The Effects of Manure Application on Phosphorus Loss

Jenna Falor

Author Profile

Author Name: Jenna Falor

Professional Title: Feed Sales Specialist

Affiliation (Company / Department): Active Feed Company

Current professional work / research interests:

. I am currently not involved directly in Agronomy. I do advise farmers on their animals nutritional needs as well as forage management both in the field and upon harvest time. I hope to move back into an agronomy role in a field level that still allows interaction with farmers.

Module Contents

Module Contents

Learning Objectives

- How to determine the phosphorus application rate based upon crop need.
- How to perform an assessment of potential phosphorus loss due to manure application

Introduction

Importance of Nutrient Planning

Nutrient management from manure is important for multiple reasons.

- To avoid water contamination
- Take advantage of available nutrients on farm
- Reduce off farm costs

Each farm needs to tailor their manure plan to their farm. Currently Comprehensive Nutrient Management Plans (CNMPs) are much more complex than many farms need. The time commitment and cost can discourage many farmers from participating in this unless they are required to by the government either due to size or wanting to partake in a program.

This doesn’t mean that there cannot be a plan in place to prevent excessive nutrient loss from incorrect application of manure.

Introduction

Why?

- More recently agriculture has come under public scrutiny for nutrients contaminating public waterways.

    - Gulf of Mexico Dead Zone
    - Des Moines Water Authority Lawsuit
    - Chesapeake Bay
    - Lake Erie Algal Bloom

  • While agriculture is by no means the only polluter, farmers and their practices are facing increased scrutiny.

  • It is important for farmers to be able to defend themselves and educate the public about why they apply nutrients in a certain manner.

  •As phosphorus makes it’s way into the waterway, it is no longer the limiting nutrient; thus it contributes to deterioration of water quality.

Introduction

Impact on Water Quality

- When phosphorus is no longer a limiting nutrient, eutrophication can occur.

- Eutrophication is the depletion of oxygen within waterways as the result of algae growth (Al-Kaisi and Licht, 2005).

- A depletion of oxygen within the algal blooms also known as a hypoxic or “dead” zone can lead to a loss in wildlife such as fish, shellfish, and birds that need that water to survive.

- Poor water quality caused by an excess of phosphorus not only impacts the ability of wildlife and humans to use the water, it also causes an economic loss in other industries such as fishing and recreation (EPA, 2015).

Introduction

Current Resources

Currently, there are various resources that can help farmers determine when to apply manure such as:

- Michigan State University (https://enviroimpact.iwr.msu.edu/)
- Iowa State University (http://www.agronext.iastate.edu/immag/pubsnm.html)

These tools are developed by different universities and their partners are modified as new research becomes available.

Many of these tools have been specialized based on the region the university is located in. There are also many bulletins that can be found webpages of agricultural universities.

Phosphorus Transport

Phosphorus Loss Factors and Equation

Loss Factors

- Erosion Rate
- Runoff class
- Frequency of flooding
- Distance to surface waters
- Subsurface Drainage
- Phosphorus levels in soil
- Application rate
- Application method

P-Index

- There is a formula that calculates the potential phosphorus loss, also known as P-Index, using RUSLE2, tillage, and drainage which is available online from the USDA – NRCS.

Application and Incorporation Methods

Application Methods

There are various application methods that can be utilized depending on set up and type of manure.

- Broadcast:
    - Liquid Tank Spreaders
    - Drag Hose for liquids
    - Dry Spreaders
- Knife Injection:
    - Manure is placed directly underneath the soil surface (LaBarge, 2016)
- Irrigation:
    - Only used for liquids
    - System must be appropriate for manure (Jarrett and Graves, 2014)

Broadcast application by liquid tank spreaders

Photo courtesy of B. Osantoski (personal communication, text message, 2018)

Application and Incorporation Methods

Incorporation Methods

- There are various options when it comes to incorporation of manure following application.
    - No incorporation following broadcast
        - Leads to the highest loss via runoff (Minnesota Pollution Control Agency, 2018)
    - Chisel Plow
    - Moldboard Plow

•In trials by Daverede et al. (2004) all plots that had any type of incorporation showed decreased levels of phosphorus in runoff versus plots without incorporation.

