2950 Niles Road, St. Joseph, MI 49085-9659, USA
269.429.0300 fax 269.429.3852 hq@asabe.org www.asabe.org

An ASABE Meeting Presentation

Paper Number: 1008593

The Use of Phosphorus Sorption Isotherms to Project Vegetative Treatment Life Expectancy

Jacob Baker, Undergraduate Research Assistant

Iowa State University, 3252 NSRIC, Ames, IA 50011, jfbaker@iastate.edu

Daniel Andersen, Graduate Research Assistant

Iowa State University, 3155 NSRIC, Ames, IA 50011, dsa@iastate.edu

Dr. Robert Burns, Professor

Iowa State University, 3224 NSRIC, Ames, IA 50011, rburns@iastate.edu

Lara Moody, Program Manager

Iowa State University, 3165 NSRIC, Ames, IA 50011, lmoody@iastate.edu

Written for presentation at the
2010 ASABE Annual International Meeting
Sponsored by ASABE
David L. Lawrence Convention Center
Pittsburgh, Pennsylvania
June 20 – June 23, 2010

***Abstract*.** Beef feedlots of all sizes are looking for cost-effective solutions to manage feedlot runoff. Vegetative treatment systems (VTSs) have been proposed as a potential option. A vegetative treatment system *consists of a solid settling structure followed by additional treatment components, vegetative infiltration basins (VIBs) and vegetative treatment areas (VTAs), which use soil and vegetation to treat and utilize nutrients in the applied runoff. Investigations have shown that VTSs can provide a cost effective means of treating and controlling open feedlot runoff; however, sustainability and life expectancy of these systems have not yet been determined. This study investigated, based on the vegetative treatment area's ability to absorb and utilize phosphorus, the expected life of four VTSs on beef feedlots in Iowa. For this study, VTA life was defined as the amount of time it took for the top 0.3 meters of the soil profile to become saturated with phosphorus. Soil phosphorus sorption capacity, phosphorus loading rate, and initial soil phosphorus concentration had the largest impacts on VTA life. The impact of phosphorus removal through vegetation growth and harvest varied with the area of the VTA, with larger treatment areas having a larger increase in life than smaller vegetative treatment areas. Expected phosphorus sink life for the top 0.3 m of the soil for the four monitored vegetative treatment areas was calculated to range from 4.5 to 13 years.*

Keywords. Vegetative Treatment Areas, Phosphorus Sorption Isotherms, VTA life, feedlot runoff

Introduction

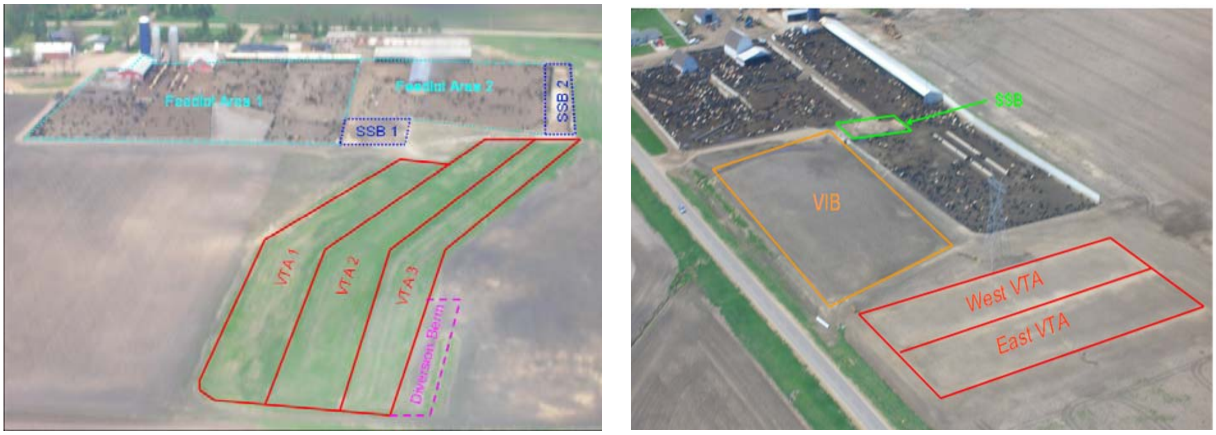
Animal feeding operations (AFOs) and concentrated animal feeding operations (CAFOs) produce large volumes of wastewater that must be handled properly. This wastewater could be seen as a potential pollutant to surface and ground waters because it contains nitrogen, phosphorus, organic matter, solids, and pathogens. As a result, the U.S. Environmental Protection Agency (EPA) developed a set of effluent limitation guidelines (ELGs) that described the design and operating criteria for waste management systems on CAFOs (Anschutz et al., 1979) The U.S. EPA required open-lot beef feedlot CAFOs to contain all wastewater and runoff resulting from storms smaller than the 25-year, 24-hour event (EPA, 2008). These effluent limitation guidelines historically required collection, storage, and land application of feedlot runoff; however, the 2003 CAFO rule allowed the use of alternative technologies that meet or exceed the performance of a containment basin system.

Traditionally, beef feedlot runoff was to collect it in a settling basin, the solids settled out, and then transferred to a storage structure. Periodically, the effluent in these structures needed to be land applied to maintain sufficient storage capacity for a 25-year, 24-hour rain event. Increases in feedlot size require additional storage capacity to be constructed. This can be costly as construction of a containment basin costs on average $205 per head and $136 per head for AFOs and CAFOs feedlots (Bond et al., 2009). Beef producers have expressed interest in non-basin technology that eliminate the need for the long term storage and provide a less expensive option for feedlot runoff control (Woodbury et al., 2005). One way to decrease costs would be a vegetative treatment system (VTS). Bond et al. (2009) reported average construction costs for VTSs averaged $77 and $85 per head for AFOs and CAFOs respectively.

A VTS is a combination of treatment components, at least one of which utilizes vegetation, ot manage runoof from open lots (Moody et al., 2006). Typical components of a VTS include a solid settling basin (SSB), a vegetative infiltration basin (VIB), and a vegetative treatment area (VTA). Figure 1a shows a VTS with a SSB and a VTA and Figure 1b shows a VTS with a SSB, VIB, and VTA. The SSB receives feedlot runoff during a rainfall event allowing the solids to settle over a period of time. Once the solids have settled, the effluent is then pumped or allowed to flow by gravity to the VIB or VTA. A VIB is a flat area, surrounded by berms, and planted to permanent vegetation (Moody et al., 2006). The effluent is applied over the entire VIB surface and infiltrates through the soil into tile lines that are buried 1.2 meters (4 feet) underground. From these tile lines, the effluent is transported into a sump where it is then pumped onto the VTA. The effluent is uniformly distributed across the top of the VTA to allow for sheet-flow. The VTA uses vegetation and soil to treat and utilize nutrients in the applied runoff effluent.

