A FRAMEWORK FOR ASSESSING VIABILITY OF ADOPTION OF CONSERVATION PRACTICE FOR REDUCING NITRATE-N

BY

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THESIS

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ABSTRACT

In recent years, lots of conservation practices have been developed to solve the ever-increasing problem of non-point source pollution. The impact of some practices on the environment, however, is not fully understood, and non-point source pollution continues to be a substantial source of contamination to our waterbodies. Most of the conservation practices are experimentally proven to be effective for reducing non-point source pollution. The lag in environmental improvement is likely due to a low adoption rate from users of these conservation practices. This study investigated some of the most widely used conservation practices and evaluated the potential for combinations of different conservation practices to improve overall performances and address stakeholder needs. Factors that affect adoption of conservation practices such as cost, time, maintenance, education, social networks, and aesthetics are studied and summarized into a set of criteria to evaluate different combination configurations. This study shows that practices with higher Nitrate-N removal tend to be the less desirable to users. These practices tend to be less desirable due to high construction and maintenance efforts and long learning processes, and hence, less adoption potential, which makes state-of-art engineering practices difficult to advance beyond the experimental phase. A compromise between the performance of non-point source pollution control practices and stakeholder interest must be made for all conservation efforts. Without proper acceptance rates, conservation practices are not given a chance to show their potential in improving environmental impacts. On the other hand, without satisfactory performance, it is unlikely that users will continue applying the practice in the long run. Thus, the best conservation practice is the practice more likely to be accepted by landowners while producing the satisfactory performance.

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CHAPTER 1

INTRODUCTION

With the world population estimated to reach 9.6 billion by 2050 (United Nations, 2013), current agricultural land use and natural crop yields will be unable to feed such a vast and still-growing population. Although many alternatives such as soil-less farming, vertical farming, etc., have been developed and applied, these cannot entirely replace traditional cultivation methods, and most of our crops will continue to come from outdoor, soil-based agriculture (Massachusetts Institute of Technology, 2015).

To ensure food security, fertilizers are needed to achieve sufficient yields to feed the population. However, fertilizers are susceptible to loss from leaching and runoff. This has contributed to the problem of non-point source (NPS) pollution. Due to the large scale of agricultural practices, the effect of NPS pollution can be tremendous. There is a large and still expanding hypoxia zone in the Gulf of Mexico, primarily caused by fertilizer runoff from agricultural lands of the Midwest, via the Mississippi River. Excessive Nitrate-N in drinking water can cause Methemoglobinemia in babies, also known as Blue Baby Syndrome, a symptom that leads to complicated health issues and even deaths in some extreme cases.

Ironically, despite the adverse impact of NPS pollution, success of the efforts towards its remediation have been limited thus far. The Clean Water Act (CWA) by the Environmental Protection Agency (EPA) does not regulate NPS pollution at the federal level and excludes NPS pollution from its National Pollutant Discharge Elimination System (NPDES) permit (Angelo, 2013). Over the past decades, treatment of industrial and domestic wastewater achieved great success, with pollutants in effluent wastewater was consistently under the regulated limit because of the implementation of NPDES permitting. Agricultural wastewater, on the other hand, is exempt from this type of permitting. The lack of progress in NPS pollution control can be attributed to its intrinsic untraceable nature, making it difficult to monitor and regulate.

Landowners do play a big part in the collective efforts to reduce NPS pollution. Extensive research has been done on numerous conservation practices to evaluate their ability to reduce agricultural pollution. However, without the general adoption of these practices, the current water pollution situation will continue, and this will discourage stakeholders and researchers from further considerations to address the problem, taking NPS pollution treatment into a vicious circle. Currently, landowners' adoption of conservation practices is somewhat limited. Numerous surveys and outreach activities have been conducted to attempt to identify the reason, and in contradiction to the general hypothesis, the financial factor may be just one of the major limitations that affects landowners' decisions (Carlisle, 2016; Christianson et al., 2013b; Prokopy et al., 2014).

Every single conservation practice has its advantages and disadvantages. It would be a lengthy and ineffective way to promote each practice separately because the capacity of nutrient reduction is limited and landowners would have to spend extra time to understand and decide if they should adopt the practice. On the other hand, promoting multiple conservation practices in a single session can be intimidating. It would be a good idea to merge different conservation practices into a single combination. The purpose of this study is to discover the relation between Nitrate-N removal performance and users' adoption potential by finding a good way to combine several conservation practices to produces better Nitrate-N reduction capacity than a single practice alone, brings an easy-to-understand information package, and possibly reduces costs or/and increases earnings for landowners. The result will contribute to a wider adoption of conservation practices from landowners.

This study targets specifically on the reduction of Nitrate-N in agricultural runoff. This is one of the dominant compounds being discharged from agricultural fields. While phosphate is an equally significant pollutant, due to its chemical and biological attributes. Relatively few conservation practices target phosphate and consistent elimination is hard to achieve, making it beyond the scope of this study.

CHAPTER 2

OBJECTIVES

The main objective of this study is to investigate relations between Nitrate-N removing potential and landowners' adoption potential of conservation practices by finding an effective way to combine several conservation practices into one package. Effective combinations are built by following these specific tasks:

1. Combine advantages of several conservation practices while minimizing their disadvantages, generating better results in Nitrate-N reduction from NPS pollution.
2. Investigate possibilities of combining several practices into one complete system to be delivered to farmers, and avoid information overflow while considering all factors needed to improve the environment, reduce the time and space from landowners while requiring low capital investment or generating additional income to the user, making the adaptation easier.

CHAPTER 3

LITERATURE REVIEW

To recommend effective combinations of conservation practices to curb NPS pollution, the first thing to do is to evaluate the effective available conservation practices and analyze their features. Successful practices from areas outside of agriculture such as industrial and domestic wastewater treatment could also provide valuable perspectives for innovative construction of the combination. Landowners' needs and concerns are also an important part of this study so literature covering this topic would be helpful.

Most conservation practices are relatively new, with limited research and data available. To ensure the estimation reflects conservation practices’ true Nitrate-N reduction capabilities, only relatively well-developed practices are discussed here.

3.1 Practices that Require Minimal Cost and Effort, Even Cost Savings

Some conservation practices are simple and easy to implement. They require minimal extra work done or may only require switching to an alternative product. Very often, these practices are widely accepted and recommended by the government.

3.1.1 Nitrogen Management

Nitrogen management can be simplified as “applying the right source of nitrogen fertilizer at the right rate, right time, and right place”(Christianson et al., 2016).

The right source means the correct type of fertilizer corresponding to climate conditions, soil types, crop needs and many other aspects (Mikkelsen et al., 2009). Examples of available nitrogen sources include anhydrous ammonia, urea, urea ammonium nitrate (UAN) solution, natural animal manures, etc. Each of these sources has advantages and disadvantages and should be carefully considered before application. Anhydrous ammonia is a popular source of nitrogen because it contains the highest N content among all nitrogen fertilizers and is widely available. It is also good for preventing leaching (Bauder et al., 2013). However, it is also a dangerous part of agricultural practices. Due to its low boiling point, it must be stored under pressure to keep in liquid form. The high pressure and active chemical property make anhydrous ammonia a fertilizer that requires specialized education and training for the application. Urea is another common nitrogen source readily available with high N content. It undergoes hydrolysis to convert to ammonia but is susceptible to volatile loss. For acidic soils, this loss becomes dominant and inhibitor additives should be considered to reduce such loss. Urea ammonium nitrate (UAN), a solution of urea and ammonium nitrate in water, is a popular nitrogen source due to ease of handling and high compatibility with herbicides. It is, however, difficult to apply with other soil nutrients. Natural animal manures are the first fertilizer before the advent of chemical fertilizers. Widely considered clean and natural nowadays due to its sustainable feature and benefit in improving soil structure, manures release very slow and could contain unknown nutrients and may disturb the overall nutrient management.

The right rate means apply the correct amount of fertilizers. There used to be a misconception among farmers that more fertilizer the better is not the case. Quite the opposite, too many fertilizers could disturb the osmotic balance within the soil and dehydrate plants, resulting in burn or death of plants. The right rate is the most important contributor to the reduction of nutrient in agricultural wastewater. Applying just enough nutrient to supply plant growth will not affect crop yield. However, the right rate is not easy to determine without professional help in accurately predict rainfall.

The right time means applying fertilizers when the plant needs it. A simplified explanation to choose between conventional fall application and suggested spring application of fertilizer. Both times have its advantage, and the main concern is the weather during winter. Fall application has the advantage of more time for nutrient mineralization, however, chances of more nutrient loss if high precipitation occurs in winter. Spring application shortens the time between fertilizer application and seeding, reduces the chance of nutrient loss, but shorter time also means nutrients might not fully settle.

The right place means applying fertilizer at the correct depth according to nature of the crop. Applying it too shallow will lead to possible runoff loss; if applied too deep, the plant root will have a hard time reaching the fertile zone and thus less uptake will occur, increasing leaching loss. Applying fertilizers at the band where plant root grows will ensure best plant uptake and minimize fertilizer loss to drainage.

Ammonia undergoes the natural process of nitrification and eventually turns into nitrate. Proper nitrogen management reduces the load of ammonia, and subsequently less nitrate dissolves in leaching water. It should be noted though, while properly adopted by many, nitrogen management has limited benefit to water quality (Lawlor et al., 2008), reducing only about 6% Nitrate-N in the effluent, likely due to increasing soil nutrient requirement to feed the growing population.

With help from outreach attempts, nitrogen management becomes as simple as a change in habit, while potentially decreasing fertilizer use and saving money. If a field was previously over-fertilized to the extent that plants were harmed, nitrogen management could even increase plant yield. However, nitrogen management will very likely reduce the amount of fertilizers used by landowners, and this negatively impacts the income of fertilizer manufacturers and dealers, and a potential conflict of interest exists here.

3.1.2 Conservation Tillage

Tillage is necessary for agricultural production as it loosens the ground and allows air to get in, which is crucial for plant growth. It also provides space for ease of fertilizing, planting and weed/pest removing. However, while providing the essential environment for agricultural practices, conventional tillage greatly disturbs soil surface and exposes the surface soil, which is the layer of soil that allows the growing of plants, to high risk of erosion (Schonbeck et al., 2017). In the event of heavy precipitation, the intensively tilled soil is very likely to be carried away by water, resulting in loss of fertility of agricultural land. Excessive nutrients and sediments will eventually get into the waterbody and result in NPS pollution.

Starting in the 1980s, more people started realizing this problem and practices of conservation tillage was developed (Gebhardt et al., 1985). In general, if more than 30% soil surface is covered by residue after planting the next crop, the tillage practice can be identified as conservation tillage. Common practices in conservation tillage include no-till, ridge-till, and mulch-till.