Tillage shanks attached behind broadcast spreader
Photo courtesy of Falor, 2018

Application and Incorporation Methods

Incorporation Methods

- A study done by Rotz et al. (2011) that evaluated different applications of both swine and dairy manure showed a reduction in phosphorus loss in most cases when incorporation was used.

Phosphorus Loss by Incorporation Method as a Percentage of Phosphorus Loss by Broadcast Application		
	Chisel Plow	Injection
Dissolved Phosphorus		
Dairy	35.7%	45.7%
Swine	14.9%	54.5%
Total Phosphorus		
Dairy	59.5%	54.4%
Swine	77.2%	104.5%

Adapted from Rotz et al., 2011

Application and Incorporation Methods

Incorporation Methods (cont.)

- While increased incorporation led to decreased phosphorus concentration in surface runoff, forms of incorporation that reduced surface residue increased overall soil erosion of the fields (Al-Kaisi and Licht, 2005).
- If a crop, such as alfalfa, is present in a field when manure is applied, this helps reduce erosion as well as facilitate nutrient uptake.

Dragline in current alfalfa field
Photo courtesy of Falor, 2018

Effect of Soil Type and Tiling

Soil Type

- More coarsely textured soil provide a more uniform flow of nutrients throughout the soil profile (Glaesner et al., 2011). Since there is a more structure to the soil this means that the nutrients can flow more freely through the soil.

- Phosphorus loss on the other hand is higher in clay loams than loamy sands (van Es et al., 2004).

Tiling

- If a field has tile drainage, it has an higher potential for phosphorus leaching (van Es et al., 2004). A study by Hergert et al. (1981) concluded that manure applications increased the probability of phosphorus parts above 30 parts per billion in tile discharge.
    - With a 35 metric ton application the increase in occurrence at 1 year was 0.05 and at 3 years .08
    - With a 200 metric ton application the increase in occurrence at 1 year was 0.06 and at 3 years 0.47

Effects of Slope

Slope

- The slope of a field or section of field plays a role in nutrient loss, largely from erosion and surface run-off of unincorporated manure.

- The direct correlation of soil loss and slope gradient has been debated over the years and continues to be a current agricultural research topic. In a study by Shen et al. (2016) soil erosion greatly increased when a slope gradient went from 10 degrees to 15 degrees; however, the difference was much less from 15 degrees to 20 degrees. This indicates that slope plays a part in soil erosion, but once it hits a certain gradient the changes are less dramatic.

- An increase in soil slope leads to an increase in surface runoff when rain events occur (Davis, 2013).

Application Timing

Weather

- If a rain event takes place too soon after application and before incorporation, an increase in manure loss from surface run-off occurs.

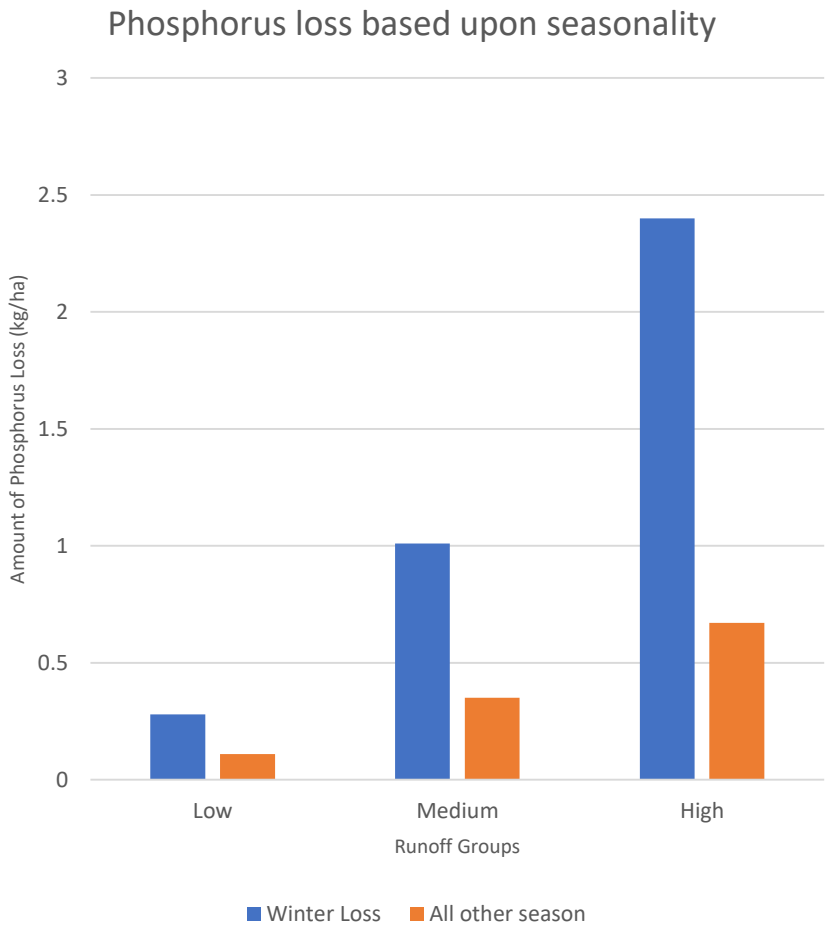
Example of run-off through pasture after rain event