Vegetative treatment areas are being researched in many regions of the United States for control of different types of wastewater (Andersen et al., 2009; Zhang et al., 2009). VTSs have shown the ability to reduce feedlot runoff phosphorus concentrations and surface transport by 62% and 86% respectively, as compared to settling basin effluent releases (Andersen et al., 2009); however, the sustainability *and life expectancy of these* systems has not been evaluated. Research by Andersen et al. (2009), not included in published material, determined that P application rates were greater than the P uptake by the vegetation. Moreover, Zhang et al. (2009) also reported phosphorus loading rates in excess of what the vegetation could utilize. This could cause phosphorus to build-up in the soil, increasing the possibility of phosphorus leaching from the soil and reduced treatment in the VTS.

Phosphorus sorption isotherms have been used to determine phosphorus sorption capacities of soils (Khang et al., 2009; Kleinman and Sharpley, 2002; Sui and Thompson, 2000; Zhang et al, 2005; Zhang et al., 2009). In this study, these isotherms were used to determine the soil sorption capacity at a known phosphorus concentration. The depth and length of time it takes phosphorus to move through the soil can be calculated once the sorption capacity is known along with soil bulk density, VTA area, cattle capacity, and phosphorus loading rate.



(a) (b)

Figure 1. Diagrams of VTS configurations (a) solid settling basin – vegetative treatment area system (b) solid settling basin – vegetative infiltration basin – vegetative treatment area system

Objective

The objectives of this study were to calculate the length of time needed to saturate the top 0.3 meters of the soil profile with phosphorus for four VTAs in Iowa and develop a method to predict VTA phosphorus life. The calculated lives were then compared to estimated values determined from soil phosphorus accumulation data. Knowing the life expectancy of the system could help producers determine if a VTA could benefit their operation and improve vegetative treatment systems design. This was done by developing phosphorus sorption isotherms, which were used to determine the soil's phosphorus sorption capacity. Effluent flow and concentration monitoring data was then used to calculate phosphorus loading onto the VTA. Based on the collected data, the length of time it took for phosphorus to saturate different depths of the soil profile were calculated. This calculated life was compared to phosphorus accumulation patterns in the VTA's surface soil to verify the methodology.

Methods and Materials

Site Descriptions

Research on four VTAs in Iowa has been conducted by Iowa State University. Table 1 summarizes the number of cattle and VTA areas for each site and Figure 2 shows the approximate locations of each site. For a detailed description of each site, surface runoff concentrations, and monitoring equipment, refer to Andersen et al (2009), Moody et al. (2006), and Khanijo (2008). Soil at the Central IA 1 VTA consisted of Clarion loam, Cylinder loam, and Wadena loam. Northwest IA 1 VTA consisted of Galva silty clay and Radford silt loam. Northwest IA 2 consists of Moody silt clay loam and Southwest IA 2 consists of Kennebec silt loam (Soil Survey Staff, NRCS USDA, 2010). Northwest IA 1 and Northwest IA 2 are both in the 64 centimeter average annual rainfall region and Central IA 1 and Southwest IA 2 are in the 84 centimeter average annual rainfall region. The beef feedlot runoff that was being applied had a yearly average DRP concentration that ranged from 26-46 mg/L between the four sites (Andersen et al., 2009). Since the P application rate was greater than the P uptake by the vegetation, there was a concern about phosphorus concentrations increasing in the soil profile. Surface soil samples were collected throughout the VTA for all sites during the four-year monitoring period every year in late fall using a hand sampler probe at a depth of 0.3 m (1 ft.). The samples were analyzed by the Iowa State University Soil and Plant Analysis Laboratory, Iowa State University, Ames, IA, USA.

Table 1. The number of cattle, VTA size, and VTA area / 100 head for each site

Site ID	Cattle (head)	VTA Size ha (acre)	VTA area / 100 head (ha)	(acre)
Central IA 1	1,000	1.52 (3.75)	0.15	0.38
Northwest IA 1	1,400	1.68 (4.15)	0.12	0.30
Northwest IA 2	4,000	0.89 (2.20)	0.02	0.05
Southwest IA 2	1,200	3.44 (8.50)	0.29	0.71

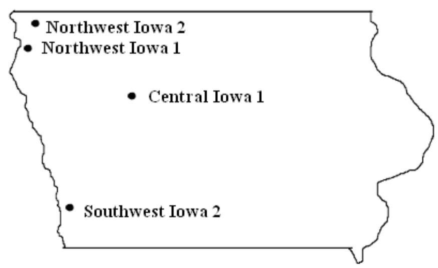


Figure 2. Map showing the locations of the four VTSs monitored for this study.

Isotherm Soil Sample Collection and Analysis

Soil samples were collected in the fall of 2009 for the four VTA sites to develop the phosphorus isotherms. These samples were collected in a grassed area outside of the VTA in a 0.09 m^2 (1 ft^2) area at a depth of 0.3 m (1 ft.). The reason samples were collected outside of the VTAs was to have a non-loaded phosphorus soil that was comparable to the soil of a newly constructed VTA. Using non-loaded phosphorus soil would give a better representation of the soil sorption capacity. The samples were air-dried, crushed, and passed through a 2mm sieve. The Iowa State University Soil and Plant Analysis Laboratory, Iowa State University, Ames, IA, USA analyzed the soil for pH and Melich-3 Al, Ca, Fe, and P. The particle size distribution was determined by the pipette method (Gee and Bauder, 1986) after organic matter was removed by treating the soil with hydrogen peroxide (H_2O_2). Organic matter (OM) was determined by loss on ignition. The soil analysis data is displayed in Table 2.

Table 2. Soil chemical properties and particle distribution for the four phosphorus sorption isotherm soils.

Site ID	Melich-3 Extractable Elements (mg/kg)				pH	OM (%)	Clay Content (%)	Silt (%)
	P	Ca	Al	Fe				
Central IA 1	542	3,966	459	435	7.5	7.6	20	40
Northwest IA 1	323	3,018	753	262	7.0	7.7	31	57
Northwest IA 2	189	3,433	637	263	7.3	7.2	23	47
Southwest IA 2	331	2,952	397	273	6.6	8.8	25	44

Phosphorus Sorption Isotherms

Phosphorus sorption isotherms were developed according to the method of Graetz and Nair (2000). One gram of air-dried soil was placed into each of seven 50 mL vials and mixed with 25 mL of 0.01 M calcium chloride ($CaCl_2$) solution containing phosphorus concentrations of 0, 2, 5, 10, 50, 100, and 200 mg P/L in the form of KH_2PO_4. Three drops of chloroform were added to inhibit microbial growth. The samples were run in duplicates. They were shaken on an orbital shaker for 24 hours at 27±2 °C. They were then allowed to settle for one hour. The supernatants were filtered through a 0.45 μm filter. DRP concentrations were analyzed by an 880nm wavelength spectrophotometer using the ascorbic acid method (AWWA, 1998). This process was carried out three times for each site. Sorption isotherms using the Langmuir method were created by using the sorption isotherm spreadsheet by Carl Bolster (Bolster, 2007).