No-till, as its name suggests, is to plant crops directly into the residue that was not tilled at all. With planting applied in a narrow seedbed created by disk openers, in-row chisels or roto-tillers, the ground is almost undisturbed in its entirety, reducing erosion by more than 90%

(Janssen and Hill, 1994). With no tillage at all, soil moisture is conserved. Time, money and labor that must be invested in tillage process are saved as well. The no-till method does bring problems in weed control and subsurface drainage.

Ridge-till involves preparation of ridges by sweeps, row cleaners, or disc openers. The rebuilding of ridges takes place during cultivation, and other than nutrient injection, the soil is undisturbed. Slightly more disturbance than no-till practice, ridge-till solves the problem of poor drainage condition. However, the artificial ridge provides ground for ridge erosion to occur. This can be offset by planning ridges according to the contour lines, which means it is best suited for flat grounds, such as Illinois.

Mulch-till disturbs soil surface more than no-till and ridge-till. It is done by non-inversion tillage operations such as chiseling, disking and sweeping, so compared to conventional tillage, disturbance to soil surface is limited. Mulch-till uniformly mixes soil and residue and requires some effort in planning the sequence, timing, and direction of tillage. While not as effective in controlling erosion, mulch till adds organic matter (residue) to soil structure and improves soil health. One step closer to conventional tillage, mulch tillage suits the needs of most lands.

3.1.3 Controlled-Release Fertilizer

Most N-fertilizers are in the form of ammonia or nitrate, which are chemically active in soil and readily soluble. While this is good for plant uptake, it makes them susceptible to loss through leaching during the settling period.

Controlled-Release Fertilizers (CRFs) address this issue by adding inhibitors that reduce the activity of nitrogen compounds to the fertilizer or adding a non-active coating to fertilizer particles (Liu et al., 2014). This way, N-fertilizers can be released to the soil at a controlled rate, reducing the amount of fertilizers lost before plant uptake, but providing just-in-time nutrition for plants at their growing stage. Thus, CRFs must meet the following requirements: (1) less than 15% released in 24 hours; (2) less than 75% released in 28 days; (3) more than 75% released within stated time (40-360 days) (Trenkel, 1997).

Some of the popular Controlled-release fertilizers (CRFs) on the market include Urea Formaldehyde (UF), Methylene Urea (MU), Isobutylidene Diurea (IBDU), Sulfur-coated Urea (SCU), and Polymer-coated Urea (PCU). UF is a very popular CRF worldwide. It combines urea and formaldehyde chemically and has no coating, at least 60% nitrogen cold-water-insoluble (CWIN), with releasing period lasts from months to a year. It is not good for turf or cold climate. MU is another popular choice for CRF. It combines urea and methylene chemically and has no coating, between 25% - 60% N CWIN, with releasing period up to 4 months. It is good for turf or climate that is not warm enough to break down coating. IBDU is the chemically combined urea and isobutyraldehyde and has no coating, 90% N CWIN, with releasing period up to 4 months. IBDU is the most consistent CRF, giving a very predictable performance, and good for winter fertilization. SCU is urea particles covered with a layer of sulfur, releasing in 9 to 12 weeks. It is good for calcareous soil in Southwest. PCU is urea particles covered with a layer of semi-permeable polymer membrane, releasing in 2-6 months. It is good for turf. PCU is expensive but produces a consistent and predictable performance (Sartain, 2017).

Use of CRFs can eliminate the possibility of fertilizer burn due to reduced chemical activity. The controlled release could translate to controlled leaching, thus reducing the total amount of fertilizer required for given crop and lower the amount of nitrogen compound entering the waterbody. Currently, production of CRF is rather expensive, offsetting the financial advantage by reducing the amount of fertilizer (Madhavi et al., 2016). CRFs are not used much in the Midwest due to various limitations. Technological advancement and possible government subsidy may turn CRFs into an economical choice for landowners.

3.1.4 Bio-Organic Fertilizer

A relatively new form of fertilizer called bio-organic fertilizer is being produced at an incredible pace in Asia. Due to overpopulation and the long history of outdated agricultural practices, many Asian countries are facing problems like high acidity, high salinity, heavy metal pollution, soil sealing, loss of organic matter, resulted from overuse of chemical fertilizers. Bio-Organic Fertilizers (BOFs) could serve as a solution to all the problems Asian countries are facing (Masso et al., 2015), as BOFs uses microbes and organic nutrient source instead of chemicals to fertilize and treat soil, making it a controlled alternative to natural organic fertilizers such as manure. BOFs are made by mixing specifically bred microorganisms and organic nutrients to achieve specific outcomes in treating soil, such as fertility restoration, soil texture restoration, heavy metal inactivation, etc.

Compared to chemical fertilizers, BOFs can provide a wider range of nutrients in slow-release manner, which inherit advantages from CRFs. On the other hand, microorganisms in BOFs serve as an eco-friendly solution to pests, thus reducing the use of pesticides, which is also a major pollutant in agricultural wastewater. Due to bio-diversity, there is unlimited potential in which selectively bred microorganisms can achieve. For example, the LMGold, a major BOF manufacturer in China, is working to breed microorganism species that inactivate heavy metals, the most problematic pollutants in China. While not confirmed by controlled research, experiences show that some BOFs can improve certain traits, such as size, shape, softness, and sweetness of plants, which could be an advantage of BOFs over chemical fertilizers that do not affect (sometimes even detrimentally affect) plant quality. The BOFs are overall more versatile and environmental-friendly option over chemical fertilizers (Carvajal-Muñoz and Carmona-Garcia, 2012).

Compare to manures, BOFs are better sorted and treated before application. This eliminates the possibility of harmful microorganisms in manures ruining crops. Unprocessed manures could undergo fermentation process after application in the anaerobic environment, which releases a large amount of heat, potentially kills seedlings. The BOF manufacturing process also eliminates most of the unpleasant odor of organic materials, while manure and even chemical fertilizers often come with an unpleasant smell (Huang et al., 2015).

There are disadvantages associated with BOFs. Living microorganisms is an essential part of BOFs, which means they could mutate during storage or after application, compromising BOFs' claimed effect to the soil. Also, extreme heat and cold could kill microorganisms, which limit general adoption of BOFs. The Corn Belt faces harsh winter, and most people in the area are not familiar with BOFs. However, with genetic modification technology, microorganisms that treat soil and stand harsh weather is not too far away(Ritika and Utpal, 2014). Currently, the Chinese government puts great emphasis on BOFs, claiming to have zero growth in chemical fertilizers by 2020, and eventually reduce the use of chemical fertilizers in China (Liu, 2017). BOFs may very likely be the choice of future.

3.2 Practices that Limit Water within the Field

3.2.1 Drainage Water Management

In the Midwest, where extensive tile drain systems are in place, drainage water management is a practical conservation practice that aids agricultural production. By adding a control structure right before the main outlet of tile drain system, farmers can manually control the water table underneath their land to fit production needs. Drainage water management can be divided into three steps based on the timing of growing season: non-growing season, before growing season, and during the growing season.

In non-growing season, the outlet position is raised to raise the water table, so nutrients are "locked" within the soil, reducing nutrient loss. Higher water table also means less air available, which could potentially reduce weed growth, saving weed removal efforts in spring.

Before growing season, when heavy equipment needs to come in and till, fertilize and cultivate farmland, the outlet position is lowered to lower the water table and improve trafficability of field.

The outlet position is raised again before planting to preserve water and nutrients. Then the outlet position is adjusted according to crop and precipitation after planting season so that water table is at the right position for plants to uptake water and nutrients while leaving enough room for air and letting plants breath. Fig. 1 shows a schematic diagram of these practices.

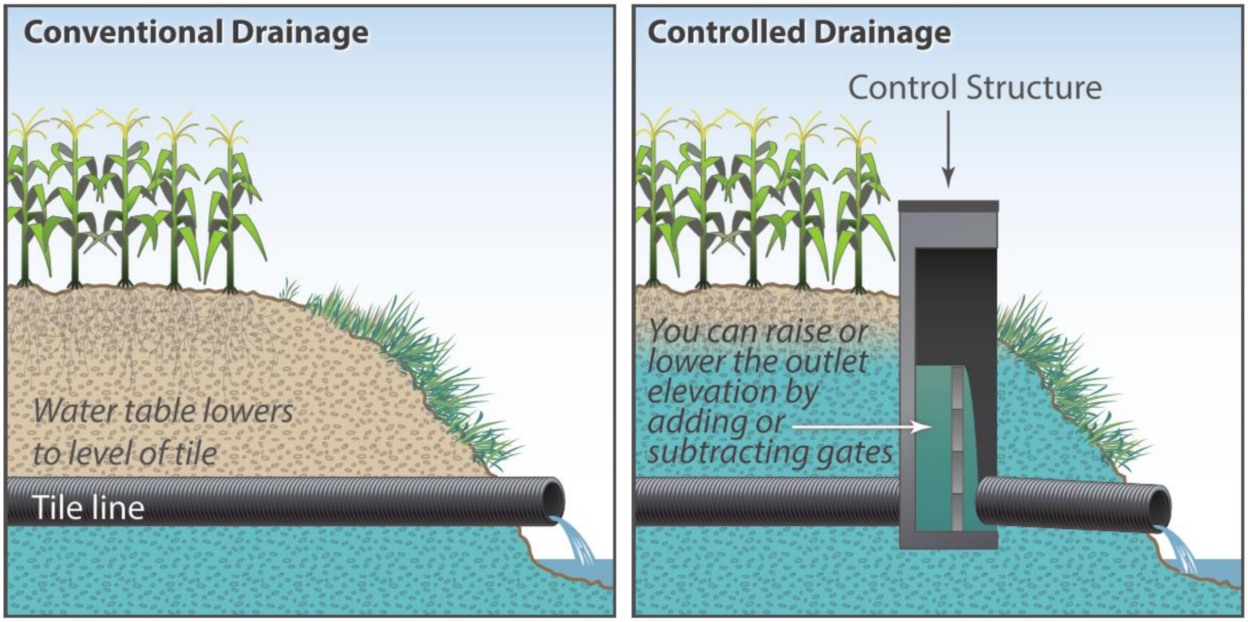

Fig. 1 Comparison between Conventional Drainage and Controlled Drainage (Christianson et al., 2016)

The main effect to reduce Nitrate-N loss using drainage water management comes from reduced drain flow. Less flow and flow only when necessary drainage keeps water and dissolved nutrients within the field. Drainage water management reportedly reduces 30% Nitrate-N loss from the field on average although actual performance could range from 15% to 75% (Christianson et al., 2016).

Limitation of this practice is that drainage water management works best for a relatively flat surface. It will work on steep slopes, but in that case, multiple control structures will have to be built to effectively manage water table, and that adds to the complexity of the work, and more labor will have to be invested, making it an undesired conservation practice. Given the current low adoption rate for this practice, it makes sense to avoid drainage water management in areas with big elevation change.