Photo courtesy of A. Tyrrell (personal communication, text message, 2018)

Application Timing

Seasonality

- Fall applications of manure result in the highest loss of nitrates due to a number of factors including timing until crop uptake (van Es et al., 2006).
- Applying manure on frozen ground can lead to an increase in nutrient loss due to a decrease in infiltration and the inability to incorporate, thus leading to an increase in manure present in surface run-off (Sawyer and Mallarino, 2009).
- Levels of increased phosphorus in runoff occur during late winter and early spring as the ground is thawing (Minnesota Pollution Control Agency, 2018).



Adapted from Vadas et al., 2017

Species Specific Information

Farm Planning and Management Practices

The most accurate way for a farm to develop a plan is to use specific data. This includes:

- Taking manure samples correctly and using those analysis when planning
- Having soil sample results for fields they are planning to spread on

If manure sample results are not available for a farm, there are “book values” available from various universities that can be used.

However, accuracy of these values is not guaranteed as there is much variation in these “book values”.

Photo courtesy of B. Osantoski (personal communication, text message, 2018)

Manure Samples

How to sample liquid manure

Lagoon or Liquid Storage Surface:

- Use plastic cup on end of 10 to 12 foot handle
- Take multiple samples from around the pit at approximately 1 foot below surface and 6 ft off bank (Chastain, 2018)
- Mix samples in bucket
- Take a 16 ounce sample of this mixture and place in a 20 ounce plastic bottle with cap.
- If possible freeze before sending
- Mail to an accredited lab for testing

Agitated Liquids:

- Throw bucket toward center of lagoon
- Stay within 75 to 100 feet of the agitator (Chastain, 2018)
- Make sure that the bucket has time to sink as dragging back in with rope.
- Make sure that the bucket is above the water before it hits the bank
- Mix individual samples in large bucket
- Take 16 ounce sample of this mixture and place in a 20 ounce plastic bottle with cap.
- If possible freeze before sending
- Mail to an accredited lab for testing

Manure Samples

How to sample solid manure

Stockpile

- Take multiple samples from around the pile
- Samples must be at least 18 inches deep in the pile (Zhang and Hamilton, 2017)
- Mix all samples thoroughly in bucket, quickly as to avoid letting it dry
- Take sample from bucket place in plastic bag
- If possible freeze before shipping
- Ship to accredited lab for manure analysis

Photo Courtesy of C. Tyrrell (personal communication, text message, 2018)

Manure Samples

How to read manure sample results

- Once samples have been sent to the lab the results will be received in a manner similar to soil samples.
- When samples are sent in, the selection of test to run can provide a variety of information. The very basic tests should provide at least total nitrogen, phosphorus, potassium and dry matter. While more intensive testing can include micronutrients (Rieck-Hinz et al., 2011).
- When reading manure results be sure to monitor the following variations that can be included:
    - Nitrogen – Is it reported as total nitrogen or do they also include ammonium-N (inorganic) which allows calculation of organic nitrogen (Rieck-Hinz et al., 2011)?
    - Phosphorus – Is it reported as P or P_2O_5 (Rieck-Hinz et al., 2011)?
    - Potassium – Is it reported as K or K_2O (Rieck-Hinz et al., 2011)?

