated that was anticipated. Additional costs for power would need to be determined based on the cost of power in the site location plus the final scope of design for the individual application. Capital costs would also need to be estimated based on the treatment strategy to be employed, the volume of manure and frequency of treatment plus specific site equipment and site layout required. In general, based on multiple quotes provided for swine applications, the initial in-scope capital costs would run approximately $400K - $425K for a targeted recovery of P_2O_5 of 50% up to an estimated cost of $500K - $525K for a maximum recovery of P_2O_5 as determined in this program for a facility treating 700K gal/year.

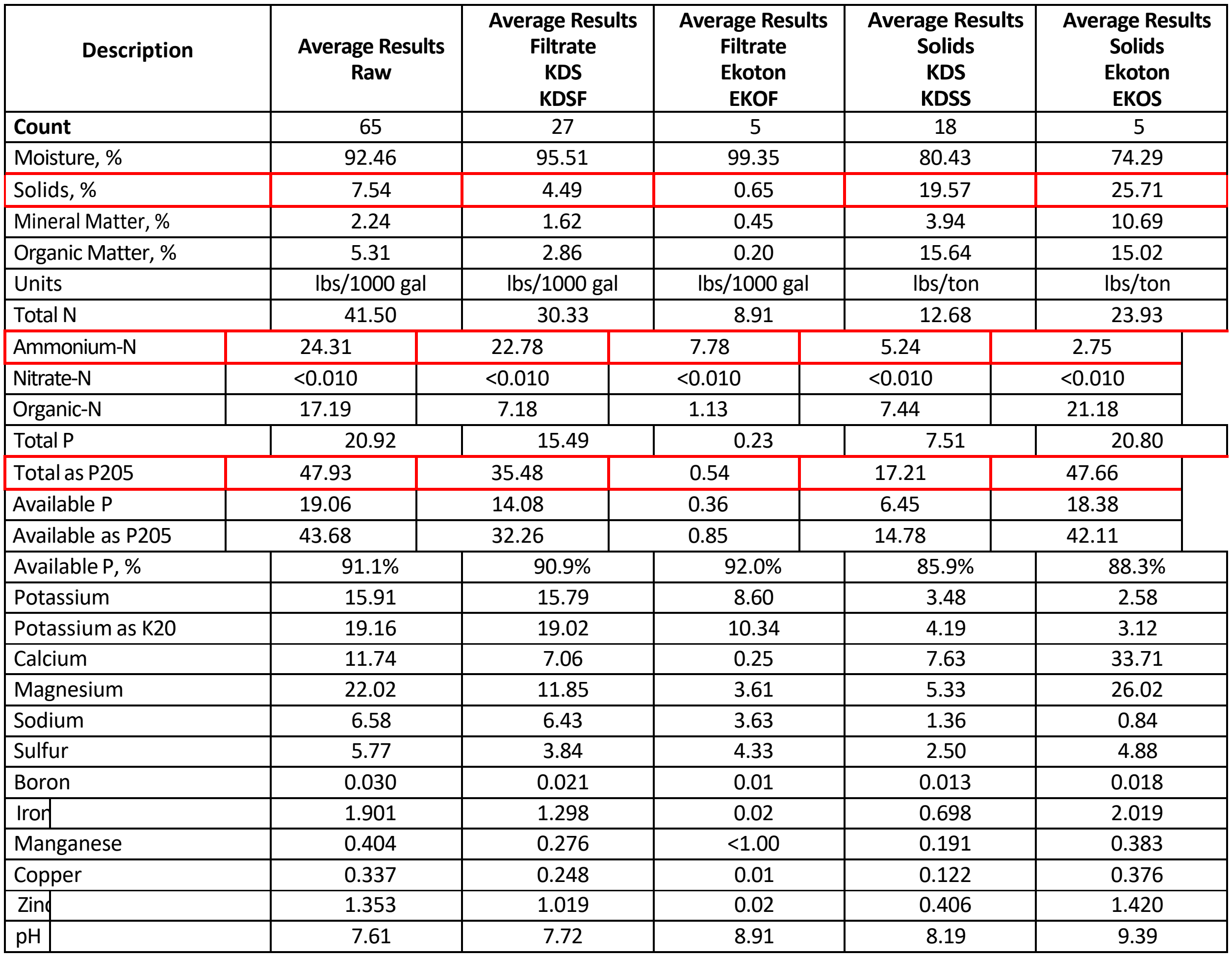
The final figure to consider in defining economics of a typical installation would be the labor requirement. In general, it is estimated that a full-time equivalent (FTE) of approximately 0.5 would be required to operate and maintain a facility treating 700K gal/year.

It is worth noting that the above economic estimates do not consider the value of the recovered nutrients.

Objective 3:

Determine the estimated value of the recovered products produced with the treatment process. Recovered products included dewatered manure and recovered phosphorus.

Figure 5.15 is a summary of manure analysis conducted on each sample as a function of process step (Figure 5.1). This analysis does not include results of special studies conducted during the course of the program, such as the influence of polymer dosage on KDSF levels.



Description	Average Results Raw	Average Results Filtrate KDS KDSF	Average Results Filtrate Ekoton EKOF	Average Results Solids KDS KDSS	Average Results Solids Ekoton EKOS
Count	65	27	5	18	5
Moisture, %	92.46	95.51	99.35	80.43	74.29
Solids, %	7.54	4.49	0.65	19.57	25.71
Mineral Matter, %	2.24	1.62	0.45	3.94	10.69
Organic Matter, %	5.31	2.86	0.20	15.64	15.02
Units	lbs/1000 gal	lbs/1000 gal	lbs/1000 gal	lbs/ton	lbs/ton
Total N	41.50	30.33	8.91	12.68	23.93
Ammonium-N	24.31	22.78	7.78	5.24	2.75
Nitrate-N	<0.010	<0.010	<0.010	<0.010	<0.010
Organic-N	17.19	7.18	1.13	7.44	21.18
Total P	20.92	15.49	0.23	7.51	20.80
Total as P205	47.93	35.48	0.54	17.21	47.66
Available P	19.06	14.08	0.36	6.45	18.38
Available as P205	43.68	32.26	0.85	14.78	42.11
Available P, %	91.1%	90.9%	92.0%	85.9%	88.3%
Potassium	15.91	15.79	8.60	3.48	2.58
Potassium as K20	19.16	19.02	10.34	4.19	3.12
Calcium	11.74	7.06	0.25	7.63	33.71
Magnesium	22.02	11.85	3.61	5.33	26.02
Sodium	6.58	6.43	3.63	1.36	0.84
Sulfur	5.77	3.84	4.33	2.50	4.88
Boron	0.030	0.021	0.01	0.013	0.018
Iron	1.901	1.298	0.02	0.698	2.019
Manganese	0.404	0.276	<1.00	0.191	0.383
Copper	0.337	0.248	0.01	0.122	0.376
Zinc	1.353	1.019	0.02	0.406	1.420
pH	7.61	7.72	8.91	8.19	9.39

Figure 5.15: Average Manure Analysis Results as a Function of Process Step

Additionally, Figure 5.16 compares the trends in average values for key characteristics as a function of process step. This data is grouped by Liquid and Solids for ease of reviewing.