VTA Life Expectancy Calculations

The VTA life expectancy was defined as the length of time it takes for the top 0.3 m (1 ft) of the soil profile to become completely saturated with phosphorus. This 0.3 m (1 ft) depth was decided on for several reasons. Surface soil samples were collected at a depth of 0.3 m (1 ft) throughout the entire VTA during the four-consecutive year monitoring period. This allowed for an estimation of the time length for the 0.3 m (1 ft) soil profile to become saturated with phosphorus. This depth would also allow the producer to make some adjustments in application practices. Several assumptions were made in order to calculate VTA life:

- One year of precipitation was equal to the average annual precipitation for that region
- Average annual precipitation was evenly distributed among months
- Applied SSB effluent was evenly distributed on the entire VTA area
- The phosphorus moved through the soil in an even front

The VTAs were sized to contain and treat the effluent applied to them. If a VTA was undersized, runoff could occur or soil nutrients would quickly build up potentially causing leaching. Feedlot size, capacity, and rainfall are the main factors to consider when sizing a VTA. Andersen et al. (2009) calculated the phosphorus loading factor for six beef feedlots in Iowa which has units of mg P per 100 head per centimeter of precipitation. This factor was the average amount of phosphorus, in mg, that was applied to the VTA per 100 head per centimeter of precipitation. The phosphorus loading factor was based over a long period of time such as a year and was not applicable for short durations. So for a 100 head feedlot, if the phosphorus loading factor is 6,300 mg P per 100 head per cm and it rains one cm, then 6,300 mg of phosphorus was applied onto the VTA. This example is for a small duration just to give a better illustration of how the phosphorus loading factor is applied. For Northwest IA 2, this factor was from the VIB not the

SSB. This factor was averaged for five earthen feedlots to get a representation of the potential amount of phosphorus being released from SSBs on earthen feedlots throughout Iowa. This value would vary from feedlot to feedlot because feed rations, soil types, and cattle concentrations will change the amount of phosphorus being applied to the VTA. Table 3 shows the phosphorus loading factors for each site and the value that was used to represent the state of Iowa.

Table 3. The phosphorus loading factors for the four sites and for the state of Iowa.

Phosphorus Loading Factors (mg P per 100 head per cm of precipitation)				
Central IA 1	**Northwest IA 1**	**Northwest IA 2**	**Southwest IA 2**	**Iowa**
5,600	8,200	1,300	5,300	6,300

Soil density, area, cattle capacity, sorption capacity, phosphorus concentration, and the amount of phosphorus applied to the VTA were needed to determine the life expectancy. Previous research by Iowa State University found that soil densities ranged from 1,200 to 1,400 kg/m^3 among the four VTAs. The soil density was assumed to be 1,300 kg/m^3 for calculations. To create a more versatile life expectancy graph, the area per 100 head (APH) of cattle was used instead of area and cattle capacity on their own. Equation 1 demonstrates how this ratio was calculated.

$$APH = \frac{VTA\ area}{\frac{Feedlot\ Capacity}{100}} \qquad \text{Equation 1}$$

where APH is the VTA area per 100 head of cattle (m^2 100 head^{-1}), VTA area is the area of the VTA (m^2), and Feedlot Capacity is the number of cattle on the feedlot (head).

Phosphorus concentration for each site was determined by averaging the four-year applied effluent phosphorus concentration data. Using this phosphorus concentration value, the sorption capacity of the soil for each site was predicted using the site's developed phosphorus sorption isotherm. Figure 3 demonstrates how the phosphorus sorption isotherm was used to predict soil sorption capacity. The SSB effluent being applied to the VTA had a phosphorus concentration of 50 mg/L. The soil sorption capacity which in this example is 1,100 mg P/kg soil was determined by intersecting the phosphorus sorption isotherm at the known SSB effluent phosphorus concentration.

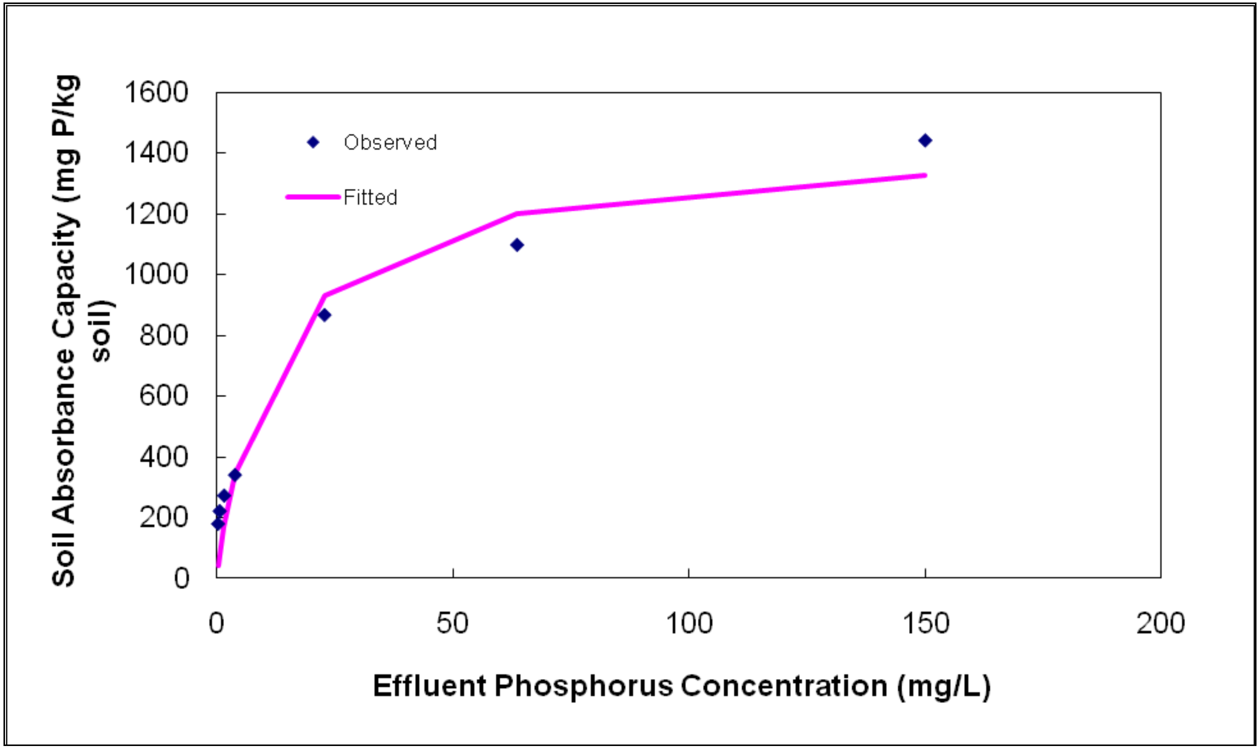


Figure 3. Demonstration of how the phosphorus sorption isotherm is used to predict soil phosphorus sorption.