Manure Samples

Manure Applications based on Nutrient Needs

- Recommendations for manure application can be made based upon either phosphorus requirements or nitrogen requirements.
- If recommendations are based on Nitrogen requirements for the plant, the phosphorus level in the soil can build (Sharpley and Beegle, 2001).
- Even if recommendations are based on nitrogen needs, it is advised that it should not exceed 4 years worth of phosphorus.
- To keep phosphorus levels in check there are two methods:
    - Full application for needed nitrogen in one year and then no subsequent applications until phosphorus has been utilized (Lory et al., 2005).
    - Limited application to one year worth of phosphorus removal and then manure can be reapplied yearly (Lory et al., 2005).

Manure Samples

Nutrient Availability

When planning manure applications to manage nutrients, it is important to remember that all nutrients applied are not available the first year.

The table to the right provides data on nutrient availability for the first 3 years following manure application for 3 of major species grown in confinement.

Nutrient Availability as a percent of total nutrient applied			
	Year 1	Year 2	Year 3
Cattle			
Nitrogen	30-50**	25*	10-15*
Phosphorus	80-100**	-	-
Potassium	90-100**	-	-
Swine			
Nitrogen	35-80*	15*	0*
Phosphorus	90-100**	-	-
Potassium	90-100**	-	-
Poultry			
Nitrogen	45-70**	25*	0*
Phosphorus	90-100**	-	-
Potassium	90-100**	-	-

*Wilson, 2018

**Sawyer and Mallarino, 2016

Species Specific Information

- The previous section explains one method of how to sample each type of manure. There are other methods that can be utilized as well.
- This section also includes how to interpret the results that are obtained from manure samples.
- It also included the nutrient availability by year for specific species to be used when determining manure application rates.
- The next section provides information that can be utilized if pulling manure samples is not a feasible option.
- These numbers are generalized and are not tailored to the individual farm. Diet being fed to livestock or the amount of time manure is being stored before being spread among other factors can effect the nutrient values of manure.

Species Specific Information

Using Book Values

- The following 2 slides have book values that can be utilized if a manure sample is not available.
- These numbers can vary widely depending on which source you use for a book value.
- As indicated by the table to the right, there can be a lot of variation depending on which source is used.

Examples of Variations in Manure Nutrient Value "Book Values"

	Iowa State University	University of Nebraska	Difference
Swine Slurry (Wet Dry)			
Nitrogen	58	59	-1
P_2O_5	44	40	4
K_20	40	24	16
Dairy Slurry			
Nitrogen	31	25	6
P_2O_5	15	25	-10
K_20	22	40	-18
Turkey Litter			
Nitrogen	40	-	-
P_2O_5	50	15	35
K_20	30	30	0

Adapted from Sawyer, 2009 and Koelsch and Shapiro, 2006

Species Specific Information: Average Values

Average Manure Nutrient Content (pounds per ton (solids), pounds per 1000 gallons (semi-solids))			
	Nitrogen	P_2O_5	K_2O
Dairy			
Solid	9	4.5	7
Slurry	25	25	40
Liquid Effluent (pounds per acre inch)	679	674	1082
Beef			
Solid*	9	5	8
Slurry***	25	17.3	24.7
Liquid Effluent (pounds per acre inch)	79	47	92
Swine			
Liquid Effluent (pounds per acre inch)	136	104	189
Slurry			
Grow-Finish (wet/dry feeder)	59	40	24
Grow-Finish (dry feeder)	39	34	24
Grow-Finish (Earthen Storage)*	32	22	20
Nursery*	25	19	22
Breeding Gestation*	25	25	24
Solids***	13	7.5	4.5

Koelsch and Shapiro, 2006

*Sawyer, 2009.

**Hashemi et al., 2013

*** Adapted from Sawyer, 2009 data

Species Specific Information: Average Values (cont.)