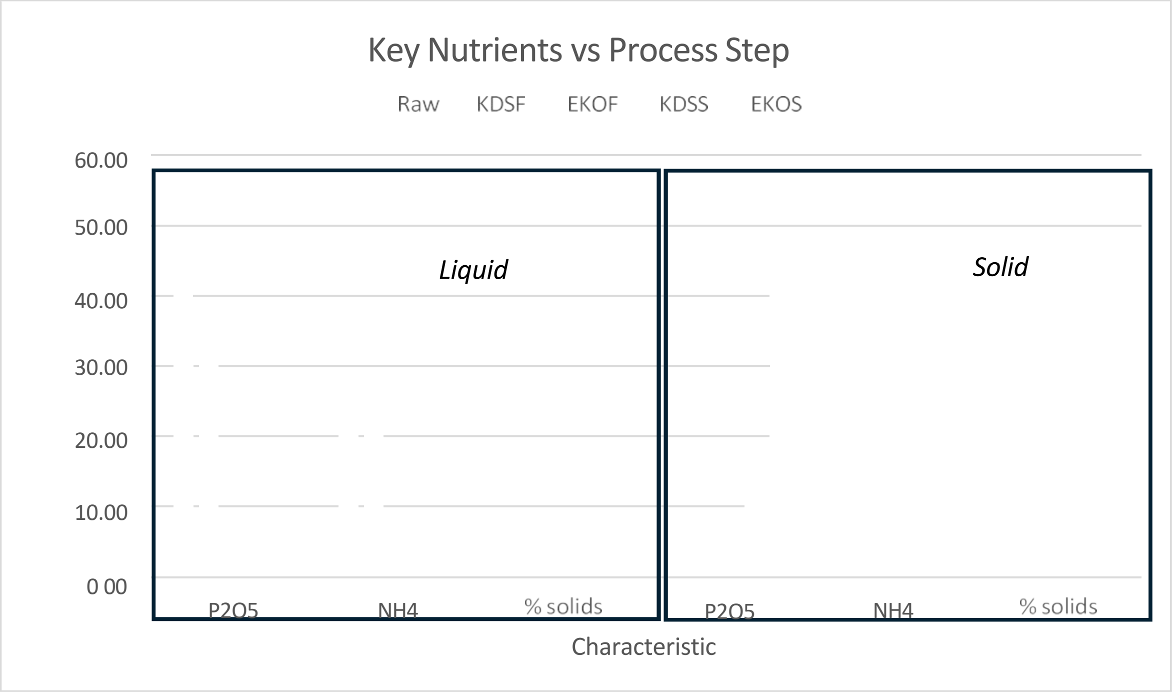


Figure 5.16: Average Characteristic Results as Function of Process Step

These data confirm that the trends observed in Product Characteristics were in line with expectations.:

- Key liquid nutrient levels decreased as processing progressed
- Conversely, key solid nutrient levels increased as processing progressed

There are 3 primary beneficial products which result from the technology investigated:

1. A lower P2O5 product with lower operational costs (KDSS),
2. A higher P2O5 product with further processing (EKOS), and
3. A residual water after P2O5 had been removed (EKOF). While outside of the scope of this investigation, this water would also be relatively high in NH4 levels (see EKOF summary), but this can also be recovered resulting in a lower P2O5 and NH4 residual water.

To enhance the value of the higher P2O5 and residual water beneficial products, 2 separate efforts were undertaken that were outside of the original scope of this program. These are summarized below.

Higher P2O5 product

At the completion of the final EKOS runs, material was sent to be further dried and converted into pellets. The finished product is shown in Figure 5.17, with analysis summarized in Figure 5.18. It is worth noting that in addition to a much higher level of P2O5, there were also higher levels of some other potentially beneficial constituents, such as calcium, magnesium, and sulfur. These are primarily related to the consumables used (dolomitic lime and sulfuric acid).

Figure 5.17: EKOS Pellets

Description	Average Results Solids Ekoton EKOS	Pellets Ekoton EKOS-P
Count	5	1
Moisture, %	74.29	12.81
Solids, %	25.71	87.19
Mineral Matter, %	10.69	34.17
Organic Matter, %	15.02	53.02
Units	lbs/ton	lbs/ton
Total N	23.93	64.24
Ammonium-N	2.75	8.70
Nitrate-N	<0.010	<0.010
Organic-N	21.18	55.54
Total P	20.80	68.90
Total as P205	47.66	157.88
Available P	18.38	55.48
Available as P205	42.11	127.12
Available P, %	88.3%	80.52%
Potassium	2.58	12.40
Potassium as K20	3.12	14.94
Calcium	33.71	94.66
Magnesium	26.02	75.88
Sodium	0.84	3.68
Sulfur	4.88	16.66
Boron	0.018	0.063
Iron	2.019	10.161
Manganese	0.383	1.239
Copper	0.376	1.246
Zinc	1.420	4.593
pH	9.39	8.32

Figure 5.18: Pellet Analysis compared to Average EKOS

Recovery of NH4

As shown in Figure 5.15, there was still a reasonable level of ammonium left in the liquid (EKOF) after recovery of the P2O5 solids. The average reported value of 7.78lb/1000gal equates to a level of 931mg/L, which has considerable potential value. Using the companion technology for ammonium recovery (QW-N), the profile shown in Figure 5.19 was developed. This amounted to a 98.0% recovery of ammonium with an additional benefit of increased K20 composition. This allows for 2 additional potentially added benefits:

1. The ammonium is recovered in the form of ammonium sulfate as a liquid (in this example, the ratio of ammonium to sulfur was 8.2:11.6 lb./1000gal, NH4:S, respectively.

2. In order to maintain a target pH for NH4 to NH3 conversion, a targeted hydroxide is used. Use of KOH results in a boost in available K20 to support favorable irrigation water for some crops, such as corn.