The amount of phosphorus applied to the VTA was dependent on precipitation due to the phosphorus loading factor so life expectancy was dependent on precipitation as well. For this reason, the total precipitation required to apply enough phosphorus to saturate the VTA was solved. A list of acronyms is provided to better understand the equations:

- $P_{applied}$ (mg P per 100 head) is the amount of phosphorus applied to the VTA
- $P_{vegetation}$ (mg P per 100 head) is the amount of phosphorus removed from the soil by the vegetation
- P_{soil} (mg P per 100 head) is the total amount of phosphorus absorbed by the soil
- $P_{removal}$ (mg P / m^2*year) is the annual amount of phosphorus removed from the VTA by the vegetation per square meter
- Precipitation (cm) is the amount of precipitation it takes to saturate the 0.3 m (1 ft.) soil profile with phosphorus due to the applied SSB effluent
- Annual Precipitation (cm) is the average annual precipitation for that region
- d (m) is the depth the phosphorus will reach in the soil profile, in this case 0.3 meters (one foot)
- $S_{sorption}$ (mg P/kg soil) is the sorption capacity of the soil
- $S_{initial}$ (mg P/kg soil) is the initial amount of absorbed P the soil contained
- ρ_b (kg/m^3) is the soil bulk density
- APH (m^2/100 head) is the VTA area per 100 head of cattle ratio
- PLF (mg P per 100 head per cm of precipitation) is the phosphorus loading factor
- $T_{saturation}$ (years) is the amount of time it takes for phosphorus saturation to occur

Equation 2 is the overall phosphorus mass balance of the VTA assuming no phosphorus leaching. The phosphorus applied to the VTA was absorbed by the soil and removed by vegetation. The vegetation won't remove all of the phosphorus which means the soil would eventually reach the absorption maximum. The 0.3 m (1 ft.) soil depth would now be considered full of phosphorus and won't accept anymore. P_{soil} shown in Equation 3 is the amount of phosphorus the soil can absorb on a mg P per 100 head basis. $P_{vegetation}$ and $P_{applied}$ are calculated in Equation 4 and Equation 5 and are both dependent on precipitation. This precipitation is the amount of precipitation it takes for the 0.3 m (1 ft.) soil profile to become completely saturated with phosphorus. P_{soil} is a known value so Equation 2 is rearranged into Equation 6 so precipitation can be factored out and then eventually solved. Equation 7 shows how precipitation is then solved. Dividing this by the average annual precipitation for that region will determine the length of time it will take for the phosphorus saturation to occur. Equation 8 was used to determine that length of time.

$$P_{applied} = P_{soil} + P_{vegetation} \qquad \text{Equation 2}$$

$$P_{soil} = d * (S_{sorption} - S_{initial}) * \rho_b * APH \qquad \text{Equation 3}$$

$$P_{vegetation} = P_{removal} * APH * \frac{Precipitation}{Annual\ Precipitation} \qquad \text{Equation 4}$$

$$P_{applied} = PLF * Precipitation \qquad \text{Equation 5}$$

$$P_{soil} = P_{applied} - P_{vegetation} \qquad \text{Equation 6}$$

$$Precipitation = \frac{d * (S_{sorption} - S_{initial}) * \rho_b * APH}{PLF - (P_{removal} * APH * \frac{1}{Annual\ Precipitation})} \qquad \text{Equation 7}$$

$$T_{saturation} = \frac{Precipitation}{Annual\ Precipitation} \qquad \text{Equation 8}$$

Phosphorus Accumulation Method

Surface soil samples were collected at each VTA every year for the four year monitoring period. These soil samples were collected throughout the VTA and averaged to get an overall VTA soil phosphorus concentration. The time, in days, since initiation of system operation was plotted against the average Melich-3 soil phosphorus concentration. These values were plotted to determine how long it would take for the soil to reach the equilibrium sorption capacity. Figure 4 displays the plotted surface soil samples with a best fit linear function for Northwest IA 2. The linear function was used to determine the length of time it would take for the 0.3 m (1 ft.) soil profile to become saturated with phosphorus. The saturation soil phosphorus limit was set as the value determined from the phosphorus sorption isotherm experiment. This analysis was carried out for all four sites. The expected life found from the graphs was compared to the calculated values.

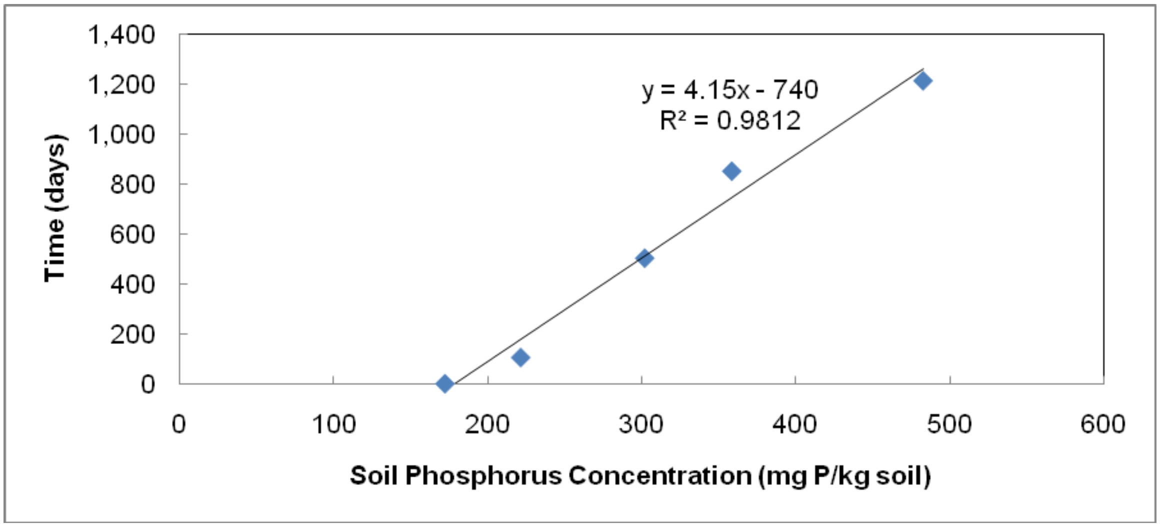


Figure 4. The graphed surface soil samples from Northwest IA 2. The equation was used to find the length of time to saturate the soil profile.