Currently, drainage water management is not an approved conservation practice by the Illinois Nutrient Loss Reduction Strategy (INLRS). Therefore, landowners are waiting for it to be approved with estimates of performance, resulting in low adoption rate in Illinois.

3.2.2 Retention Ponds

There is another type of pond worth mentioning, detention ponds. Both retention ponds and detention ponds are structures that that holds excessive water from agricultural land (Laramie County Conservation District, 2016). The difference is retention ponds hold water permanently, and detention ponds hold water only in events of heavy precipitation and dry out afterward (Le and Martel-gagnon, 2011). A graphical comparison between the retention pond and detention pond is shown in Fig. 2. The choice between retention ponds and detention ponds are very much decided by the local climate. For west part of the United States where precipitation is limited, and water resources are scarce, compare to the east part, maintaining a pond is very costly. Thus, detention pond is the better solution. For areas with a lot of precipitation, such as the Midwest, it makes more sense to maintain permanent retention ponds (Pennsylvania Department of Environmental Protection, 2006). Both types of ponds serve as storage zones for excessive water from the field. They not only store nutrient-rich water but settle down the sediments carried by water as well. Thus, they serve as great ways to reduce pollution from the field by limiting water and sediment within the field. On top of that, with water rich in nutrient and sediment binding phosphorus compound retained, ponds are good sources of organic fertilizers. In Asian countries like China, there has been a long tradition of collecting sludge from the bottom of ponds to fertilize the field. Under certain conditions, retention ponds could even become sources of methane gas. If used correctly, ponds could become a treasury of the farm.

Retention ponds maintain a pool of water throughout the year and hold stormwater runoff following storms.

Detention ponds hold water for a short period of time; this pond temporarily holds water before it enters the stream.

Fig. 2 Comparison between Retention Ponds and Detention Ponds (Laramie County Conservation District, 2016)

Compare to detention ponds, retention ponds are more versatile and can better serve the purpose of this thesis. There is at least two ways to make use of retention ponds. The first way is to recycle. For all conservation practices previously mentioned, a significant portion of nutrients will eventually make it to the water body, adding to existing NPS pollution situation. By recycling water from retention ponds, the majority of the nutrients will stay within the field and keep the effluent from agricultural land low in nutrients (Bauder et al., 2013). By recycling, need for fertilizers and irrigation water are greatly reduced since water collected in retention pond is fertilizer solution. Sludge at the bottom of ponds is dense in nutrients and organic matters and can be used to add extra fertility and improve soil structure. Use of sludge is also applicable for detention ponds. Second is to dilute. This does not necessarily require precious irrigation water -

natural precipitation will do the job. In events of heavy precipitation, water pour from the sky will dilute retention pond, so it is safe to discharge excessive water in the pond, preventing flooding of the field.

Other than conserving the environment, retention ponds serve as great entertainment sites. While not the best swimming pool, due to high nutrient content and soft, dangerous bottom, they are aesthetically appealing, provides good fishing site if maintained properly, and can be easily accepted by the community. However, there are several limitations to this practice. First, for recycling, fuel or electricity cost for pumping water from lower altitude to higher altitude is considerable, which may offset the saving of fertilizer and irrigation water. Consequently, larger the altitude difference, more cost will be added, so this practice is not good for mountainous areas where elevations differ a lot from place to place. Second, the effectiveness of retention ponds is very much determined by its size (Canada Mortgage and Housing Corporation, 2017), which means this practice is more suitable for smaller agricultural lands. Third, the initial cost of building a retention pond is relatively high.

3.3 Practices that Remove Nitrate-N

3.3.1 Woodchip Bioreactor

Woodchip bioreactor enhances natural process of denitrification by providing carbon source to denitrifying bacteria. The basic setup is to fill a long trench with woodchips and direct water flow through the trench. Denitrifying bacteria well-fed by the woodchips will denitrify Nitrate-N in the water flow at an increased rate and turn Nitrate-N into water and nitrogen gas, which is 70% of the air we breathe. This process is demonstrated with Equation 1:

$2\ NO_3^- + 10\ e^- + 12\ H^+ \rightarrow N_2 + 6\ H_2O$ (Equation 1)

Where NO_3^- is Nitrate-N, N_2 is nitrogen gas, and H_2O is water.

Since the denitrification process will only take place under anaerobic condition, some kinds of flow control must be implemented to woodchip bioreactor for effective denitrification. This is done by adding two drainage control structure before and after the trench. The structure before the trench diverts drainage water flow towards the trench while leaving space for overflow in events of heavy precipitation to not obstruct drainage flow and flood the field. The structure after the trench is a one-way traffic, which blocks normal water flow for enough water retention time for the best denitrifying process, but also leaves space for overflow. Fig. 3 shows a graphic illustration of a woodchip bioreactor.

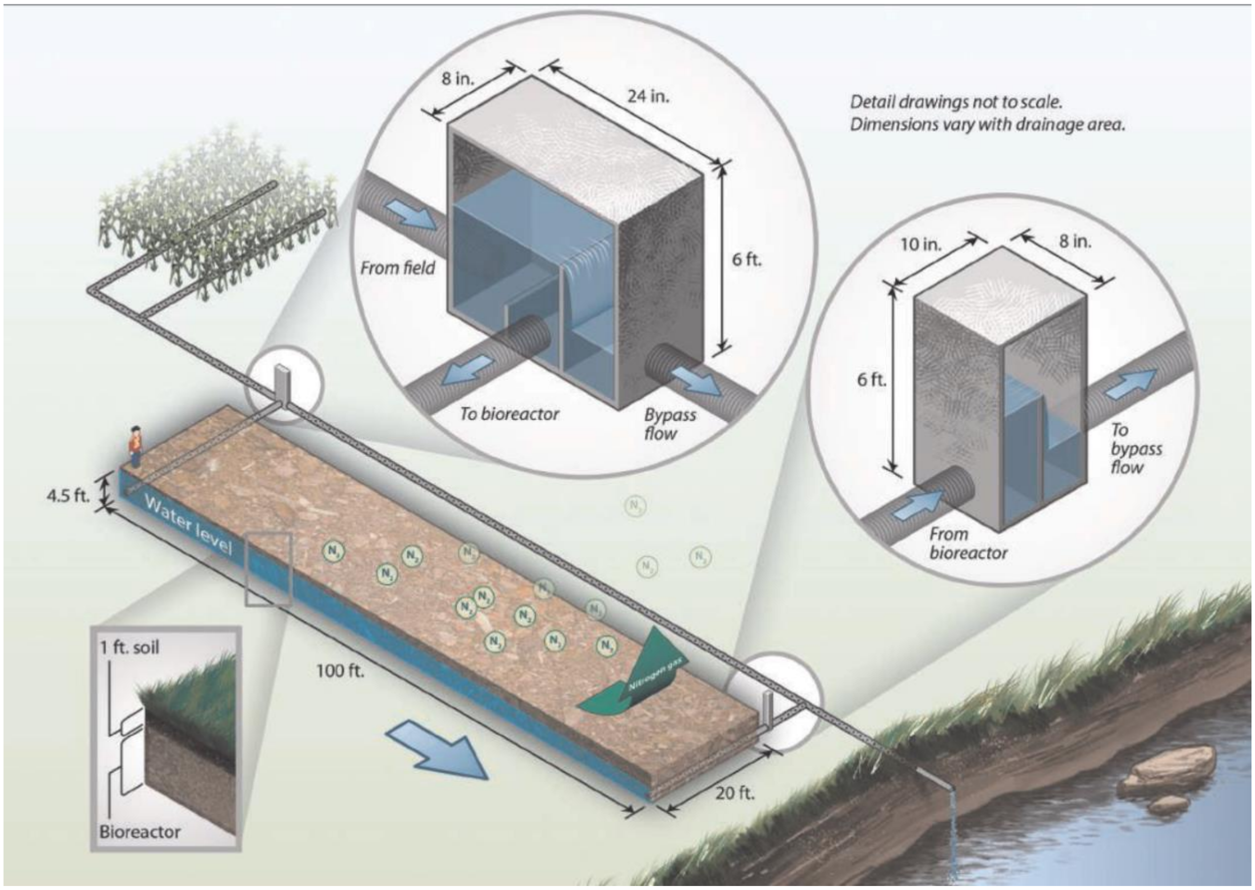

Fig. 3 Graphic Illustration of Woodchip Bioreactor (Christianson and Helmers, 2011)

Hydraulic retention time (HRT) is one of the most important factors that affect the efficiency of the woodchip bioreactor. The longer HRT, the better Nitrate-N removal outcome. However, it is not practical to set infinitely long HRT, and the denitrifying process slows down as Nitrate-N concentration drops. Research shows that reasonable HRT is about 6 to 8 hours, while during heavy precipitation events, the HRT can be as short as 4 hours, to achieve satisfactory denitrification (Hoover et al., 2016).

Temperature is another important factor that affects the denitrifying efficiency of woodchip bioreactors. Woodchip bioreactors' efficiency relies solely on bacterial activity. Since woodchip bioreactors are buried underground, with soil insulation, temperature fluctuation inside the woodchip bioreactor is limited. Studies on woodchip bioreactors suggested that higher temperature inside the bioreactor, the better denitrifying outcome (David et al., 2016). Of course, the extremely high temperature will negatively affect bacterial activity, but environment underground does not seem to be going to the extremes (Eindhoven University of Technology, 2009).

Another factor that affects woodchip bioreactors is influent Nitrate-N concentration. Studies showed that for given HRT and temperature, woodchip bioreactors achieve a better result with lower influent Nitrate-N concentration (Hoover et al., 2016). This finding suggested woodchip bioreactors have their limitations when treating excessive Nitrate-N.

Due to so many factors affecting the efficiency of woodchip bioreactors, the Nitrate-N removal efficiency on per acre basis ranges from 12% to 98%, averaging 30% to 40%. However, the Nitrate-N reduction from baseline is much lower at 13.6% (David et al., 2014). In this study, 13.6% Nitrate-N reduction was used for estimating Nitrate-N reduction efficiency for conservative estimation. Woodchip bioreactors cost relatively cheap to build and could last for 10 to 15 years (Christianson and Helmers, 2011). The biggest advantage of woodchip bioreactors is they do not affect normal agricultural practices since they should be built at the edge of the field. The obvious downside is, other than reducing the Nitrate-N load to surface water, woodchip bioreactors do not provide any benefit to the landowner, resulting in low adoption rate from landowners.

3.3.2 Wetland

Wetlands are permanent dynamic ecosystems consist of land covered by water. Affected by a lot of factors such as topography, climate, soil type, hydrology, vegetation type, human activity, wetlands differ a lot from place to place. A typical wetland consists of vegetation, soil, water and bacteria (UN-HABITAT, 2008).