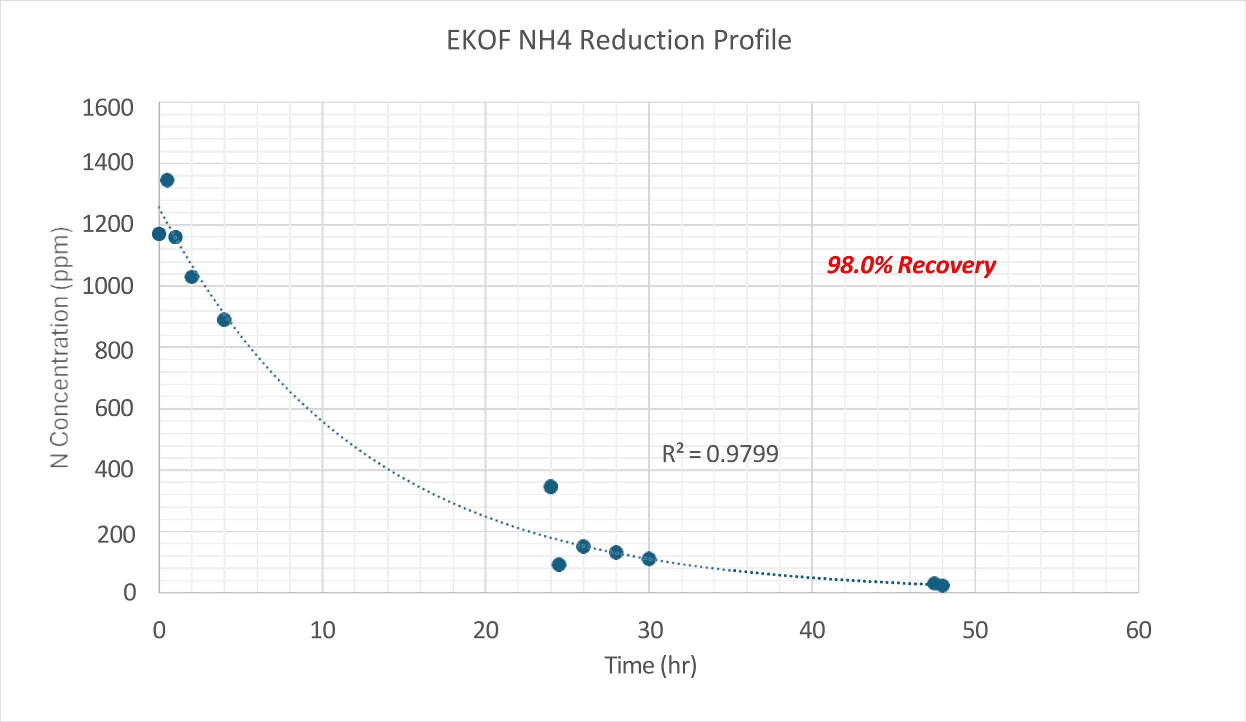


Figure 5.19: EKOF Typical NH4 Reduction Profile

To determine the estimated value of the recovered products, it was decided to simply calculate the value of the recovered nutrients on the basis of the nutrient contribution against prevailing nutrient costs. For purposes of this estimate, the following assumptions were made:

- There are 2 primary products produced through the processed evaluated: a low P2O5 product and a high P2O5 product.
- Table 5.10 is a summary of the assumed prevailing nutrient costs.

- It is worth noting that this analysis is considered conservative in that the potential values of recovered constituents, such as sulfur, calcium, or magnesium, are not considered. Nor is the value of the organic matter recovered.
- It is also worth noting that the value of recovered ammonium as liquid ammonium sulfate was not considered. Additionally, the ammonia recovered may have value as an alternative to conventional fertilizer, such as green ammonia or even as a form of hydrogen feedstock.

Table 5.10: Cost Assumptions for Value Assessment of Recovered Products

Nutrient	***$/ton***	***Unit price***	**Unit**
P205	$ 800	$ 0.40	lb
K20	$ 465	$ 0.23	lb
Ammonia	$ 943	$ 0.47	lb

Based on the above assumptions, we would estimate a conservative value of the recovered nutrients as shown in Table 5.11. The values used are based on the summary of average results shown in Figures 5.15 and 5.18.

Table 5.11: Estimated Value Based on Nutrient Only Contribution

Nutrient	***Value per Ton, $ Raw***	***Value per Ton, $ KDSS***	***Value per Ton, $ EKOS***	***Value per Ton, $ EKOF***	***Value per Ton, $ EKOS as Pellets (EKOS-P)***	***Value per Ton, $ KDSS + EKOS+ EKOF***	***Value per Ton, $ KDSS + EKOS-P + EKOF***
P2O5	$19.17	$6.88	$19.06	$0.22	$63.15	$26.16	$70.25
K20	$4.41	$0.96	$0.72	$2.38	$3.44	$4.06	$6.78
Ammonia	$11.43	$11.43	$1.29	$3.66	$4.09	$16.37	$19.17
Total	***$35.00***	**$19.27**	**$21.07**	**$6.25**	**$70.68**	***$46.60***	***$96.20***

As shown in Table 5.11, the conservative nutrient only estimated value ranges from $46.60 - $96.20 per ton depending on the degree of processing (i.e., pelletizing) of the high P2O5 material recovered. For comparison, the same calculated value on the RAW only material is $35.00/ton.

Objective 4:

Confirm the acceptability of treated water to be used as a source of irrigation water by comparing the quality of the treated water against nutrient and irrigation water standards by comparing the treated water to currently used irrigation water at other farms in the St. Joseph, St. Marys, and Upper Maumee Watersheds.

As noted previously, one of the beneficial products resulting from the treatment of swine manure in this program was a water with potential value after the recovery of P2O5. If only P2O5 is recovered, there will be a higher amount of NH4 in the water which may or may not need to be considered before use as irrigation water. In order to compare the quality of the water remaining after P2O5 recovery has occurred, samples were collected from local operations where the water remaining after production is used to support center pivot irrigation of a typical corn-soybean rotation. A total of 4 different farms were sampled and are described briefly in Table 5.12.