Results and Discussion

Soil Phosphorus Sorption Data Analysis

A correlation analysis was used to determine if a linear relationship between the maximum soil phosphorus sorption (S_{max}) and the Melich-3 Al, Melich-3 Fe, Melich-3 Ca, OM, clay content, and pH existed. Pearson correlation coefficients are shown in Table 4. Calcium and pH were highly positively correlated with S_{max} while organic matter and clay content showed a high negatively correlation. Ige et al. (2005), Zhang et al. (2005), and Zhang et al. (2009) also found a significant relationship between S_{max} and calcium. Calcium is a positively charged ion that can bridge between soil particles and phosphate ions (PO_4), creating more phosphorus binding sites in the soil. Positive and negative ions are electrically attracted to each other so as the SSB effluent infiltrates into the soil, the phosphate ions bond with the calcium. Organic matter and clay were both negatively charged which explains the negative correlation. These two were competing with phosphate for bonding with the calcium ion. Aluminum and iron were both poorly correlated with S_{max}. Usually these two elements are highly correlated; however, Kang et al. (2009) discovered that aluminum and iron were less effective for P sorption in soils with organic matter greater than 4.9 percent. The phosphorus sorption isotherm soils were well over 4.9 percent ranging from 7.2 to 8.8 percent.

Table 4. Pearson's r values produced from correlating S_{max} to different soil properties.

	Al	Fe	Ca	OM	Clay Content	pH
S_{max}	0.13	0.41	0.80	-0.86	-0.63	0.93

The sorption capacities of the soils at their effluent phosphorus concentration are shown in Figure 5. These were determined using the sorption isotherms. The SSB effluent phosphorus concentrations were determined from the four years of monitoring. Central IA 1 had the greatest adsorption capacity followed by Northwest IA 2 at concentrations of 1,110 and 955 mg P/kg soil. Northwest IA 1 and Southwest IA 2 had the lowest sorption capacities at 619 and 446 mg P/kg soil respectively.

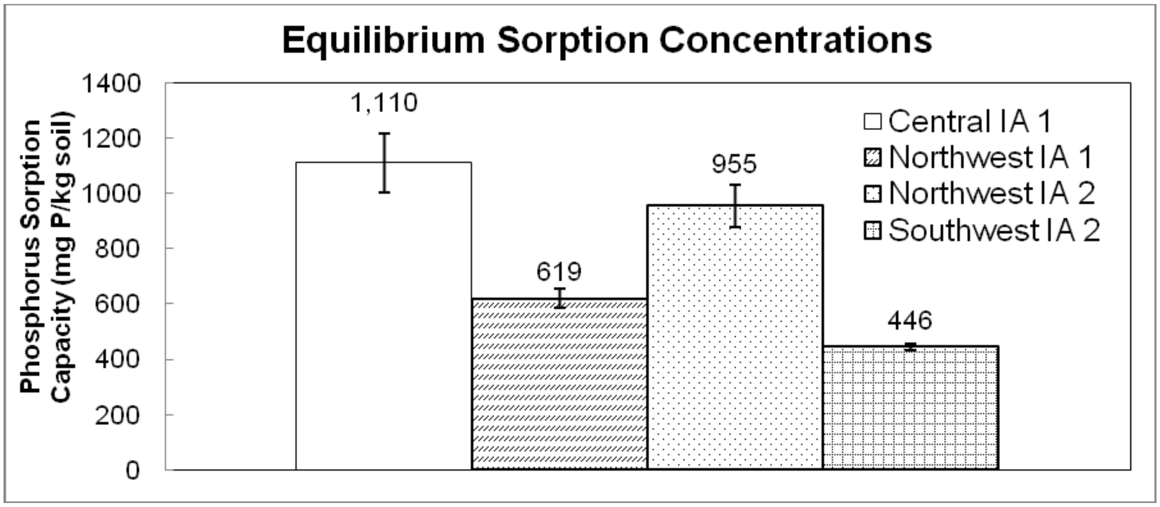


Figure 5. Equilibrium sorption concentrations determined from sorption isotherms shown with one standard deviation.

Factors influencing VTA Life

A VTA with the greatest VTA area per 100 head would be expected to have the longest life expectancy. However, this was not always the case. There were many factors that affected life expectancy: sorption capacity, phosphorus removal due to vegetation, VTA area, and cattle capacity. Sorption capacity of the soil and the amount of phosphorus being loaded onto the VTA has the greatest affect. A VTA with a high sorption capacity would be able to absorb more phosphorus thus increasing life expectancy. Figure 6 demonstrates the effect of sorption capacities with all other values holding constant.

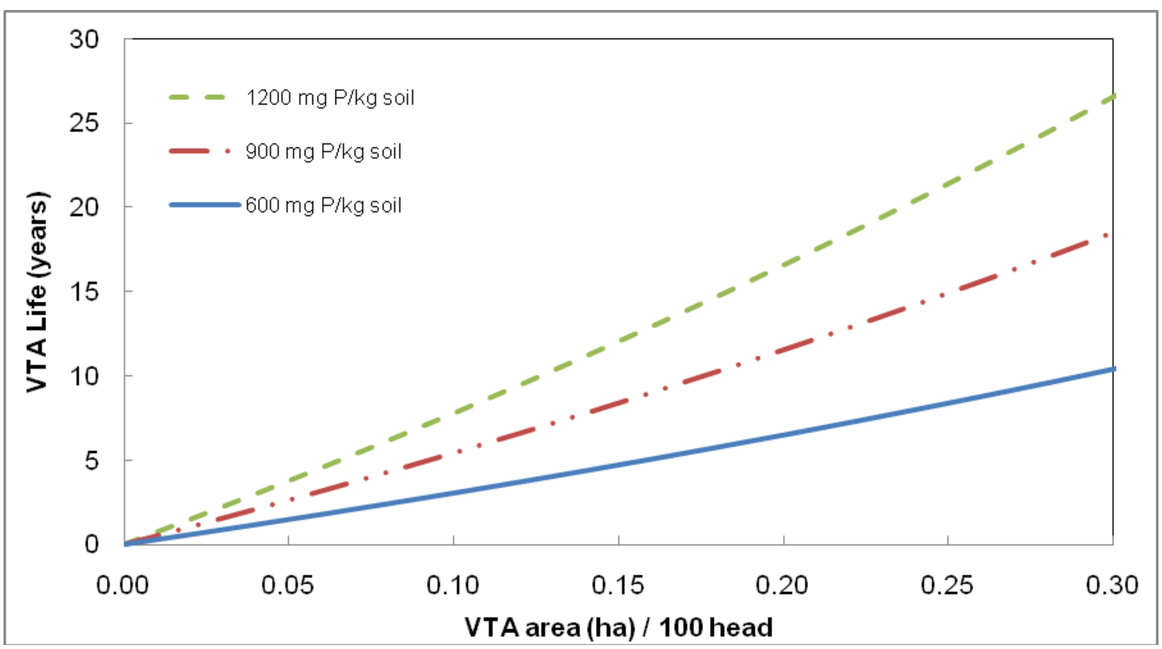


Figure 6. Effect that sorption capacity has on VTA life.