Average Manure Nutrient Content (pounds per ton (solids), pounds per 1000 gallons (semi-solids))			
	Nitrogen	P_2O_5	K_2O
Poultry			
Layer			
Slurry	57	51	33
Solid	37	55	31
Broiler			
Slurry*	63	40	29
Solid*	46	53	36
Turkey			
Solid*	40	50	30
Sheep			
Solids**	23	8	20
Horse			
Solids**	9	6	11

Koelsch and Shapiro, 2006
*Sawyer, 2009.
**Hashemi et al., 2013

Soil Samples

How to interpret soil tests for application

- Normal soil tests are important when deciding a fertilization plan, whether using manure or synthetic.
    - Frequency of testing varies depending on rotation and fertilizer being applied
    - When establishing a base, 1-2 years is needed (Warncke, 2013)
    - Once established an average number would be to sample once every 3 years (Warncke, 2013)

- In the case of manure the decision for application can be either based upon crop nitrogen needs or phosphorus needs.

- Making manure applications based upon nitrogen can lead to a build up in soil phosphorus levels.

- This means it is important to consider the amount of phosphorus a crop will use.

Soil Samples

How to interpret soil tests for application (cont.)

- It is typically suggested that no more than 4 years of crop removal be applied in a single application of manure.
    - This helps avoid an excessive soil build up
    - Optimal agronomic level is 30-50ppm (Beegle, 2002)
- In general, phosphorus can be considered 100% available in the first year. However, some research indicates that it can be as low as 80% plant available phosphorus in the first year (Wilson, 2018).
    - If application is being based upon phosphorus to be on the safe side it could be beneficial to use that 80% availability instead.

Basic Planning

Final Considerations

Many factors effect the nutrient loss that can occur from manure management. Before applying manure, keep in mind the following:

- Weather – Application timing in comparison to rain timing.
- Seasonality –The timing of nutrient uptake by crops versus application timing as well as soil temperature.
- Soil sample results – Current nutrient levels let us know what is already available.
- Manure sample results – Allow tailored suggestions based upon what will actually get applied, as long as accurate samples are taken.
- Slope of the field – The greater the slope the higher the rate of run-off.
- Soil type – Sandier soils tend to have faster infiltration rates of water, however finer soils tend to have a higher phosphorus loss.
- Application and Incorporation – The method of application and incorporation have different effects on the loss of nutrients.
- Application Rate – Using all the above information can help determine the accurate application rate to reduce the amount of nutrient loss.

Manure Application Example

Example Using Dairy Slurry

The following is an example of making a manure application based upon either nitrogen removal or phosphorus removal.

Important Numbers for Manure Calculations:

- Manure Analysis
- Soil Analysis – this gives you a base on phosphorus and potassium levels and therefore the phosphorus availability you want to use in the first year.
- 4 year crop plan and target yield
- Nutrient removal by crop
- Nutrient Availability by year for nitrogen and phosphorus
- Nitrogen based manure application plan
- Phosphorus based manure application plan

Manure Application Example

Manure and Soil Analysis

Manure Analysis (lbs/1000 gal)	
Total N	26
P_2O_5	11
K_2O	19

Soil Analysis (ppm)	
Phosphorus	59
Potassium	223

There are a lot of important details for making the best recommendation when manure application is concerned. Sample results for both manure and soil help to not only make calculations (manure) but overall picture (soil sample).

Manure Application Example (cont.)

Crop Plan and Target Yield

A crop plan and target yields are needed to calculate crop nutrient removal rate for the next four years.

Crop Plan and Target Yield		
	Crop	Target Yield
Year 1	Corn (Grain)	190 bushels
Year 2	Soybeans	60 bushels
Year 3	Corn (Silage)	25 tons
Year 4	Wheat	80 bushels

Manure Application Example (cont.)

Nutrient Removal by Crops each year

Another piece of necessary information is crop nutrient removal rates. The table below indicates removal rate per bushel or ton of production.