Table 5.12: Comparative Farm Producers Irrigation Water

Farm	Description
1	Multiple Dairy Operation discharging to single lagoon
2	Largesingle Dairy Operation
3	Large egg-breaking operation
4	Shallow pit swine operation

Samples were collected from each farm and third-party testing (Brookside Labs, New Bremen OH) conducted using a standard manure analysis used throughout this program. These are summarized in Figure 5.20 alongside analysis of the final confirmation run averages summarized in Figure 5.15 (EKOF). While outside of the scope of this program, also shown is the water quality analysis from the NH4 recovery shown in Figure 5.19. In that particular analysis, as was noted earlier, the use of hydroxide is used to maintain the process pH above 9.2 to expedite the conversion of ammonium to ammonia for recovery. In this case, KOH was used to increase the available K20 in the potential irrigation water. The objective was to show that the level of K20 in the irrigation water can be influenced through recovery of ammonium.

	Units	Farm 1	Farm 2	Farm 3	Farm 4	EKOF	NH4 Recovery
% Solids	%	1.09	1.71	0.31	0.53	0.65	1.61
NH4	lb/1000gal	4.16	8.36	0.99	3.56	7.778	<0.010
P2O5	lb/1000gal	0.75	1.92	0.58	0.17	0.54	<0.001
K20	lb/1000gal	13.56	19.4	0.5	12.67	10.34	58.45
pH	SuS	8.07	7.94	7.76	8.27	8.906	10.33

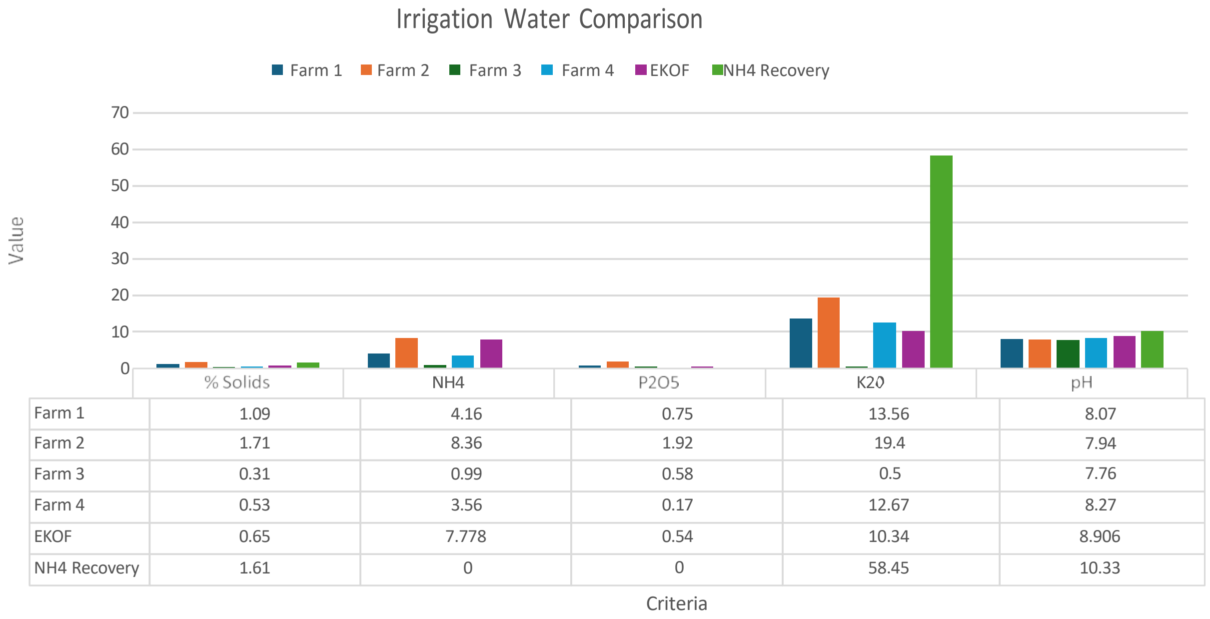


Figure 5.20: Irrigation Water Comparison

<u>Objective 5:</u>
Participate in a Project Closing Event.

Throughout the course of this program, numerous site visits and educational events were hosted. A Project Closing Event did occur on October 5, 2023, when Ohio EPA visited the site to recognize the shipment of material to an off-taker (Kurtz Brothers). During this visit, a thorough walk-thru and process overview discussion was held both at the site and at a separate conference room.

Appendix C: Reprint from Original Program Submission

Table 1: Estimated Annual P2O5 within Maumee Watershed Alliance Geographical Area

Measure	Species	Units	Michigan		Indiana						Ohio							MWA Total
			County															
			Branch	Hillsdale	Steuben	Dekalb	Noble	Allen	Adams	Wells	Williams	Defiance	Paulding	Van Wert	Mercer	Auglaize	Shelby	
Inventory	Dairy	Head	3240	10080	2785	1808	4535	1825	6518	1823	4856	4676	10232	3560	17490	6140	7716	87,284
	Swine	Head	61989	32192	-	1500	65880	43283	185713	180138	17693	13939	61268	76417	317040	110134	73160	1,240,346
Manure/head	Dairy	tons/head-yr	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	
		gal/head-yr	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	
	Swine	gal/1000 head-yr	309571	309571	309571	309571	309571	309571	309571	309571	309571	309571	309571	309571	309571	309571	309571	
Est Manure	Dairy	gal/yr	4,050,000	12,600,000	3,481,250	2,260,000	5,668,750	2,281,250	8,147,500	2,278,750	6,070,000	5,845,000	12,790,000	4,450,000	21,862,500	7,675,000	9,645,000	109,105,000
	Swine	gal/yr	19,189,997	9,965,710	-	464,357	20,394,537	13,399,162	57,491,359	55,765,501	5,477,240	4,315,110	18,966,796	23,656,487	98,146,390	34,094,293	22,648,214	383,975,152
	Total	gal/yr	23,239,997	22,565,710	3,481,250	2,724,357	26,063,287	15,680,412	65,638,859	58,044,251	11,547,240	10,160,110	31,756,796	28,106,487	120,008,890	41,769,293	32,293,214	493,080,152
P2O5 content	Dairy	lb/1000gal	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2	
	Swine	lb/1000gal	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	
Total P2O5	Dairy	Lb	8,910	27,720	7,659	4,972	12,471	5,019	17,925	5,013	13,354	12,859	28,138	9,790	48,098	16,885	21,219	240,031
	Swine	Lb	168,872	87,698	-	4,086	179,472	117,913	505,924	490,736	48,200	37,973	166,908	208,177	863,688	300,030	199,304	3,378,981
	Total	Lb	177,782	115,418	7,659	9,058	191,943	122,931	523,848	495,750	61,554	50,832	195,046	217,967	911,786	316,915	220,523	3,619,012
MWA % Area	Est		1%	40%	25%	95%	20%	70%	70%	3%	50%	30%	20%	10%	40%	30%	5%	
Est total manure	Total	Gal/Yr	232400	9026284	870313	2588139	5212657	10976288	45947201	1741328	5773620	3048033	6351359	2810649	48003556	12530788	1614661	**156,727,275**
within MWA	P2O5	Lb/yr	1778	46167	1915	8605	38389	86052	366694	14872	30777	15250	39009	21797	364714	95074	11026	**1,142,119**