An increase in phosphorus loading meant that there was more phosphorus that needed to be sorbed by the soil. This caused phosphorus to accumulate more quickly in the soil profile, shortening VTA life. The phosphorus loading factor varied throughout the four Iowa sites, possibly due to differing cattle concentration, feed rations, feedlot layout, settling basin performance, climatic conditions, and feedlot sizes.

Vegetation removal had an affect but was largely dependent on VTA area. A VTA with a larger area would allow vegetation to remove more phosphorus from the soil than a VTA with a smaller area for the same feedlot assuming the phosphorus loading was the same. There was overall more vegetation on a larger area than a smaller area. The phosphorus ass assumed to be evenly distributed across the VTA. This meant that there was a smaller amount of phosphorus per square area on a larger VTA than on a smaller VTA. Figure 7 demonstrates how vegetation removal had little significance at smaller VTA sizes. Figure 7 also shows that with an increase in VTA size, vegetation removal starts to affect how much phosphorus a VTA could absorb over a lifetime. Two vegetation removal rates were varied with two sorption capacities in these two figures. The slopes of the lines change with vegetation uptake which meant that with an increase in vegetation uptake there was an increase in VTA life. The slopes of the lines in Figure 7 for 30 and 60 kg P/ha removal were 0.0047 and 0.0049 respectively for the 0.06 VTA area (ha) per 100 head. This demonstrated that with vegetation uptake there was a small shift in VTA life. The slopes of the lines in Figure 7 for 30 and 60 kg P/ha removal were 0.0098 and 0.0105, respectively for the 0.12 VTA area (ha) per 100 head. This showed that there was a greater shift between slopes compared to the 0.06 VTA area (ha) per 100 head. This allowed for more phosphorus to be removed from the soil causing the VTA life to increase.

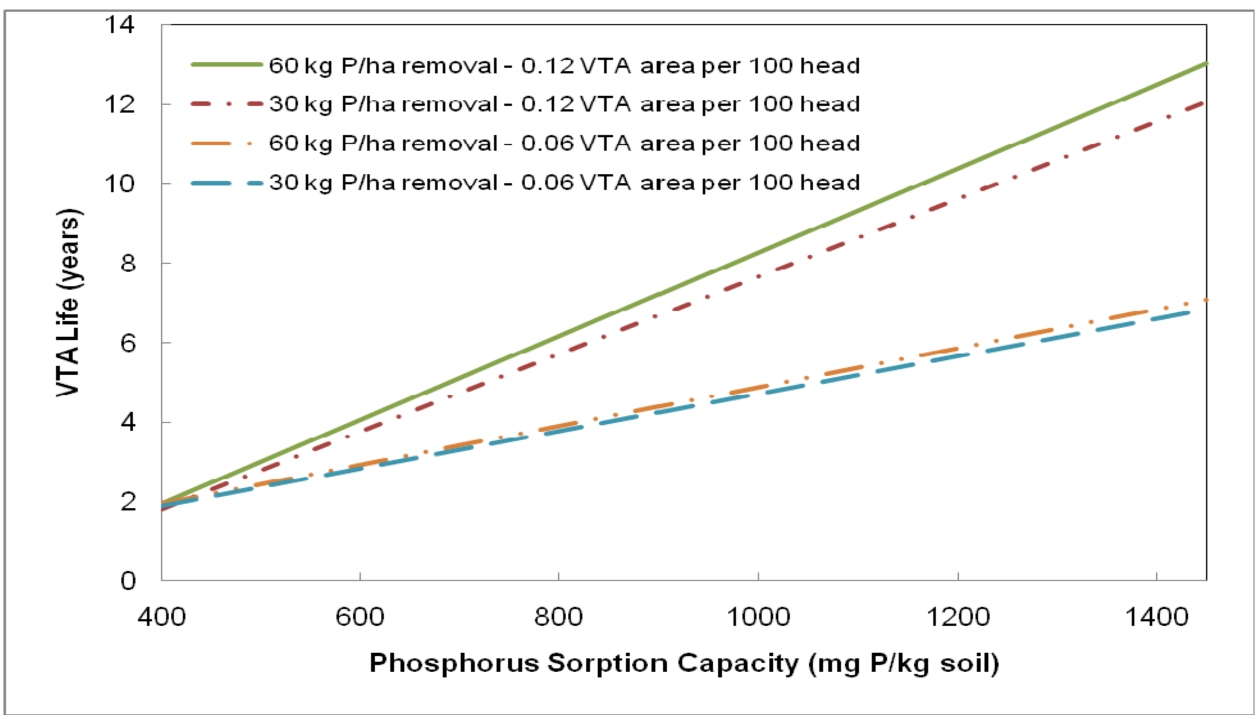


Figure 7. Displays vegetation effect on different size VTAs.

VTA Life Expectancy for the four Iowa Sites

The four Iowa VTAs life expectancies varied significantly. There were many reasons why this occurred and are discussed in detail below. The calculated values were compared to the projected life based on phosphorus accumulation in the soil. The calculated life expectancies are compared in Figure 8.

Central IA 1 had a calculated life expectancy of 13 years before phosphorus saturates the 0.3 m (1 ft.) soil profile. This was the longest length of time for the four VTAs. This was due to the high sorption capacity of the soil along with a lower average loading of phosphorus on the VTA. Vegetation was also being harvested once a year. This removed 30 kg ha^{-1} of P from the VTA which means the VTA soil was able to absorb more phosphorus. The estimated time from the phosphorus accumulation graph was a life expectancy of 11 years. This was a shorter time period than the 13 years calculated. This shorter life expectancy was possibly due to the site receiving double its average annual rainfall in 2007. This caused about double the phosphorus application than the previous year.

Northwest IA 2 had the second longest life with a life expectancy of 8.5 years. This was also due to the high sorption capacity of the soil. The amount of phosphorus loaded onto the VTA was very small compared to the other sites. The small amount of phosphorus loading was attributed to the VIB. Effluent was released from the SSB and allowed to infiltrate through the soil in the VIB reducing the amount of phosphorus applied to the VTA. Northwest IA 2 had the lowest VTA area per 100 head than any of the other sites. Vegetation removal, 30 kg ha^{-1}, had little effect on extending VTA life due to the low VTA area per 100 head. The reason it was able to have a longer life than expected was due to the high soil sorption capacity and low phosphorus application rate. The estimated life from the phosphorus accumulation graph was 9 years. This was half a year more than the calculated life expectancy. This implied that the calculated value was a good prediction of how long it would take the phosphorus to saturate the 0.3 meter (1 ft.) soil profile.