Like woodchip bioreactors, wetlands reduce the Nitrate-N load in subsurface drainage through bacterial denitrification process. Denitrifying bacteria consume dissolved oxygen during their decomposition of dead plants and create an anaerobic environment for denitrification to happen. In addition to bacteria, plants grown in wetlands consume Nitrate-N to add effectiveness of Nitrate-N removal. Plants also take water from drainage, stabilize soil within wetlands, reduce runoff velocity and trap sediment carried by runoff water from farmlands. From an environmental protection point of view, the wetland is the most effective and versatile practice among all available conservation practices (Koch et al., 2014). Fig. 4 shows a schematic view of pollutant removal mechanism of wetlands.

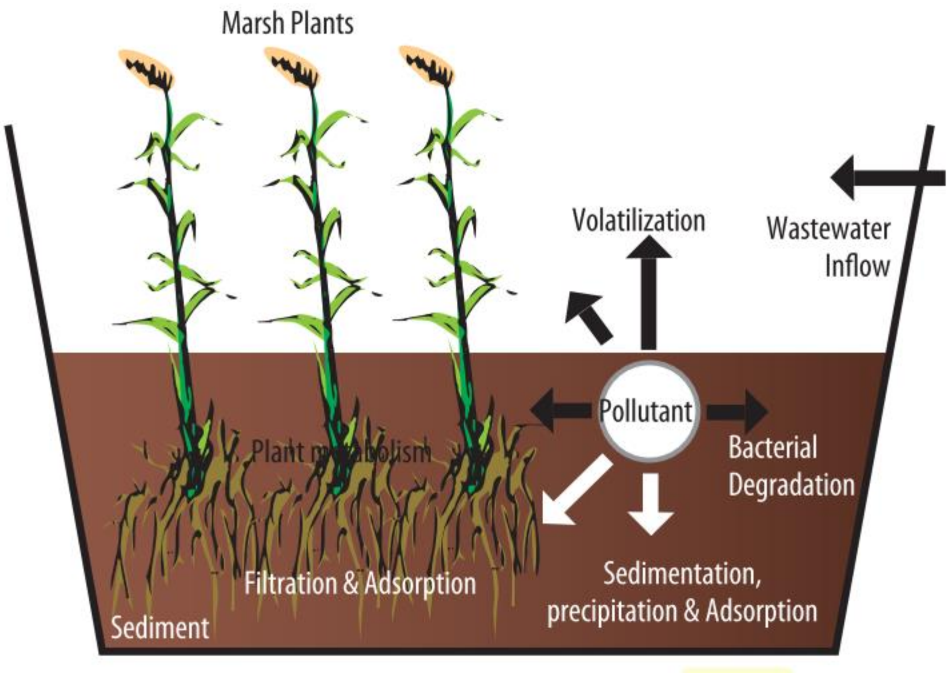

Fig. 4 Pollutant Removal Mechanism of Wetlands (UN-HABITAT, 2008)

Like woodchip bioreactors, factors that significantly affect Nitrate-N removal efficiency of wetlands are HRT, temperature, Nitrate-N concentration. Different from woodchip bioreactors, there is no artificial control structures for wetlands. Thus, HRT for a given wetland cannot be changed manually, and efficiency of wetlands are very much determined by weather. Warmer temperature increases bacterial and plant activities thus increase Nitrate-N removal efficiency. Wetlands are considered less effective in winter. In the Midwest, wetlands can reduce 20% to 50% Nitrate-N load in drainage water (Blann et al., 2009).

Wetlands work well on flat surfaces where drainage flow is slow. But more importantly, wetlands must be well-sized to achieve optimal Nitrate-N removal efficiency. Too large a size of wetland is a waste of space since the amount of Nitrate-N to be removed is limited. But if wetlands are too small, there will not be enough HRT for vegetation to take Nitrate-N and bacteria to denitrify. Various research has come up with equations to estimate the optimal size of wetlands. Since there is a lower limit in which wetland need to be sized, this means wetlands are not for all agricultural fields. If the farmland is too small, that the minimum wetland size takes a considerable amount of area in the farmland, it would not be a good idea to use it. The general rule is wetland should take 0.5% to 2% of farmland area, and the farmland should not be smaller than 500 acres (UN-HABITAT, 2008).

Wetlands are poorly adopted by landowners mostly because agriculture production must be completely taken out of the designated wetland area. 0.5% to 2% area of total farmland over 500 acres is a huge loss, and wetland is not bringing any profit to landowners. Instead, the wetland could be the perfect breeding bed for mosquitos and other pests, adding cost to landowners in pest control. Without irresistible subsidies program from the government, it is almost impossible for landowners to make such sacrifices for the greater good.

3.4 Outside Perspectives

3.4.1 Activated Sludge System

Activated sludge system is a process used in treating sewage wastewater (National Environmental Service Center, 2003). The simplest form of such system is an aeration tank follows by a clarifier to settle the sludge in influent wastewater. Part of the sludge is recycled back to aeration tank (Recycled Activated Sludge, RAS) while the rest goes to landfill (Wasted Activated Sludge, WAS). Microorganisms in influent wastewater are capable of consuming contaminants in wastewater. As microorganisms consume contaminant, they grow and forms flocs, which settle down in clarifier tank and leaves relatively clean water on top. By recycling settled sludge, more solid (sludge) retention time (SRT) is achieved and microorganisms in RAS, well-fed, reproduced, are more in number and break down contaminants more efficiently. A schematic diagram of a simple activated sludge system is shown in Fig. 5.

The aeration tank usually referred as the oxic tank, can be switched to other types of tanks by controlling available oxygen (Lamb et al., 1990). Without oxygen and presence of Nitrate-N, the oxic tank is converted to the anoxic tank, which could be used to remove Nitrate-N. Without oxygen and Nitrate-N, the oxic tank is converted to the anaerobic tank. With the presence of polyphosphate accumulating organisms (PAOs), the anaerobic tank is capable of removal of phosphate in wastewater (Tsurushima et al., 2010).

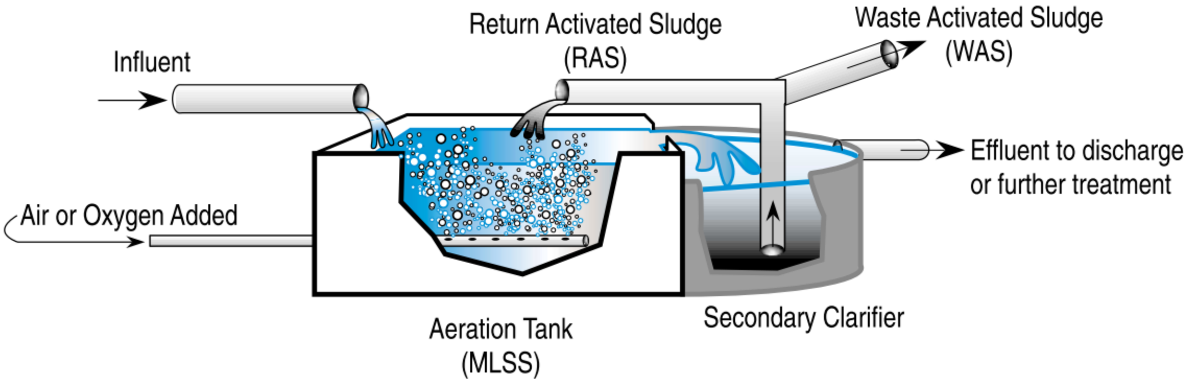

Fig. 5 Typical Activated Sludge System (National Environmental Service Center, 2003)

In practice, oxic tanks, anoxic tanks, and anaerobic tanks are often used together, with internal recycling on top of RAS recycling, to achieve better contaminant removal effect. For example, A2O, as shown in Fig. 6, is a common combination of tanks to achieve phosphorous and nitrogen removal, where an anaerobic tank and an anoxic tank are placed before oxic tank with internal recycling from the oxic tank to anoxic tank. For nitrogen removal, Modified Ludzack-Ettinger (MLE) process, shown in Fig. 7, places an anoxic tank before the oxic tank and internal recycle from oxic tank to anoxic tank. More sophisticated systems like 5-stage Bardenpho process, shown in Fig. 8, places five tanks in the order of anaerobic, anoxic, oxic, anoxic, oxic in front of clarifier tank, with internal recycling from first oxic to first anoxic, to achieve even better nitrogen and phosphorous removal result (Grissop, 2010).

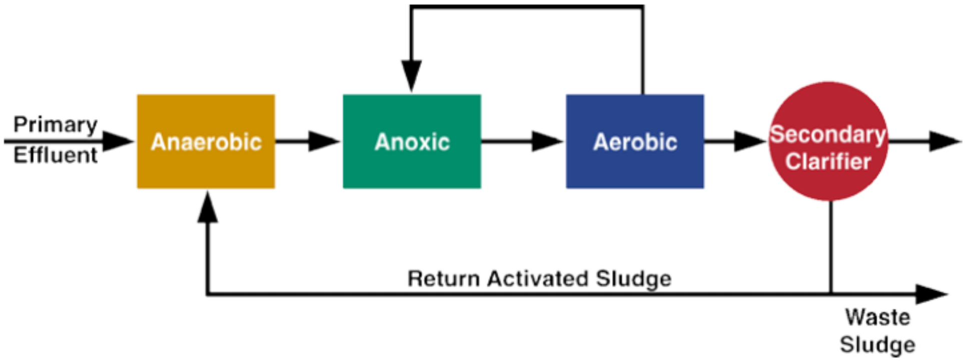

Fig. 6 A2O Process (Grissop, 2010)

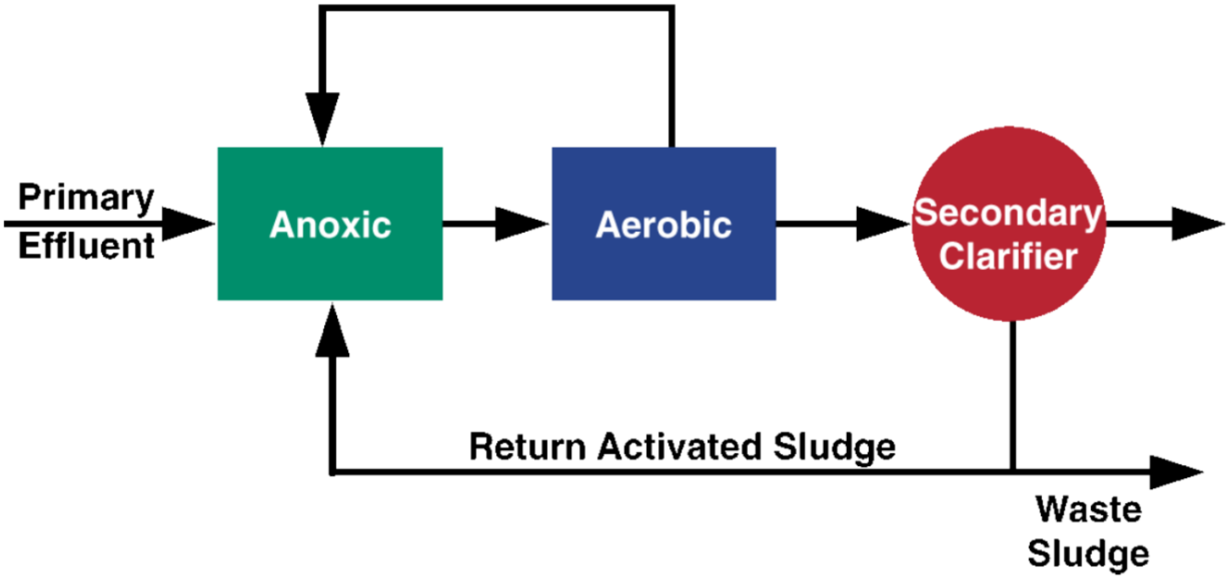

Fig. 7 Modified Ludzack-Ettinger Process (Grissop, 2010)