Crop Nutrient Removal Rate (lb/bushel or lb/ton)		
	Nitrogen	P_2O_5
Corn (Grain)*	0.9	0.37
Corn (Silage)**	9	3.6
Soybeans*	3.8	0.8
Wheat**	1.2	0.6

*Silva, 2017

** Nathan et al., 2006

Crop Nutrient Removal Rate by Year with Target Year Goals (lbs)		
	Nitrogen	P_2O_5
Year 1	171	70.3
Year 2	228	48
Year 3	225	90
Year 4	96	48

The above table takes the values from the table on the left and multiplies them by the target yield for total pounds of removal of these nutrients.

Manure Application Example (cont.)

Nutrient Availability from the Manure by year

Nutrient Availability By Year (lbs per 1000gal)				
	Year 1	Year 2	Year 3	Year 4
Nitrogen	13	6.5	3.9	0
Phosphorus	11	0	0	0

The table above is based upon the nutrient availability discussed earlier in the presentation. This did used the following values:

- Nitrogen: Year 1 – 50%, Year 2 – 25%, Year 3 – 15%
- Phosphorus: Year 1 – 100% available, based upon sources as well as this soil being sufficient in phosphorus per the soil results.

Manure Application Example (cont.)

Nitrogen Based Manure Plan

Nitrogen Based Manure Application (lbs/year or gal/acre)				
	Grain Corn	Soybean	Corn Silage	Wheat
N Required	171	228	225	96
Manure N Residual	0	85.5	122.5	84
N Still Needed	171	142.5	102.5	12
Manure Rate Required	13153	10961	7884	923
Manure P_2O_5 Applied	144.68	120.57	69.81	10.15

The above table is based from information in the previous slides.

- "N Required" is directly from nutrient removal by year.
- "Manure N Residual" = (Manure Still Required from previous year/1000) x N available second year, repeat similarly for third year availability

Manure Application Example (cont.)

Nitrogen Based Manure Plan (cont.)

Nitrogen Based Manure Application (lbs/year or gal/acre)				
	Grain Corn	Soybean	Corn Silage	Wheat
N Required	171	228	225	96
Manure N Residual	0	85.5	122.5	84
N Still Needed	171	142.5	102.5	12
Manure Rate Required	13153	10961	7884	923
Manure P_2O_5 Applied	144.68	120.57	69.81	10.15

- "N Still Needed" = N Required – Manure N Residual
- "Manure Rate Required" is calculated as follows:
  (N Still Needed / N Available year 1)x 1000= Manure Rate Required, for subsequent years add the N availability for previous applications.

Manure Application Example (cont.)

Phosphorus Based Manure Plan

Phosphorus Based Manure Application Rates (lbs/year or gal/acre)				
	Grain Corn	Soybean	Corn Silage	Wheat
Manure Rate P Removal	6390	4363.64	8181.82	6390
Manure Rate applied 4 year P Removal	23300	23300	23300	23300
Manure N applied P Removal	83.07	56.73	106.36	56.73
Manure N applied 4 year P Removal	209.38	209.38	209.38	209.38

- "Manure Rate Removal" = (P from Nutrient Removal by Year/ P available year 1) x 1000
- "Manure Rate applied 4 year P Removal" = Total P removed over 4 year crop plan/ P available year 1) x 1000
- "Manure N applied P Removal" = (Manure Rate P Removal/1000) x 1st year available N
- "Manure N applied 4 year P Removal" = (Manure Rate applied 4 year P Removal/1000) x 1st year available N

Manure Application Example (cont.)

Comparison of Recommended Rates

Comparison of Manure Application Rates (gal/acre)				
	Year 1	Year 2	Year 3	Year 4
Manure Rate P Removal	6390	4363.64	8181.82	6390
Manure Rate applied 4 year P Removal	23300	23300	23300	23300
Manure Rate Required (Using N)	13153	10961	7884	923

Manure Application Example (cont.)

Conclusions

- As indicated by the previous two slides, the application rates could have much variation depending on if the decision is based upon nitrogen or phosphorus needs.
- There also is variation depending if manure applications are based upon a single year or multiple year phosphorus use rate.
- If soil levels are low, it can be advantageous to plan for some extra phosphorus and assume there will not be 100% availability from manure in the first year.
- However, if manure is always applied based upon nitrogen need it could cause a rise in the soil phosphorus levels.