Southwest IA 2 had an expected life of 7.5 years. This was not expected because it has the largest VTA area per 100 head. However, the reason it did not have the highest expected life was from the low phosphorus sorption capacity of the soil. This low sorption was attributed to the low amount of calcium in the soil. Calcium ions bond with phosphate ions so if there was less calcium, there was a lesser amount of phosphorus in the 0.3 (1 ft.) soil profile. Vegetation was harvested once a year but had little effect on life expectancy. The estimated life from the phosphorus accumulation graph was not conducted for this site because the area that was used for the VTA previously collected the wastewater directly from the feedlot, which appeared to affect the soil's ability to sorb phosphorus.

Northwest IA 1 had the lowest life expectancy at 4.5 years. The phosphorus loading was higher than the other sites and the soil had a low sorption capacity. The low sorption capacity may have been due to the low amount of calcium in the soil. Even though vegetation was harvested twice a year, it had little effect on the life expectancy due to the high loading rate. The estimated life expectancy from the phosphorus accumulation graph was 4 years. The calculated and estimated life expectancies were very close in comparison.

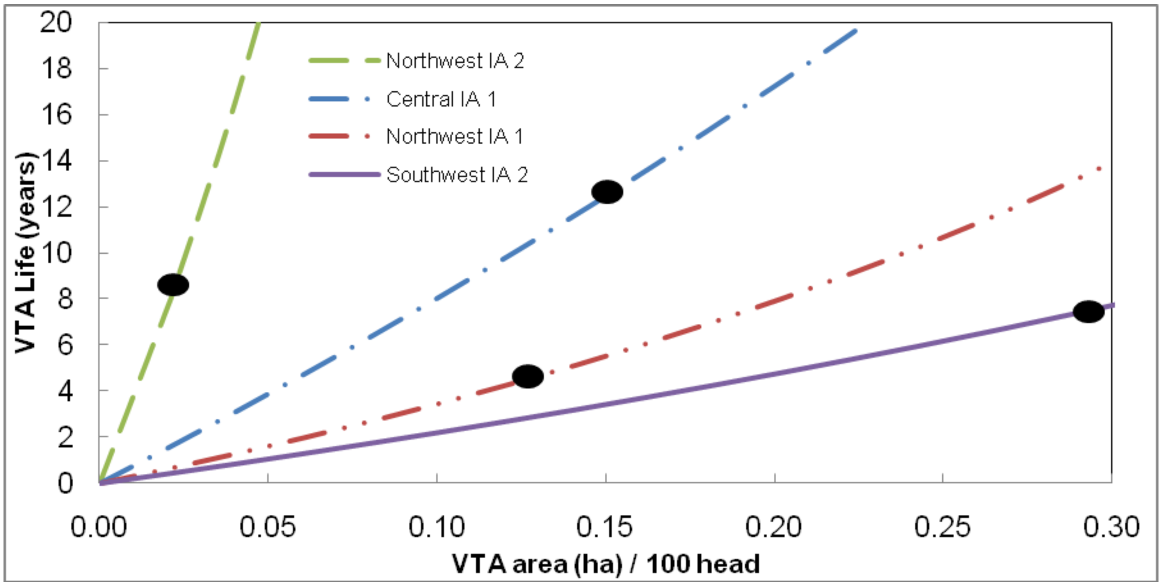


Figure 8. A comparison of VTA life expectancies for the four Iowa sites. The black circles represent where the VTA area (ha) / 100 head cross with the site's life expectancy function to find VTA life.

Each site had a different slope for their VTA life expectancy function. This demonstrates how each site was unique due to the different factors having an effect on VTA life. This shows that trying to use a graph to size VTAs in Iowa may not necessarily work if phosphorus saturation life is to be considered.

Iowa VTA Life Expectancy

Life expectancy in Iowa could vary by multiple years depending on the precipitation, sorption capacity, phosphorus loading, and phosphorus removal due to vegetation. A maximum and minimum sorption capacity was used to determine the life expectancy range for the state of Iowa. The maximum sorption capacity was 1,200 mg P/kg soil and the minimum was 400 mg P/kg soil. These values were determined by comparing the sorption capacities of the four Iowa VTAs. There could be soils with higher sorption capacities or lower sorption capacities than the determined maximum and minimum in Iowa, but these values were set as the references to get a general idea of VTA life expectancy in Iowa. The phosphorus loading factor that was used to represent Iowa was determined to be 6,300 mg P per 100 head per centimeter of precipitation. The maximum life was calculated using a vegetation removal of 60 kg P/ha at 64 cm of precipitation. The minimum life was calculated using a vegetation removal of 30 kg P/ha at 102 cm of precipitation. These life expectancies were graphed in Figure 9 to show the potential range of VTA life throughout Iowa. This life would obviously vary from the multiple factors listed; however, this graph could give a good idea of how VTA size could affect VTA life.