Notes

1. Inventory numbers obtained from 2017 USDA Agricultural Census
2. Estimated manure volumes and P2O5 loadings provide from 2019 summary from Mercer County (OH) Soil and Water Conservation District
3. MWA % Area an approximation from MWA website graphic

Appendix C is a reprint of Table 1 in the original proposal submission which provided an estimate of manure volume produced within the geographic region of the Maumee Watershed Alliance based on the 2017 USDA Agricultural Census and actual P205 composition provided by the Mercer County (OH) SWCD of 1689 tons per year.

APPENDIX D: Batch Sample Analysis (1 of 7)

The following tables contain the individual tote analysis conducted on materials prior to shipment to various off-takers. All totes had mixtures of both material sources. There is no significance to the individual numbering scheme used other that the letter “E” refers to primarily material from the Ekoton device (EKOS) and “K” refers to material primarily from the KDS (KDSS).

Description	K1	E2	E3	K4	K5	E6	E7	K8	K9-T1	K10-T2	E11-T3	E12
Lab ID	3601	3602	3603	3604	3605	3606	3607	3608	3609	3610	3611	3613
Moisture,%	82.77	74.01	78.99	84.66	80.92	77.62	77.07	78.66	79.24	80.05	76.81	77.29
Solids,%	17.23	25.99	21.01	15.34	19.08	22.38	22.93	21.34	20.76	19.95	23.19	22.71
Mineral Matter,%	4.21	9.15	6.67	3.56	4.27	8.67	9.42	8.59	7.96	4.63	9.18	5.40
Organic Matter, %	13.02	16.84	14.34	11.78	14.81	13.71	13.51	12.75	12.80	15.32	14.01	17.31
Units	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton
Total N	11.16	26.34	18.92	10.96	12.12	21.08	19.22	22.84	21.68	11.70	20.40	13.04
Ammonium-N	2.84	2.16	1.72	2.86	3.02	1.32	2.56	2.66	2.06	3.60	1.70	0.92
Nitrate-N	<0.010	0.74	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	2.00
Organic-N	8.32	23.44	17.20	8.10	9.10	19.76	16.66	20.18	19.62	8.10	18.70	10.12
Total P	8.90	29.74	16.94	5.52	8.86	22.30	17.48	16.10	15.58	11.06	21.94	13.62
Total as P205	20.36	68.14	38.78	12.64	20.30	51.08	40.04	36.88	35.66	25.34	50.28	31.20
Available P	7.34	23.60	15.12	5.00	6.98	19.88	13.90	13.18	12.74	8.42	20.40	11.54
Available as P205	16.82	54.06	34.66	11.44	15.98	45.52	31.82	30.22	29.18	19.28	46.76	26.44
Available P, %	82.61%	79.34%	89.38%	90.51%	78.72%	89.12%	79.47%	81.94%	81.83%	76.09%	93.00%	84.74%
Potassium	3.00	4.52	2.74	5.86	4.04	4.38	4.18	3.28	2.50	2.56	3.58	4.26
Potassium as K20	3.62	5.46	3.28	7.06	4.88	5.28	5.04	3.96	2.98	3.08	4.32	5.14
Calcium	20.40	13.94	12.70	13.20	8.36	22.52	37.52	34.82	34.72	13.76	25.70	17.44
Magnesium	5.78	22.46	12.64	5.10	5.92	21.98	22.28	17.32	17.02	7.22	21.48	8.86
Sodium	1.18	1.56	0.96	2.20	1.68	1.66	1.56	1.16	0.88	1.08	1.26	1.68
Sulfur	2.28	5.92	4.00	3.74	3.20	4.74	4.18	5.38	5.24	2.88	4.78	3.40
Boron	0.012	0.019	0.013	0.021	0.015	0.018	0.020	0.019	0.015	0.014	0.019	0.018
Iron	0.795	2.404	1.340	0.617	0.786	1.932	1.694	1.712	1.693	0.774	1.963	0.963
Manganese	0.267	0.506	0.365	0.170	0.218	0.396	0.321	0.329	0.321	0.318	0.382	0.362
Copper	0.124	0.530	0.289	0.148	0.178	0.372	0.323	0.662	0.645	0.175	0.369	0.210
Zinc	0.420	1.830	0.904	0.248	0.509	1.328	1.175	0.941	0.915	0.492	1.359	0.649
pH	7.03	8.30	7.74	6.95	8.20	8.05	8.49	8.00	8.04	8.30	8.48	6.58

APPENDIX D: Batch Sample Analysis (2 of 7)