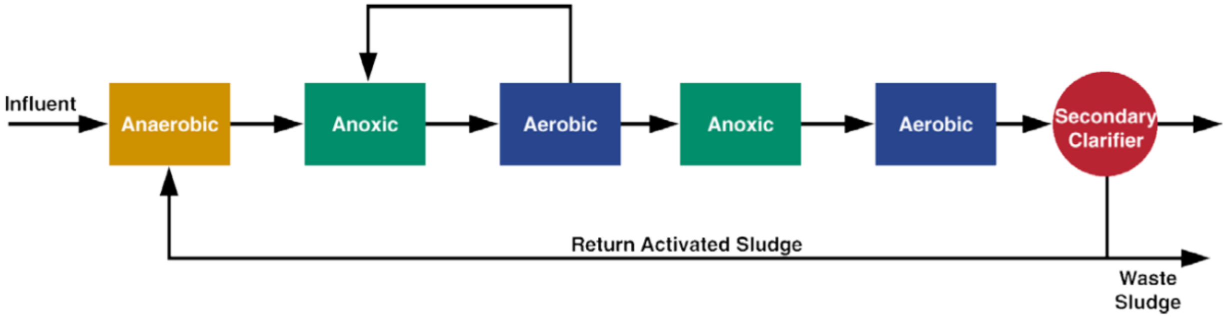

Fig. 8 5-stage Bardenpho Process (Grissop, 2010)

In agricultural wastewater treatment, we are facing a much larger scale, and it is impossible to replicate activated sludge system to the field as upscale such practice to the extent of farmland is both incompatible (unlike metal tanks, the soil is permeable) and economically prohibitive. But the idea of recycling and internal recycling to increase HRT, SRT, and microorganism activity for better treatment result is relevant to agricultural wastewater treatment and is worth trying in the combination of conservation practices we are about to find out in this thesis.

3.4.2 Landowners' Needs

A very important part of conservation effort is to have more landowners adopt them. Good practices without general adoption are as good as none. Agricultural practices are large-scale practices. Without landowners widely adopting conservation practices, the less real-life result will come to the research institute, stagnate continued research to improve existing practices and new conservation practice development. Without successful attempts in conservation practices, less awareness will happen. Thus, a good review of landowners' need is necessary for every research related to NPS pollution to set a good direction. Even if optimal nutrient removal efficiency must be compromised to tailor landowners need, an ordinary practice that gets adopted is better than an excellent practice that does not.

Lots of survey and interviews were done by researchers to identify factors that affect landowners' adoption of conservation practices (Christianson et al., 2013b; Prokopy et al., 2014). Most research shows, however, that there is no general trend on landowners’ adoption of conservation practices (Carlisle, 2016). So far there is no clear correlation researchers can use to predict whether landowners will adopt certain conservation practices as there is no factor that guarantees adoption if leveraged well. Contradict to general stereotype, financial return is only one of many factors that might initiate change. So, the effort to foster more economic gain is not very helpful for increasing landowners' adoption.

Some of the factors identified included: farmland characteristics (size, slope, soil type), availability of equipment, attitude towards environment, social networks, presence of opinion leader, system thinking (no separate plans), characteristics of the practice, maintenance effort, agronomy, finance, public policy, knowledge, community perceptions and aesthetics, demography (age, education, gender).

Farm characteristics are relevant to all the conservation practices. Smaller farm owners are less likely to adopt conservation practices, which is expected because of less information received and limitations of conservation practices. For example, wetlands require a minimum of 500 acres to work, which automatically excluded small farmlands. Interestingly, smaller farm owners are more interested in learning more about conservation practices, which suggests future outreach efforts target more on smaller farm owners. Similarly, conservation practices all have limitations on factors like slope, soil permeability, weather, etc.

Lack of equipment also limits farmers’ willingness to adopt conservation practices. For example, conservation tillage often requires specialized equipment to implement, and they are not always available to farmers, making it impossible to realize even if farmers are very interested in adopting conservation tillage practices.

Attitudes towards the environment is a crucial factor in landowners' acceptance of conservation practices. Environmental protection usually adds cost and effort to landowners with limited to no tangible return. Landowners who care about the environment and the greater good for the bigger community are more likely to adopt conservation practices because they value intangible returns, which make them feel accomplished. It would be much harder to convey the need for conservation and thus the importance of adopting conservation practices to landowners who do not care about the environment and cannot feel the reward for contributing to the greater good.

Landowners' social networks affect their decision in adopting conservation practices. Different connections exert a different level of pressure on landowners' decision. Family, chemical dealers, and seed dealers are the three most influential parties that affect landowners' decision, while outside experts such as university extension and conservation agencies have almost no influence on landowners' decision. This finding suggests trust and close relationship play a big role in landowners' decision. Gaining landowners trust and liking is a crucial job to be done in extension attempts.

Opinion leader can greatly affect landowners' decision. If a well-respected, innovative and successful farmer in the area adopted certain conservation practice for a long time, it would be much easier for other farmers in the area to adopt that conservation practice. This brings back the trust issue mentioned earlier. Chemical dealers and seed dealers could be opinion leaders to landowners in the area, and it would be necessary to find a solution in events of conflict of interest, as opinion leaders could also negatively affect adoption rate if they say no.

System thinking supports the rationale of this thesis. Selling many separate practices is not as effective as selling one integrated system containing many practices. Since farmland varies a lot from each other regarding size, soil type, weather, slope, etc., no one system fits all farmlands around the world. Modifications must be made by local characteristics. Making a systematic approach is much easier for landowners to digest information, and thus, keep a consistent understanding when they communicate with each other, dealers, and consultants, which influence decision process greatly.

Characteristics of the practice include the advantage, disadvantage, and limitations related to the conservation practice. A Clear description of conservation practices will affirm landowners' confidence, and landowners will not adopt a practice unless they are sure their concerns are addressed. Some conservation practices have characteristics that prohibit certain farm owners to adopt the practice, allowing landowners to know earlier will prevent waste of time and effort.

Maintenance is a significant cost that is often forgotten that comes with conservation practices. The added effort in maintaining conservation practices is the primary cause of landowners abandoning adopted conservation practices over time. Easy to no maintenance effort usually makes sure long-time adoption of conservation practices.

Agronomy factor is a strong motivation for landowners to adopt conservation practice. Landowners are very concern about long-term soil health of their land. In China, most farmers would like to switch from traditional fertilizers to BOFs because government sends the message that BOFs will benefit their offspring in the near and far future. If a repeated message could be sent to let landowners aware of the agronomical benefit of conservation practices, it would greatly improve landowners' acceptance of conservation practices.

Influence of financial factor was exaggerated for a long time because it does have a significant role in landowners' adoption. Landowners are not very interested in immediate payback, but rather focus on long-term soil health improvement. However, overwhelming cost, including opportunity cost, and maintenance effort would make landowners think twice before adopting conservation practices. Cost for equipment is also a factor that influences landowners' acceptance but could be solved by a rental program. The economy of scale also suggested that larger farmland would benefit from conservation practices with little sacrifice, but smaller farmland would see significant cut from profit if they adopt conservation practices. Ironically, smaller farm owners usually have more concern about environmental problems related to their land.

The public policy makes a significant influence. Even non-material support from government will make landowners more willing to give conservation practices a try. Specialized subsidies for adopting landowners will alleviate their sacrifices and make the transition more rewarding. For example, the Natural Resources Conservation Service (NRCS) provides cost-share for construction of conservation practices under their Environmental Quality Incentives Program, which might reduce the actual construction cost for certain conservation practices. Public policies can make negative impacts as well. In China, farmlands are not the private property of landowners, but the property of the government. Thus, landowners are less willing to spend their money in making upgrades. Thus, conservation practices can only rely on government subsidies.

The more knowledgeable and informed landowners are more willing to adopt conservation practices. More knowledge makes landowners more aware of the big picture and effect of nutrients to the bigger community. More knowledge also makes implementation of conservation practices easier with the saved effort to educate. However, the survey shows that most landowners lacked knowledge about soil health practices, making the educational effort a top on the extension list.

Aesthetics factor, surprisingly, plays a big role in landowners' adoption of conservation practices. If a practice looks beautiful and earns landowners' applause from the community, landowners will be more likely to adopt it, regardless of its actual economic return. This factor is relevant to retention pond practice, which could be carefully built to satisfy the taste of community and provide some social functions at the same time.

Demography, which includes age, gender, and education, could affect adoption rate of conservation practices. While not always works, college education and younger age relate to higher adoption rates. Gender plays and subtle part in conservation practice adoption. Female landowners are more interested in conservation practices, but are also less knowledgeable about these practices and eventually less likely to adopt them (Carlisle, 2016).

3.5 Winter Cover Crop

While not fitting in the categories mentioned earlier, winter cover crop is a popular conservation practice in Illinois. In this practice, cover crops are planted after harvest and grow over winter. Some cover crops survive winter while others do not. The survived crops will need to be killed in the spring, introducing herbicide problem, but have better nutrient removal capacity; those that died during winter does not have the removal problem but are also less effective in nutrient removal. Some popular cover crop plants include winter rye, barley, alfalfa, winter canola, etc. This practice reduces Nitrate-N by plants uptake of water and nutrients. Its Nitrate-N reduction capacity ranges from 13% to 94% (Kaspar et al., 2008). Other than reducing Nitrate-N, winter cover crops provide additional benefits like wind erosion resistance and improved soil health. Some cover crop plants can fix nitrogen or suppress nematodes and weeds (Christianson et al., 2016). Due to its popularity, winter cover crop is relatively easy to apply as many tools for planning are available, such as those provided by the Midwest Cover Crops Council. Despite its popularity, winter cover crop had limited implementation rate.