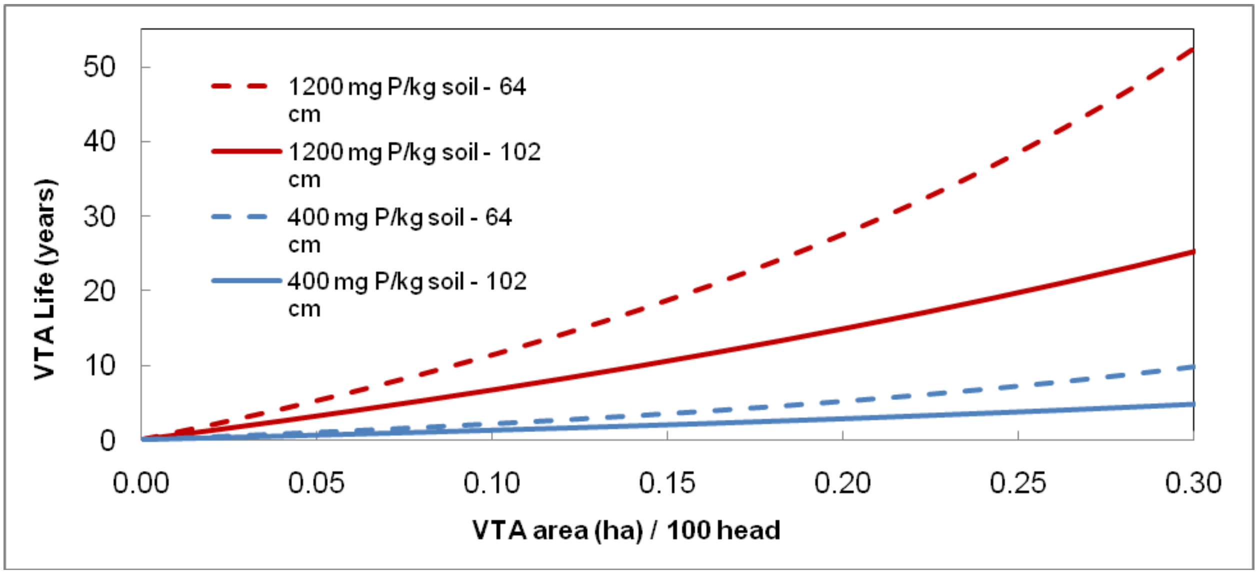


Figure9. The potential life expectancy range for VTAs in Iowa using a maximum and minimum phosphorus sorption capacity of 400 and 1200 mg P/kg soil and varying the vegetation uptake and average annual rainfall.

Conclusion

The four monitored VTAs in Iowa have a calculated life expectancy that ranged from 4.5 to 13 years. The estimated life expectancies from the phosphorus accumulation graph were close in comparison to the calculated life expectancy values. This implied that the VTA life expectancy calculations were a good estimate of how long it would take for the phosphorus to saturate the 0.3 m (1 ft.) soil profile. The two main factors that influenced VTA life were soil phosphorus sorption capacity and the amount of phosphorus applied. The two VTAs with the highest sorption capacity had the longest life expectancies. A higher sorption capacity allowed for the soil to absorb more phosphorus from the feedlot runoff. More phosphorus being applied meant that more soil was needed to absorb this phosphorus. The sorption capacity of the soil doesn't change and if it does won't change much so this means that the phosphorus saturation front will move further down the soil profile causing the 0.3 m (1 ft.) distance to become saturated quicker. A way to remove phosphorus from the VTA was by vegetation harvest. However, it has been determined that vegetation removal was less effective for smaller VTAs compared to larger VTAs. A larger VTA with vegetation removal can lengthen the time it takes for phosphorus saturation of the soil profile to occur. A method for sizing VTAs is by using the graph for VTA life expectancies in Iowa. The graph can show the life expectancy of a certain VTA area (ha) per 100 head. This could allow producers to size their VTAs to get the longest life so that they don't have to face a situation where their VTA is leaching phosphorus into water systems

References

Andersen, D., R. Burns, L. Moody, I. Khanijo, M. Helmers, C. Pederson, and J. Lawrence. 2009. Performance of Six Vegetative Treatment Systems for Controlling Runoff from Open Beef Feedlots in Iowa. ASABE Paper No. 097054. St. Joseph, Mich.: ASABE

Anschutz, J. A., J. K. Koelliker, J. J. Zovne, T. A. Bean, and M. J. Peterson. 1979. Sizing components on open feedlot runoff-control systems. *Trans. ASAE* 22(4): 803-808.

APHA – AWWA – WPCF. 1998. Standard Methods for the examination of water and wastewater. Washington, D.C.: American Public Health Association

Bolster, C.H. and G.M. Hornberger. 2007. On the use of linearized Langmuir equations. Soil. Sci. Soc. Am. J. 71:1796-1806

Bond, B, R.T. Burns, T.P. Trooien, S.H. Pohl, C. Henry, L.B. Moody, M.J. Helmers, and J. Lawrence. 2009. Comparison of Construction Costs for Vegetated Treatment Systems in the Midwest. ASABE Paper No. 096524. St. Joseph, Mich.: ASABE

Gee, G.W. and J.W. Bauder. 1986. Particle-size analysis. P. 383-411. In A. Klute (ed.) Methods of soil analysis. Part 1. 2nd ed. Agron. Monogr. 0. ASA and SSSA, Madison, WI.

Graetz, D.A. and V.D. Nair. 2000. Phosphorus sorption isotherm determination. P. 35-38. In G.M. Pierzynski (ed.) Methods of phosphorus analysis for soils, sediments, residuals, and waters. Bull No. 369. Southern Extension/Research Activity-Information Exchange Group (SERA-IEG-17), Kansas State University, Manhattan, KS

Ige, D.V., O.O. Akinremi, and D.N. Flaten. 2007. Direct and Indirect Effects of Soil Properties on Phosphorus Retention Capacity. Soil Sci. Soc. Am. J. 71:95-100

Kang, J., H. Dean, and D.L. Osmond. 2009. Soil Organic Matter Effects on Phosphorus Sorption: A Path Analysis. Soil Sci. Soc. Am. J. 73:360-366

Kleinman, P.J.A., and A.N. Sharpley. 2002. Estimating Soil Phosphorus Sorption Saturation From Mehlich-3 Data. Commun. Soil Sci. Plant Anal. 33(11&12): 1825-1839

Khanijo, Ishadeep. 2008. Monitoring vegetative treatment system performance for open beef feedlot runoff control. MS thesis. Ames, Iowa: Iowa State University, Agricultural and Biosystems Engineering Department.

Moody, L.B., C. Peterson, R.T. Burns, I. Khanijo. 2006. Vegetative treatment systems for open feedlot runoff: project design and monitoring methods for five commercial beef feedlots. ASABE Paper No. 064145. St. Joseph, Mich.: ASABE

NRCS. 2010. National cooperative soil survey: web soil survey 2.0. Washington, DC: Natural Resource Conservation Service. http://websoilsurvey.nrcs.usda.gov/app/HomePage.htm accessed on 3/9/2010

Sui, Y. and M.L. Thompson. 2000. Phosphorus Sorption, Desorption, and Buffering Capacity in a Biosolids-Amended Mollisol. Soil Sci. Soc. Am. J. 64:164-169

US EPA. 2008. Federal Register. Vol. 73, No. 225. Washington, D.C.

Woodbury B.L., J.A. Nienaber, R.A. Eigenberg. 2005. Effectiveness of a passive feedlot runoff control system using a vegetative treatment area for nitrogen control. Applied Engineering in Agriculture 21(4):581-588

Zhang, H., J.L. Schroder, J.K. Fuhrman, N.T. Basta, D.E. Storm, and M.E. Payton. 2005. Path and Multiple Regression Analyses of Phosphorus Sorption Capacity. Soil Sci. Soc. Am. J. 69:96-106

Zhang, W., J.W. Faulkner, L.D. Geohring, and T.S. Steenhuis. 2009. Phosphorus Sorption and Desorption Properties of Surface and Subsurface Horizons at Three Vegetative Treatment Areas in New York. ASABE Paper No. 097002. St. Joseph, Mich.: ASABE