Description	K13	K14	K15	K16	K17	K18	K19	K20	K21	K22	K-25	K-26
Lab ID	3612	3614	3615	3616	3617	3618	3619	3620	3621	3622	9179	9180
Moisture,%	77.88	80.11	79.62	80.98	80.64	79.67	80.38	78.52	73.40	79.48	79.59	77.97
Solids,%	22.12	19.89	20.38	19.02	19.36	20.33	19.62	21.48	26.60	20.52	20.41	22.03
Mineral Matter, %	6.84	4.76	4.46	4.50	4.37	4.65	4.35	5.04	7.55	4.92	3.87	5.67
Organic Matter, %	15.28	15.13	15.92	14.52	14.99	15.68	15.27	16.44	19.05	15.60	16.54	16.36
Units	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton
Total N	17.06	11.72	10.08	14.74	14.42	13.74	11.38	11.98	14.46	9.94	32.12	39.16
Ammonium-N	2.46	2.50	4.86	4.40	4.36	4.40	4.98	5.08	1.24	2.40	4.66	4.52
Nitrate-N	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	3.30	<0.010	<0.010	0.74
Organic-N	14.60	9.22	5.22	10.34	10.06	9.34	6.40	6.90	9.92	7.54	27.46	34.64
Total P	19.64	9.10	10.28	10.04	10.58	13.06	9.66	9.28	15.10	9.12	10.20	8.16
Total as P205	45.00	20.88	23.52	23.02	24.24	29.92	22.14	21.26	34.64	20.88	23.38	18.68
Available P	16.46	8.36	9.86	8.74	9.72	8.82	8.20	8.64	14.26	9.06	4.82	6.12
Available as P205	37.70	19.14	22.62	20.04	22.26	20.20	18.80	19.80	32.66	20.76	11.02	14.06
Available P, %	83.78%	91.67%	96.17%	87.05%	91.83%	67.51%	84.91%	93.13%	94.28%	99.43%	47.13%	75.27%
Potassium	3.18	3.90	4.04	4.18	3.18	3.04	3.96	3.78	4.04	4.40	2.12	2.68
Potassium as K20	3.84	4.70	4.86	5.06	3.84	3.66	4.78	4.56	4.90	5.30	2.58	3.22
Calcium	12.70	7.64	9.00	8.22	7.62	15.42	11.70	10.62	17.92	8.94	8.82	9.48
Magnesium	15.22	6.44	7.06	6.96	7.44	9.02	6.12	5.92	10.26	6.68	7.18	6.04
Sodium	1.16	1.64	1.54	1.64	1.20	1.14	1.56	1.46	1.54	1.80	1.42	1.76
Sulfur	4.96	2.94	2.82	3.12	2.94	2.96	2.74	2.88	4.04	3.36	2.98	3.26
Boron	0.019	0.015	0.015	0.015	0.013	0.013	0.015	0.012	0.016	0.014	0.014	0.016
Iron	1.547	0.866	0.924	,968	1.077	0.998	0.844	0.822	1.309	0.845	0.815	0.717
Manganese	0.407	0.224	0.239	0.226	0.223	0.320	0.229	0.236	0.421	0.243	0.245	0.237
Copper	0.342	0.185	0.145	0.145	0.168	0.171	0.145	0.150	0.263	0.181	0.128	0.141
Zinc	1.014	0.502	0.489	0.514	0.644	0.624	0.484	0.480	0.785	0.488	0.455	0.481
pHI	7.76	8.17	8.14	8.09	8.27	8.24	8.26	8.17	6.11	8.12	8.31	8.14

APPENDIX D: Batch Sample Analysis (3 of 7)

Description	**K-27**	**K-28**	**K-29**	**K-30**	**K-31**	**K-32**	**K-33**	**K-34**	**K-35**	**K-36**	**K-37**	**K-38**
Lab ID	**9154**	**9155**	**9156**	**9157**	**9158**	**9159**	**9160**	**9161**	**9162**	**9163**	**9164**	**9165**
Moisture,%	81.33	77.90	78.13	79.75	78.89	75.06	80.27	79.49	76.60	80.11	79.88	79.82
Solids,%	18.67	22.10	21.87	20.25	21.11	24.94	19.73	20.51	23.40	19.89	20.12	20.18
Mineral Matter, %	3.97	4.91	5.32	4.33	4.87	4.89	4.69	4.55	4.79	4.00	4.29	4.18
Organic Matter, %	14.70	17.19	16.55	15.92	16.24	20.05	15.04	15.96	18.61	15.89	15.83	16.00
Units	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton
Total N	11.32	12.76	11.70	12.90	13.08	14.28	12.78	14.62	13.40	13.28	11.12	12.94
Ammonium-N	5.40	2.04	4.26	5.76	5.78	0.92	5.02	3.26	5.06	5.48	4.86	5.66
Nitrate-N	<0.010	0.44	<0.010	<0.010	<0.010	0.68	<0.010	<0.010	<0.010	2.00	<0.010	<0.010
Organic-N	5.92	1028	7.44	7.14	7.30	12.68	7.76	11.36	8.34	7.80	6.26	7.28
Total P	7.70	9.60	9.88	9.04	11.48	8.18	9.48	11.40	11.32	10.94	8.98	8.28
Total as P205	17.62	21.96	22.66	20.70	26.30	18.76	21.70	26.12	25.98	25.06	20.56	18.96
Available P	7.06	7.96	8.66	7.86	7.60	5.94	7.46	9.18	8.00	9.18	6.92	6.90
Available as P205	16.16	18.22	19.86	18.02	17.40	13.62	17.08	21.04	18.34	21.04	15.86	15.82
Available P, %	91.71%	82.97%	87.64%	87.05%	66.16%	72.60%	78.71%	80.55%	70.59%	83.96%	77.14%	83.44%
Potassium	2.68	2.88	2.94	2.60	2.54	2.80	2.64	2.88	2.72	2.38	2.42	2.46
Potassium as K20	3.24	3.44	3.54	3.12	3.04	3.34	3.20	3.44	3.28	2.86	2.90	2.94
Calcium	6.16	10.38	11.86	10.78	11.74	8.88	11.32	7.92	11.04	10.18	9.10	7.96
Magnesium	5.46	6.14	6.64	6.44	7.76	5.64	6.74	8.20	8.20	7.16	5.96	5.70
Sodium	1.80	1.86	1.96	1.74	1.68	1.80	1.74	1.92	1.82	1.56	1.60	1.66
Sulfur	2.76	3.40	3.36	2.88	2.92	4.54	3.00	4.22	3.80	3.02	2.98	3.06
Boron	0.017	0.020	0.019	0.017	0.017	0.017	0.016	0.017	0.019	0.016	0.016	0.017
Iron	0.768	0.813	0.810	0.736	0.824	0.927	0.801	1.064	0.975	1.083	0.931	0.837
Manganese	0.191	0.229	0.260	0.247	0.321	0.243	0.263	0.255	0.289	0.247	0.219	0.210
Copper	0.141	0.160	0.152	0.141	0.144	0.173	0.138	0.191	0.177	0.155	0.138	0.152
Zinc	0.481	0.533	0.526	0.491	0.489	0.588	0.461	0.746	0.618	0.564	0.467	0.528
pHI	8.32	6.41	8.33	8.46	8.47	6.58	8.38	8.41	8.48	8.33	8.50	8.39

APPENDIX D: Batch Sample Analysis (4 of 7)