CHAPTER 4

METHODS

4.1 Establish Criteria for Successful Plan

Before trying to find a good plan to combine conservation practices that satisfy the objectives of this thesis, we must have criteria to evaluate proposed plans. From literature, we can summarize factors that must be considered in designing the conservation plan, which includes: performance in Nitrate-N removal, construction and maintenance time and cost, education program, conflict of interest, and aesthetics.

Financial profit is not listed for several reasons. First, not all conservation practices increase financial profit. Some practices, like wetlands, decrease profit by taking a significant portion of agricultural land out of production. Second, for those conservation practices that help increase profit, they do so by either reducing fertilizer usage or improving soil health by reducing erosion and limiting nutrient within the field. While improved soil health is appreciated by everyone, the effect will only appear after long-term practices, which makes few noticeable effects on profit on an annual basis. Drainage water management is claimed by many research studies to increase yield significantly, even offsetting construction and maintenance cost. However, recent research results suggest this may not be true (Allerhand et al., 2013), as both increase and decrease in yield reported in the Midwest. On the other hand, reduction in fertilizer use will negatively affect fertilizer dealers, and they are among the most trusted in the social network of farmers.

Performance in Nitrate-N removal is estimated using available data in the literature. Agricultural lands differ a lot across the world, and there is no universal simulation model available to model performance of every conservation practice mentioned in this thesis. Factors considered in estimating Nitrate-N removal performance include input Nitrate-N, Nitrate-N removal efficiency, temperature, drainage flow rate, runoff rate, and leaching rate. A normal farmland in central Illinois (100 acres, Drummer soil, < 2% slope) (USDA, 2017) is used for calculation since this area is flat, which allows all conservation practices to apply. And because Illinois produces a lot of NPS pollution that accounts for a significant portion of the Nitrate-N load that creates the hypoxia zone in the Gulf of Mexico (Jaynes and James, 2007), eliminating Nitrate-N load from this area using conservation practices is a valuable task to achieve (USGS, 2014).

Time and cost spent on construction and maintenance should be kept as low as possible. Extended construction time will not only put landowners' patience to test but also affects the normal timeline of agricultural production. Maintenance should be simple and less frequent, so it does not become an unwanted chore over time. Construction and maintenance time could be considered a shut-off factor in landowners' adoption. The detrimental effect of extended construction or maintenance time will make adoption of conservation practices less desirable. Even if landowners adopt the practice initially, too much time devotion will consume their energy and result in abandoning of conservation practice in the long run. Construction and maintenance should be kept low as well, but cost-effect trade-off should be considered, and it very much depends on landowners' perception.

Education programs developed from the proposed combinations should be interesting and easy to understand. Out of the 16 factors that affect landowners' adoption of conservation practices identified previously in this study, 7 of them must be directed to education. This fact requires that the exact combination be reasonably simple and works as one integrated structure so anyone, after education, will understand the combination in the same way. The proposed combination must also contain certain entertainment element, so it appeals to landowners' interests.

Conflict of interest is an inevitable problem when a practice, such as nitrogen management, reduces the use of fertilizers. Reduction in fertilizer demand will result in less unit of fertilizer sale, and potentially reduces the price of each unit of fertilizer (Ibendahl, 2017). This means loss of revenue for fertilizer manufacturers and leftover inventory for dealers, who happen to be a group of people that farmers trust. To avoid such unfavorable situations, it is possible that fertilizer dealers run against the application of conservation practices, convincing not to adopt them. To avoid this situation, the proposed combination should refrain from large-scale fertilizer reduction. Small-scale fertilizer reduction that will not move market equilibrium is good enough.

Aesthetics and entertainment appeal are important in the proposed design because they attract compliment and attention. Compliments from community affirm landowners' continued passion in adopting conservation practice, and attention creates value to landowners while attracting more potential adopters. An aesthetically appealing and entertaining design will serve as its advertisement and is one goal of the proposed design.

4.2 Determine Practices to be Combined

Characteristics of farmlands and landowners’ needs vary a lot from place to place. There will not be such thing as the universal combination that fits every climate, topography, or soil type. Thus, the ideal combination should be readily adaptable to different local conditions. This objective can be accomplished by building a “core” combination that allows simple add-on of other “satellite” practices. Core combination contains structural practices, namely, drainage water management (control structure present), retention pond, and woodchip bioreactor. These practices require special structural design to be combined and will be discussed in detail in this study. Despite its versatility and numerous benefits to farmland, the wetland has very limited adoption potential due to a large minimum area required, a significant portion of agricultural land out of production, and added pest control problem. Adding it to the core will very likely decrease the overall adoption potential of the combination. Thus, it is excluded from the core. Conservation practices like nitrogen management, winter cover crops, conservation tillage, controlled-release fertilizer, bio-organic fertilizer, are non-structural practices, which can be applied in addition to the core based on expert advice or upon request by landowners without any modification to the core necessary.

4.3 Proposed Combinations Plan

Without considering connection configurations, there are four possible combinations using the three conservation practices: drainage water management + retention ponds (DR); drainage water management + woodchip bioreactors (DB); retention ponds + woodchip bioreactors (RB); drainage water management + woodchip bioreactors + retention ponds (DRB). According to their functions, the three conservation practices must be implemented after the drainage in the order of drainage water management (to control water table), retention ponds (contains drainage within agricultural land), and woodchip bioreactor (remove excess Nitrate-N before drainage water enters waterbody). They can be connected in series (with or without internal recycling) or parallel (with or without internal recycling).

For illustration purposes, each element in the combination is given a symbol. The legend is shown in Fig. 9:

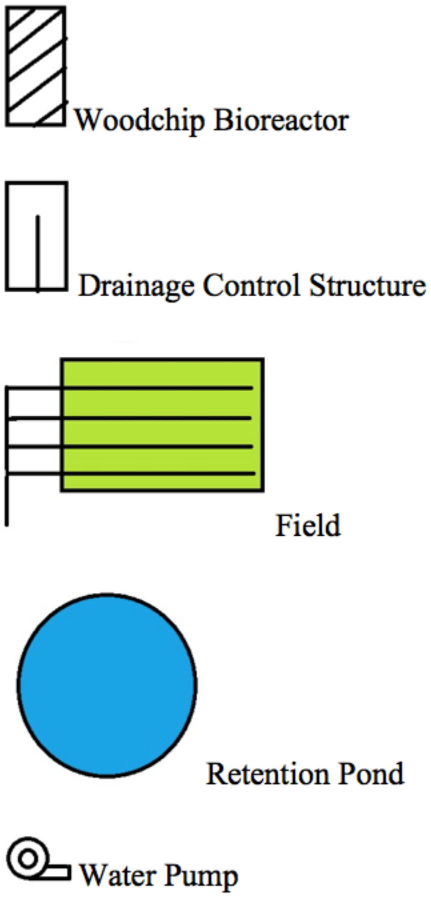

Fig. 9 Symbol for Elements Present in Combination Configurations

For Drainage Water Management + Retention Pond combination, since HRT is not an issue without woodchip bioreactor, there is one possible configuration. The control structure is placed directly after main pipe and retention pond connected to the control structure with plastic tubing. The DR configuration is shown in Fig. 10:

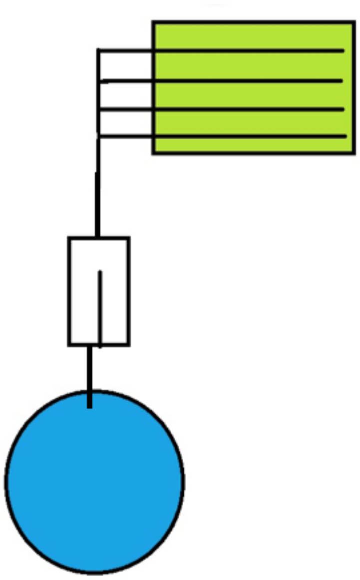

Fig. 10 Drainage Water Management + Retention Pond Configuration (DR)

For Drainage Water Management + Woodchip Bioreactor combination, without retention pond, there is no median for meaningful internal recycling to happen. Thus, there is one possible configuration. The control structure is placed directly after main pipe and bioreactor is connected to the control structure with plastic tubing. The DB configuration is shown in Fig. 11:

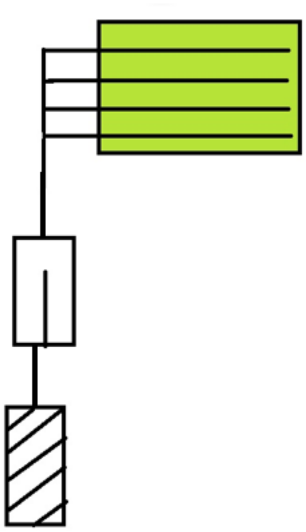

Fig. 11 Drainage Water Management + Woodchip Bioreactor Configuration (DB)

For Retention Pond + Woodchip Bioreactor combination, with the addition of retention pond for possible internal recycling, there are six possible configurations.

RB1: retention pond connected to the main pipe with plastic tubing, woodchip bioreactor connected to retention pond with plastic tubing. This configuration is shown in Fig. 12:

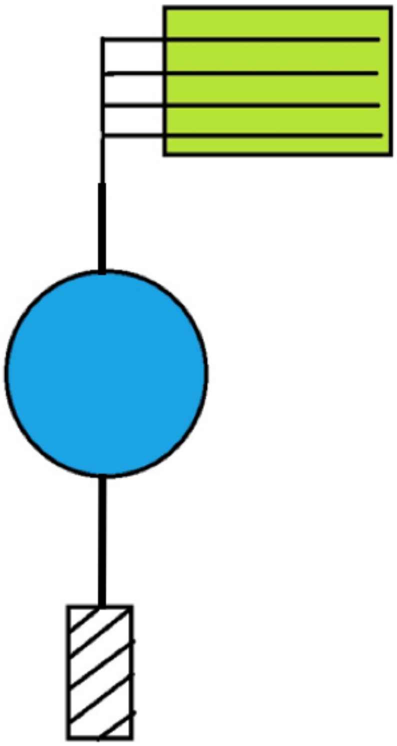

Fig. 12 Retention Pond + Woodchip Bioreactor Configuration 1 (RB1)

RB2: same as RB1, with the added pump to recycle part of the effluent from woodchip bioreactor back to the retention pond. Configuration is shown in Fig. 13:

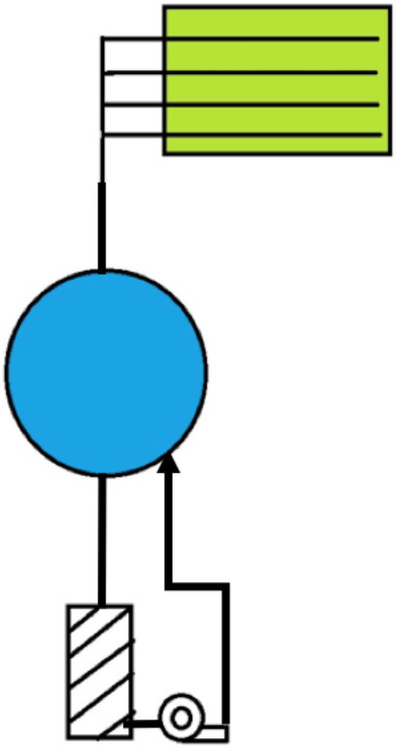

Fig. 13 Retention Pond + Woodchip Bioreactor Configuration 2 (RB2)