Summary

- A little planning can go a long way when trying to reduce nutrient loss from manure application and thus taking the maximum economic benefit from them.
- With farming under increasing scrutiny for issues with nutrient contamination in public waterways, now is the time for farmers and agronomists to put extra focus on proper nutrient management from manure.
- In order to properly plan it is important to use the best information available.
- By keeping up to date soil tests, crop plans and manure tests allows for the calculation of manure applications in a way that best utilizes the nutrients available from the manure

References

- Al-Kaisi, M.M. and J. Licht. 2005. Tillage, manure management and water quality. Iowa State University Extension. PM1901h. https://store.extension.iastate.edu/Product/Tillage-Manure-Management-and-Water-Quality-Resources-Conservation-Practices-PDF&sa=U&ved=0ahUKEwjBo6Li__ncAhWug-AKHROiDtYQFggEMAA&client=internal-uds-cse&cx=014153082229948236703:4fobzs0gqdo&usg=AOvVaw0jtaMzC1j6YTbVM-VLmjlr (accessed 19 August 2018).
- Beegle, Douglas. 2002. Managing phosphorus for crop production. Pennsylvania State University. UC055. https://extension.psu.edu/programs/nutrient-management/educational/soil-fertility/managing-phosphorus-for-crop-production/extension_publication_file
- Chastain, J.P. 2018. Manure sampling procedures. Clemson University Cooperative Extension. https://www.clemson.edu/extension/camm/manuals/common_chapters/pch7c_03.pdf (accessed 5 August 2018).
- Daverede, I.C., A.N. Kravchenko, R.G. Hoeft, E.D. Nafziger, D.G. Bullock, J.J. Warren, and L.C. Gonzini. 2004. Phosphorus runoff from incorporation and surface-applied liquid swine manure and phosphorus fertilizer. J. Environ. Qual. 33:1535-1544.
- Davis, Ashley. 2013. What's the p index?. Colorado State University. https://articles.extension.org/pages/38322/whats-the-p-index (accessed 19 August 2018).
- EPA. 2015. A compilation of cost data associated with the impacts and control of nutrient pollution. US EPA. https://www.epa.gov/sites/production/files/2015-04/documents/nutrient-economics-report-2015.pdf (accessed 27 April 2018).

References

- Glæsner, N., C. Kjaergaard, G.H. Rubæk, and J. Magid. 2011. Interactions between soil texture and placement of dairy slurry application: I. Flow characteristics and leaching of nonreactive components. J. Environ. Qual. 40(2):337-343. doi:10.2134/jeq2010.0317
- Hashemi, M., S. Weis, and M. Magin. 2013. Nutrient credits from manure. University of Massachusetts Amherst Center for Agriculture. CDLE 13-03. https://ag.umass.edu/sites/ag.umass.edu/files/fact-sheets/pdf/Nutrient%20Credits%20from%20Manure.pdf (accessed 19 August 2018).
- Hergert, G.W., S.D. Klausner, D.R. Bouldin, and P.J. Zwerman. 1981. Effects of dairy manure on phosphorus concentrations and losses in tile effluent. J. Environ. Qual. 10(3):345-349. doi: 10.2134/jeq1981.00472425001000030018x.
- Iowa State University Extension and Outreach. 2016. Using manure nutrients for crop production. PMR 1003. https://store.extension.iastate.edu/product/Using-Manure-Nutrients-for-Crop-Production (accessed 5 August 2018).
- Jarrett, A.R. and R.E. Graves. 2014. Irrigation of liquid manures. Penn State College of Agricultural Science Extension. F-254. https://extension.psu.edu/programs/nutrient-management/educational/manure-storage-and-handling/irrigation-of-liquid-manures/extension_publication_file (accessed 5 August 2018).
- LaBarge, G. 2016. Understanding regulations, definition, noncompliance penalties, on fertilizer and manure application in ohio wleb. Ohio State University Extension. https://agcrops.osu.edu/newsletter/corn-newsletter/fertilizer-and-manure-application-compliance-ohio-and-civil-penalties (accessed 5 August 2018).
- Lory, J.A., R. Massey, B. Joern. 2005. Using manure as a fertilizer for crop production. EPA. https://www.epa.gov/sites/production/files/2015-07/documents/2006_8_25_msbasin_symposia_ia_session8.pdf (accessed 19 August 2018).