Description	**K-39**	**K-40**	**K-41**	**K-42**	**K-43**	**K-44**	**K-45**	**K-46**	**K-47**	**K-48**	**K-49**	**K-50**
Lab ID	**9166**	**9167**	**9168**	**9169**	**9170**	**9171**	**9172**	**9173**	**9174**	**9175**	**9176**	**9177**
Moisture,%	80.09	81.60	79.67	77.78	80.01	80.78	81.62	81.78	80.61	80.55	80.63	79.86
Solids,%	19.91	18.40	20.33	22.22	19.99	19.22	18.38	18.22	19.39	19.45	19.37	20.14
Mineral Matter, %	4.16	3.50	4.23	4.56	3.80	3.97	3.62	4.03	3.92	3.86	3.75	4.15
Organic Matter, %	15.75	14.90	16.10	17.66	16.19	15.25	14.76	14.19	15.47	15.59	15.62	15.99
Units	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton
Total N	11.62	11.28	11.26	13.32	11.50	12.76	11.56	16.50	11.76	15.64	17.76	23.56
Ammonium-N	5.40	5.30	5.40	3.22	5.26	4.50	4.90	4.90	5.60	5.18	5.34	5.50
Nitrate-N	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	3.30	<0.010	<0.010	<0.010	<0.010	<0.010
Organic-N	6.22	5.98	5.86	10.08	6.24	8.26	6.66	11.60	6.16	10.46	12.42	18.06
Total P	8.16	7.72	8.54	8.62	8.56	8.38	7.94	11.08	7.72	6.80	8.80	11.16
Total as P205	18.72	17.70	19.56	19.78	19.60	19.22	18.20	25.40	17.68	15.60	20.14	25.58
Available P	7.40	5.78	7.08	7.92	6.52	8.04	7.28	7.88	4.30	4.32	4.02	4.80
Available as P205	16.96	13.24	16.22	18.14	14.92	18.42	16.68	18.04	9.86	9.88	9.22	11.00
Available P,%	90.60%	74.80%	82.92%	91.71%	76.12%	95.84%	91.65%	71.02%	55.77%	63.33%	45.78%	43.00%
Potassium	2.54	2.46	2.48	2.62	2.36	2.42	2.28	2.52	2.52	2.42	2.16	2.26
Potassium as K20	3.06	2.98	2.96	3.16	2.84	2.92	2.76	3.02	3.02	2.92	2.60	2.70
Calcium	8.92	6.92	5.94	7.78	7.16	6.18	6.36	10.68	9.22	5.52	12.60	16.64
Magnesium	5.58	5.26	5.98	6.00	6.08	5.80	5.96	7.58	5.20	4.56	5.78	6.96
Sodium	1.72	1.70	1.66	1.68	1.60	1.66	1.54	1.72	1.70	1.68	1.52	1.58
Sulfur	2.90	2.68	2.84	3.74	2.76	3.12	2.58	2.92	2.80	2.76	2.64	2.62
Boron	0.016	0.015	0.016	0.017	0.015	0.015	0.013	0.015	0.016	0.016	0.014	0.015
Iron	0.754	0.655	0.708	0.780	0.700	0.724	0.737	0.922	0.673	0.692	0.667	0.705
Manganese	0.204	0.194	0.196	0.213	0.215	0.209	0.198	0.258	0.237	0.168	0.230	0.293
Copper	0.140	0.128	0.137	0.151	0.130	0.139	0.132	0.154	0.129	0.129	0.118	0.130
Zinc	0.500	0.439	0.482	0.524	0.465	0.514	0.488	0.595	0.453	0.443	0.423	0.454
pHI	8.28	8.40	8.39	8.46	8.42	8.20	8.26	8.21	8.21	8.35	8.33	8.12

APPENDIX D: Batch Sample Analysis (5 of 7)

Description	K-51	K-52	K-53	K-54	K-55	K-56	K-57	K-58	K-59	K-60	K-61	K-62
Lab ID	**9178**	**12617**	**12618**	**12619**	**12620**	**12621**	**12622**	**12623**	**12624**	**12625**	**15238**	**15239**
Moisture,%	80.78	78.75	79.89	79.32	78.85	78.33	78.64	78.86	79.06	78.57	78.34	78.21
Solids,%	19.22	21.25	20.11	20.68	21.15	21.67	21.36	21.14	20.94	21.43	21.66	21.79
Mineral Matter, %	4.07	4.72	3.89	4.95	5.16	5.54	5.63	5.06	4.68	4.74	5.28	5.17
Organic Matter, %	15.15	16.53	16.22	15.73	15.99	16.13	15.73	16.08	16.26	16.69	16.38	16.62
Units	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton
Total N	28.94	14.40	13.18	13,84	12.84	15.70	15.40	13.66	13.48	17.72	14.88	15.08
Ammonium-N	5.26	3.52	3.84	4.78	4.92	1.24	1.58	1.78	1.88	1.00	2.62	2.64
Nitrate-N	<0.010	<0.010	<0.010	<0.010	<0.010	0.56	<0.010	0.68	<0.010	<0.010	<0.010	0.94
Organic-N	23.68	10.88	9.34	9.06	7.92	13.90	13.82	11.20	11.60	16.72	12.26	11.50
Total P	7.54	11.04	8.76	13.12	12.70	12.78	14.82	12.82	11.10	10.32	13.34	11.20
Total as P205	17.26	25.32	20.12	30.02	29.06	29.30	33.96	29.34	25.42	23.66	30.58	25.66
Available P	4.76	9.18	7.36	10.84	10.36	11.18	13.12	10.96	8.38	10.24	11.26	7.02
Available as P205	10.92	21.04	16.86	24.82	23.74	25.62	30.04	25.08	19.18	23.48	25.82	16.08
Available P, %	63.27%	83.10%	83.80%	82.68%	81.69%	87.44%	88.46%	85.48%	75.45%	99.24%	84.43%	62.67%
Potassium	2.30	3.40	2.98	3.44	3.34	4.50	3.72	3.76	5.36	4.16	3.76	3.62
Potassium as K20	2.76	4.08	3.58	4.14	4.02	5.42	4.48	4.52	6.44	5.02	4.54	4.36
Calcium	11.00	12.66	9.12	13.32	14.88	10.06	13.24	18.34	10.52	7.62	13.60	17.70
Magnesium	5.26	8.08	6.12	9.64	8.76	9.18	11.06	9.04	7.88	7.68	10.14	8.14
Sodium	1.58	1.58	1.40	1.54	1.44	2.00	1.58	1.70	2.38	1.84	1.52	1.44
Sulfur	2.50	3.02	2.78	3.26	3.38	4.16	4.02	3.38	4.14	4.32	3.72	3.00
Boron	0.014	0.015	0.014	0.015	0.015	0.016	0.015	0.015	0.018	0.016	0.017	0.016
Iron	0.569	0.905	0.760	1.185	1.087	1.177	1.323	1.266	0.925	1.074	1.238	0.997
Manganese	0.240	0.306	0.243	0.336	0.325	0.291	0.355	0.376	0.284	0.248	0.304	0.312
Copper	0.110	0.166	0.140	0.182	0.186	0.212	0.232	0.168	0.175	0.202	0.156	0.145
Zinc	0.381	0.593	0.490	0.677	0.693	0.822	0.918	0.603	0.621	0.774	0.769	0.525
pHI	8.17	8.23	8.39	8.12	8.09	7.06	7.25	8.00	8.01	7.70	8.03	7.81