References

- Minnesota Pollution Control Agency. 2018. Runoff reductions with incorporated manure. Minnesota Pollution Control Agency. Wq-f1-08. https://www.pca.state.mn.us/sites/default/files/wq-f1-08.pdf (accessed 19 August 2018).
- Nathan, M.V., Y. Sun, D. Dunn. 2006. Nutrient removal values for major agronomic crops in Missouri report for 2006. http://aes.missouri.edu/pfcs/research/prop706a.pdf (accessed 7 October 2018).
- Rieck-Hinz, A., T.G. Miller, and J.E. Sawyer. 2011. How to interpret your manure analysis. Iowa State University Extension and Iowa USDA-NRCS. PM3014. https://store.extension.iastate.edu/product/How-to-Interpret-Your-Manure-Nutrient-Analysis (accessed 19 August 2018).
- Rotz, C.A., P.J.A. Kleinman, C.J. Dell, T.L. Veith, D.B. Beegle. 2011. Environmental and Economic Comparisons of Manure Application Methods in Farming Systems. J. Environ. Qual. 40:438-448. doi: 10.2134/jeq2010.0063.
- Sawyer, John. 2009. What are the average manure nutrient analysis values?. Iowa State University Agronomy Extension Soil Fertility. http://www.agronext.iastate.edu/soilfertility/currenttopics/WhatAreAverageManureNutrientAnalysisValues_1-24-09.pdf (accessed 5 August 2018).
- Sawyer, J. and A. Mallarino. 2016. Using manure nutrients for crop production. Iowa State University Extension and Outreach. PMR1003. https://store.extension.iastate.edu/product/Using-Manure-Nutrients-for-Crop-Production (accessed 19 August 2018).
- Sharpley, A. and D. Beegle. 2001. Managing phosphorus for agriculture and the environment. UDSA-ARS and Pennsylvania State University. CAT UC162. https://extension.psu.edu/programs/nutrient-management/educational/soil-fertility/managing-phosphorus-for-agriculture-and-the-environment (accessed 19 August 2018).

References

- Shen, H., F. Sheng, L. Wen, Y. Han, W. Hu. 2016. Impacts of rainfall intensity and slope gradient on rill erosion processes at loessial hillslope. Soil and Tillage Research. 155:429-436. doi: 10.1016/j.still.2015.09.011
- Silva, George. 2017. Nutrient removal rates by grain crops. Michigan State University Extension. http://www.canr.msu.edu/news/nutrient_removal_rates_by_grain_crops (accessed 7 October 2018).
- Vadas, P.A., L.W. Good, W.E. Jokela, K.G. Karthikeyan, F.J. Arriaga, and M. Stock. Quantifying the impact of seasonal and short-term manure application decisions on phosphorus loss in surface runoff. J. Environ. Qual. 46(6):1395-1402. doi: 10.2134/jeq2016.060220
- Van Es, H.M., R.R. Schindelbeck, and W.E. Jokela. 2004. Effect of manure application timing, crop and soil type on phosphorus leaching. J. Environ. Qual. 33(3):1070-1080. doi: 10.2134/jeq2004.1070
- Warncke, Darryl. 2013. Sampling soils for fertilizer and lime recommendations and frequency of soil sampling. Michigan State University. E0498. https://www.canr.msu.edu/resources/farm_soil_sampling (accessed 6 October 2018).
- Wilson, Melissa. 2018. Manure characteristics. University of Minnesota Manure Management Extension. https://extension.umn.edu/manure-land-application/manure-characteristics#nitrogen-817860 (accessed 19 August 2018).
- Zhang, H. and D.W. Hamilton. 2017. Sampling animal manure. Oklahoma State University Extension Service. PSS-2248. http://factsheets.okstate.edu/documents/pss-2248-sampling-animal-manure/ (accessed 5 August 2018).