APPENDIX D: Batch Sample Analysis (6 of 7)

Description	K-63	K-64	K-65	K-66	K-67	K-68	K-69	K-70	K-71	K-72	K-73	K-74
Lab ID	**15240**	**15241**	**15242**	**15243**	**15244**	**15245**	**15246**	**15247**	**15248**	**15249**	**15250**	**15251**
Moisture,%	79.71	80.46	79.63	80.32	80.12	79.38	79.33	79.37	79.38	79.52	79.06	79.18
Solids,%	20.29	19.54	20.37	19.68	19.88	20.62	20.67	20.63	20.62	20.48	20.94	20.82
Mineral Matter, %	5.08	4.80	5.21	4.44	4.31	4.96	4.50	4.80	5.00	4.93	5.10	5.02
Organic Matter, %	15.21	14.74	15.16	15.24	15.57	15.66	16.17	15.83	15.62	15.55	15.84	15.80
Units	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton
Total N	16.04	14.36	16.16	11.76	12.50	12.64	12.30	16.06	14.46	13.12	13.78	15.20
Ammonium-N	3.36	4.04	7.32	4.22	4.68	4.70	3.68	4.00	2.74	4.22	4.04	2.78
Nitrate-N	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Organic-N	12.68	10.32	8.84	7.54	7.82	7.94	8.62	12.06	11.72	8.90	9.74	12.42
Total P	11.20	10.52	11.62	9.28	7.52	10.40	8.14	11.84	11.54	11.84	11.22	10.96
Total as P205	25.64	24.08	26.60	21.30	17.22	23.80	18.64	27.14	26.48	27.12	25.72	25.10
Available P	10.72	9.06	9.20	7.88	7.48	8.42	7.52	11.42	11.14	9.10	9.76	10.16
Available as P205	24.56	20.80	21.10	18.02	17.14	19.26	17.24	26.20	25.52	20.84	22.36	23.28
Available P,%	95.79%	86.38%	79.32%	84.60%	99.54%	80.92%	92.49%	96.54%	96.37%	76.84%	86.94%	92.75%
Potassium	3.54	3.60	3.42	3.62	3.50	3.58	3.68	3.42	3.46	3.44	3.44	3.74
Potassium as K20	4.26	4.34	4.12	4.36	4.22	4.34	4.42	4.12	4.16	4.14	4.14	4.50
Calcium	8.12	9.38	9.38	12.48	10.06	15.54	11.24	15.34	13.16	14.30	10.88	8.42
Magnesium	8.68	8.02	8.92	6.66	5.48	7.38	5.78	7.56	8.54	8.72	8.50	6.62
Sodium	1.34	1.36	1.30	1.42	1.44	1.44	1.48	1.40	1.36	1.40	1.38	1.50
Sulfur	3.48	3.16	3.46	3.04	2.78	2.88	2.98	3.02	3.38	2.94	3.02	3.28
Boron	0.015	0.015	0.015	0.015	0.015	0.016	0.016	0.015	0.016	0.015	0.015	0.015
Iron	1.149	1.093	1.208	0.943	0.704	1.071	0.835	0.892	1.096	1.000	0.957	0.821
Manganese	0.242	0.244	0.265	0.235	0.211	0.295	0.234	0.281	0.294	0.308	0.276	0.216
Copper	0.205	0.191	0.211	0.133	0.124	0.148	0.129	0.153	0.179	0.158	0.156	0.147
Zinc	0.840	0.751	0.805	0.458	0.409	0.529	0.435	0.593	0.715	0.612	0.597	0.572
pHI	8.65	8.61	8.60	8.63	8.27	8.52	8.71	8.59	8.51	8.52	8.46	8.36

APPENDIX D: Batch Sample Analysis (7 of 7)

Description	**K-75**	**K-76**	**K-77**	**K-78**	**K-79**	***Average***
Lab ID	**15252**	**15253**	**15254**	**15255**	**15256**	*72*
Moisture, %	79.32	79.31	79.67	79.68	81.04	***79.33***
Solids,%	20.68	20.69	20.33	20.32	18.96	***20.67***
Mineral Matter, %	5.09	5.11	4.83	4.82	4.44	***5.03***
Organic Matter,%	15.59	15.58	15.50	15.50	14.52	***15.64***
Units	lbs/ton	lbs/ton	lbs/ton	lbs/ton	lbs/ton	***lbs/ton***
Total N	12.46	12.08	14.46	12.26	10.34	***15.16***
Ammonium-N	3.04	4.44	3.96	4.66	4.68	***3.78***
Nitrate-N	<0.010	<0.010	<0.010	<0.010	<0.010	***<0.010***
Organic-N	9.42	7.64	10.50	7.60	5.66	***25.37***
Total P	9.68	8.98	10.24	9.38	8.34	***11.22***
Total as P205	22.16	20.56	23.46	21.50	19.12	***25.70***
Available **P**	8.80	7.74	8.82	8.98	7.02	***9.25***
Available as P205	20.18	17.72	20.20	20.56	16.08	***21.18***
Available P, %	91.06%	86.19%	86.10%	95.63%	84.10%	***82.43%***
Potassium	3.84	3.32	3.04	3.58	3.30	***3.27***
Potassium as K20	4.64	3.98	3.66	4.30	3.98	***3.93***
Calcium	11.58	15.64	10.28	9.42	8.84	***12.43***
Magnesium	7.16	6.24	7.68	5.52	6.14	***8.40***
Sodium	1.58	1.28	1.14	1.42	1.28	***1.56***
Sulfur	3.02	2.48	2.88	2.72	2.36	***3.36***
Boron	0.016	0.014	0.015	0.015	0.014	***0.016***
Iron	0.816	0.821	1.191	0.787	0.978	***1.000***
Manganese	0.268	0.250	0.242	0.209	0.216	***0.271***
Copper	0.135	0.122	0.242	0.130	0.129	***0.190***
Zinc	0.503	0.392	0.188	0.434	0.427	***0.628***
pHI	8.50	8.38	8.33	8.33	8.42	***8.11***