RB3: the main pipe diverted to 2 ways, with one way goes to the retention pond, and the other goes to woodchip bioreactor. The configuration is shown in Fig. 14:

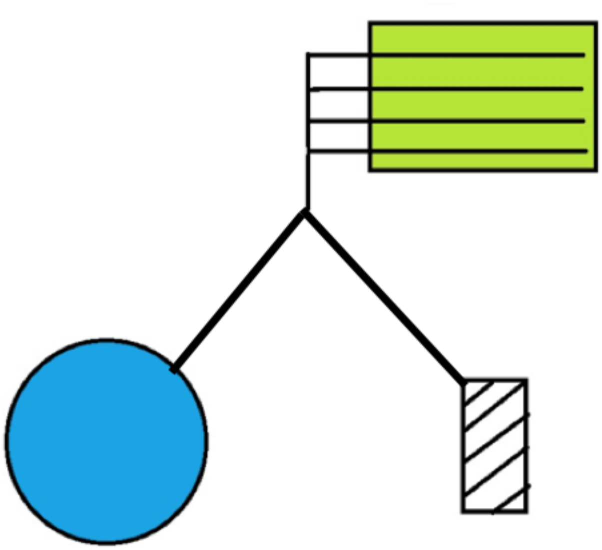

Fig. 14 Retention Pond + Woodchip Bioreactor Configuration 3 (RB3)

RB4: same as RB3, with added plastic tubing to move part of the effluent from woodchip bioreactor to retention pond. The configuration is shown in Fig. 15:

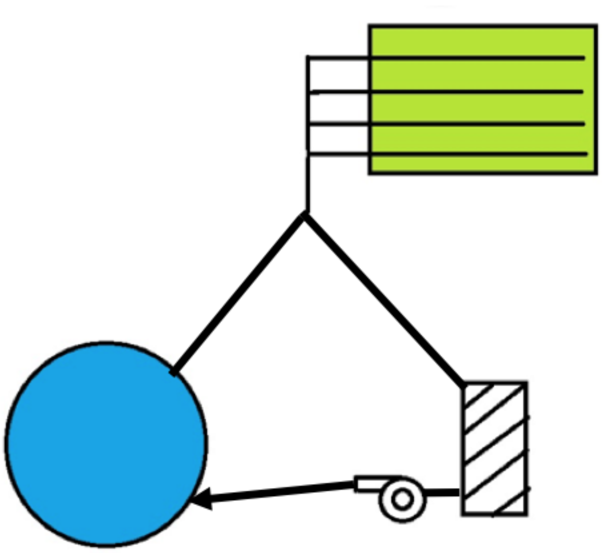

Fig. 15 Retention Pond + Woodchip Bioreactor Configuration 4 (RB4)

RB5: same as RB3, with the added pump to move some water from retention pond to woodchip bioreactor. This configuration is shown in Fig. 16:

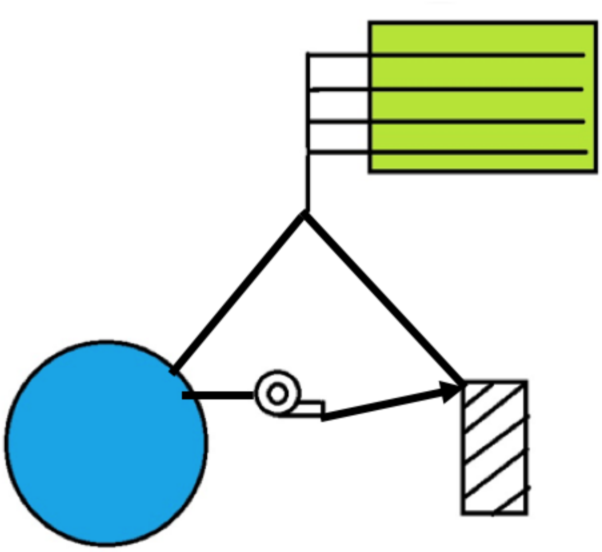

Fig. 16 Retention Pond + Woodchip Bioreactor Configuration 5 (RB5)

RB6: same as RB3, with added plastic tubing to move part of the effluent from woodchip bioreactor to retention pond, and added the pump to move some water from retention pond to woodchip bioreactor. The configuration is shown in Fig. 17:

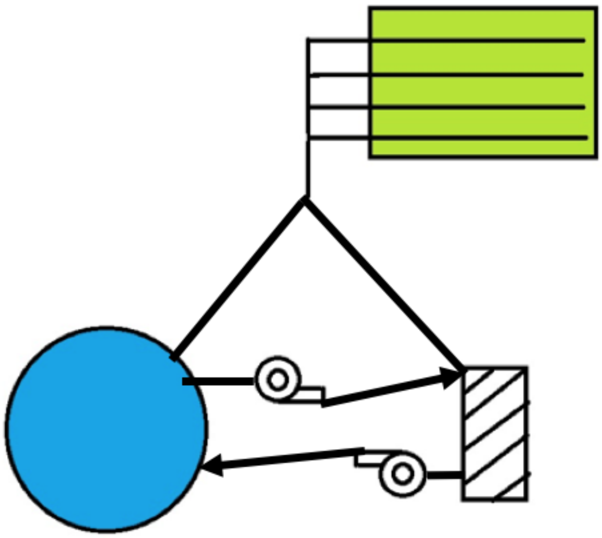

Fig. 17 Retention Pond + Woodchip Bioreactor Configuration 6 (RB6)

For Drainage Water Management + Retention Pond + Woodchip Bioreactor combination, like Retention Pond + Woodchip Bioreactor combination, there are six possible configurations. Addition of control structure will not increase the number of configurations because it will not join the internal recycling process.

DRB1: same as RB1, with added control structure. The configuration is shown in Fig. 18:

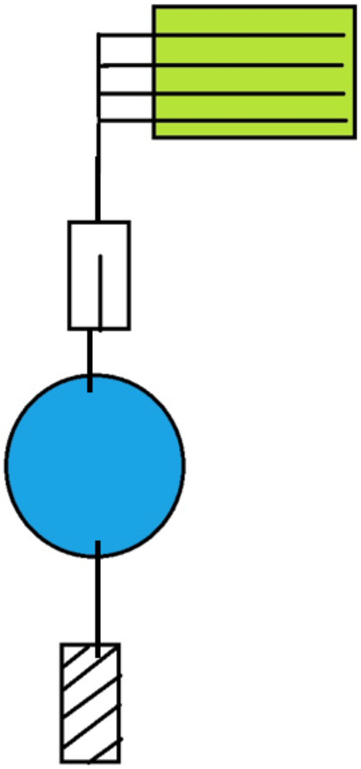

Fig. 18 Drainage Water Management + Retention Pond + Woodchip Bioreactor Configuration 1 (DRB1)

DRB2: same as RB2, with added control structure. The configuration is shown in Fig. 19:

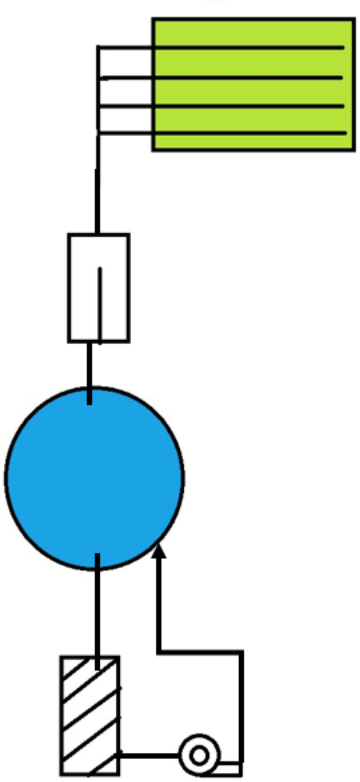

Fig. 19 Drainage Water Management + Retention Pond + Woodchip Bioreactor Configuration 2 (DRB2)

DRB3: same as RB3, with added drainage control structure. This configuration is shown in Fig. 20:

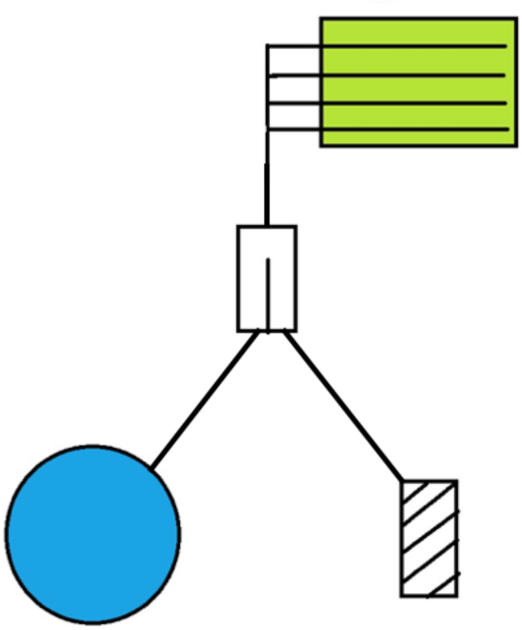

Fig. 20 Drainage Water Management + Retention Pond + Woodchip Bioreactor Configuration 3 (DRB3)

DRB4: same as RB4, with added drainage control structure. This configuration is shown in Fig. 21:

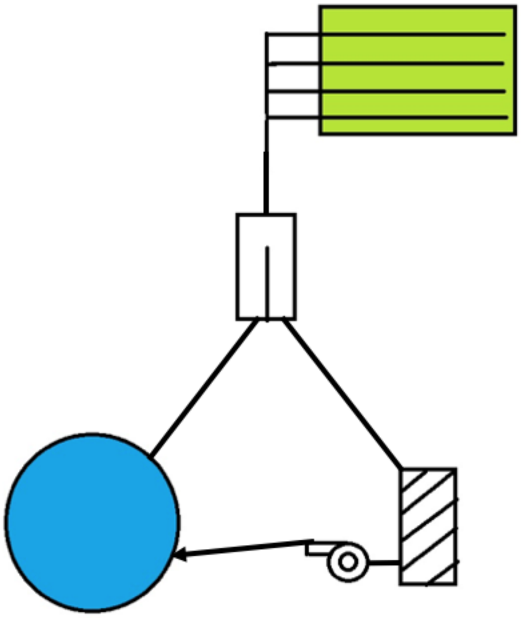

Fig. 21 Drainage Water Management + Retention Pond + Woodchip Bioreactor Configuration 4 (DRB4)

DRB5: same as RB5, with added drainage control structure. This configuration is shown in Fig. 22:

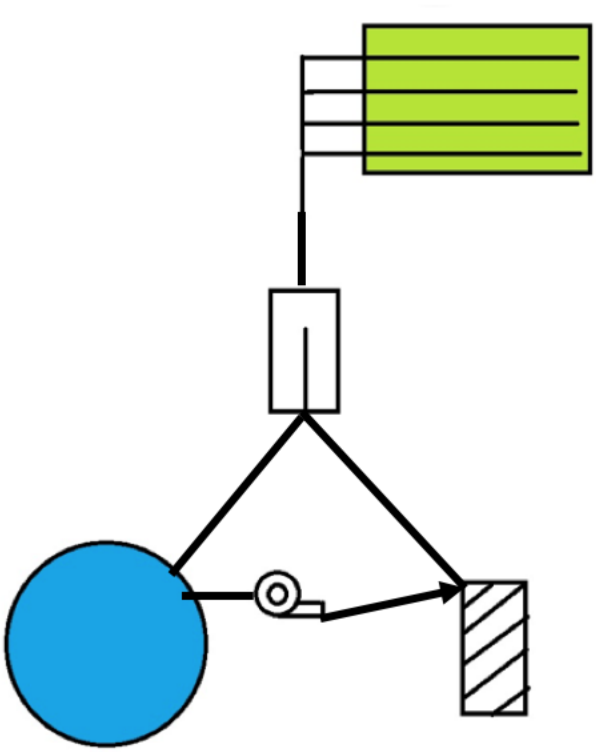

Fig. 22 Drainage Water Management + Retention Pond + Woodchip Bioreactor Configuration 5 (DRB5)

DRB6: same as RB6, with added drainage control structure. This configuration is shown in Fig. 23:

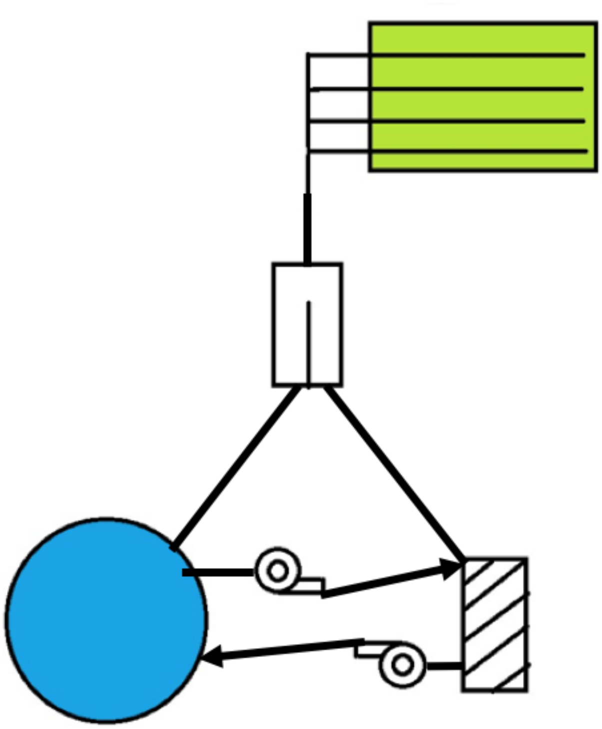

Fig. 23 Drainage Water Management + Retention Pond + Woodchip Bioreactor Configuration 6 (DRB6)

In total, we have 14 combination configurations to analyze in this study.

4.4 Construction and Maintenance Cost and Time Estimation

Cost for construction of each configuration consists of the cost of elements in the conservation structures, connecting pipes and pumping mechanism if internal recycling is used, parts transportation fee, design cost and contractor fee (labor).

Cost for maintenance consists of the cost of replacing elements in conservation structures, replacing connecting pipes and pumping mechanism, electricity and fuel to drive pumping mechanism, raising and lowering control structure, water to maintain the wet pond, pond cleaning, and routine inspection.

Construction time is affected by various factors like contractor efficiency, availability of funding, weather, farmland characteristics, etc. Since accurately predict construction time is difficult, a time factor system is used in this study. Each part of the combination configuration is arbitrarily assigned a nominal time factor according to the nature of the part. Time factors are added for each configuration to show the relative time consumption in construction.

Maintenance time is measured in term of maintenance frequency. The number of maintenance required within 50 years is added for each configuration for comparison.

4.5 Nitrate-N Reduction Estimation

Although current data and model are not enough for the three conservation practices and nothing at all for alternative connecting configurations to allow complex and accurate simulation base on all aspects of farmland specifications, the available information from literature is good enough for some valid estimation. Because of drainage water management and retention pond store Nitrate-N in the land, but woodchip bioreactor removes excessive Nitrate-N, the overall

Nitrate-N reduction will be discussed separately in the context of Nitrate-N saving and Nitrate-N removing for each configuration. However, Nitrate-N reduction percentage will still be calculated for each configuration by multiplying reduction capacity of each constituent to show the overall contribution to the environment. The equation for overall reduction percentage is shown in Equation 2:

$$\text{Overall reduction percentage} = 1 - \prod_{1}^{n}(1 - Reduction\ Percentage_n) \quad \text{(Equation 2)}$$

Where n is different conservation practices, and $\prod$ is the multiplication operator to find the product of all terms from 1 to n.

Drainage water management is a practice that does not remove Nitrate-N directly. It reduces Nitrate-N load into waterbody by reducing drainage flow and limit drainage water within the water table. Not only less drainage flow results in less Nitrate-N entering the waterbody, by forcing more drainage water staying in the field, but drainage water management creates an extended period for Nitrate-N to mineralize in the soil as well, improving soil health. It also allows microorganisms present in the soil to denitrify Nitrate-N, removing a small portion of Nitrate-N outside production season. The efficiency of drainage water management in reducing the Nitrate-N load to waterbody varies from 35% to 96% from field experiences, simulation results from DRAINMOD showed that drainage water management could reduce drainage Nitrate-N loss by about 40% (Negm et al., 2017). For conservative estimation, 30% reduction rate from literature review will be used for estimation. Under storm condition, drainage water management cannot do anything but let drainage water overflow and discharge to avoid flooding the field, so reduction efficiency is 0 under such condition.

The efficiency of woodchip bioreactors is affected by temperature, hydraulic retention time (HRT), and influent Nitrate-N concentration. Working temperature of woodchip bioreactors is mostly decided by environment temperature. Artificial heating to improve woodchip bioreactor performance is not well-researched and could be an unwanted extra maintenance task. Nitrate-N concentration is very much dependent on fertilizer application rate by farmers, and will not be affected by reuse of diluted drainage water from the retention pond. Thus, the efficiency of woodchip bioreactors in this study is determined by HRT alone. The relationship between HRT and Nitrate-N removal performance is available from literature (Christianson et al., 2013a; Hoover et al., 2016), which is also shown in Fig. 24. Presence of the control structure and retention pond could alter HRT, so Nitrate-N removal efficiency is analyzed on a case-by-case basis. Under normal operating conditions, i.e., the flow rate is low, HRT can be made a few days, ensure mean Nitrate-N removal efficiency at least 50% (Woli et al., 2010). However, for conservative estimation, the 13.6% reduction rate from literature review will be used for estimation. It's meaningful to compare Nitrate-N removal both under storm flooding conditions (minimum reduction capacity) when peak flow rate occurs if without any conservation practices present, and normal operating conditions (standard reduction capacity).

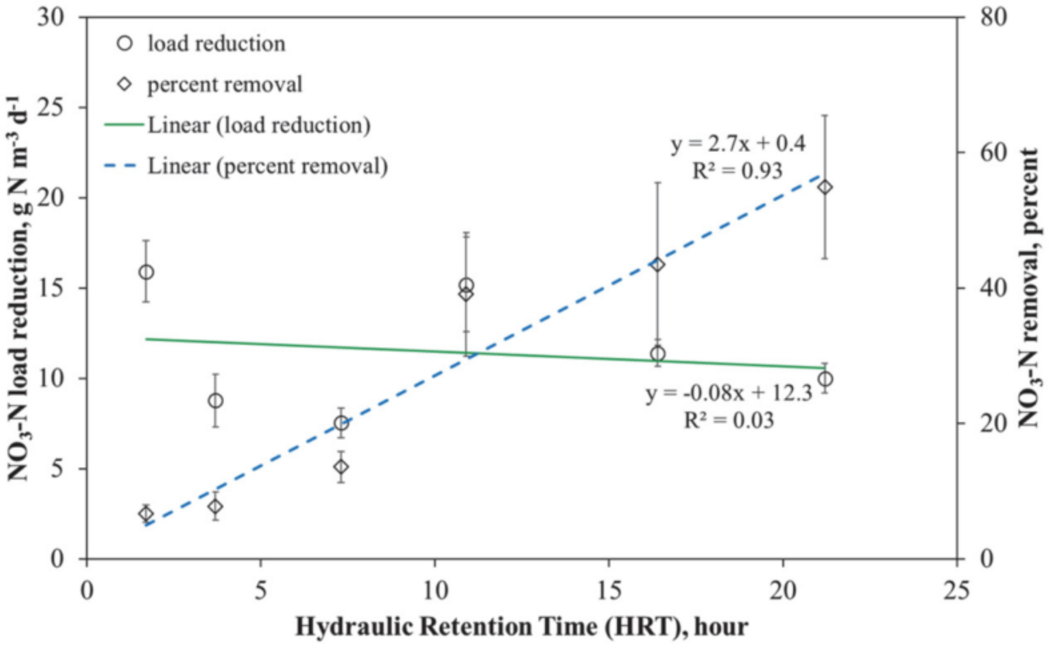

Fig. 24 Relationship between HRT and Nitrate-N Removal for Woodchip Bioreactors (Hoover et al., 2016)

Retention ponds collect excessive drainage water for dilution or recycling in the means of back to the field (irrigation) or back to woodchip bioreactor (longer HRT). While not directly removing Nitrate-N, it stops almost all Nitrate-N from going directly to waterbody without treatment. While not intentional, sludge down at the bottom of the retention ponds does have some denitrifying capability. However, nitrification happens at the same time and reduction in Nitrate-N within retention ponds is not obvious. Studies show opposite opinions on whether retention ponds reduce Nitrate-N or add Nitrate-N (Gruber et al., 2011; Koch et al., 2014). Some claim retention ponds oxic environment and promote nitrification, while others claim retention ponds anoxic environment, promote denitrification. For convenience, we regard retention ponds as woodchip bioreactor support with no Nitrate-N removal capability on its own.

4.6 Education

Successful education is equally important as finding the best combination configuration. It is the only way to make sense of the conservation practice to landowners and encourage adoption. To help successful education, combination configuration should not be overly complex and require minimum manual operations. To evaluate simplicity and automation, they are graded on the scale of 1 to 3, with 1 being the simplest and most automated and 3 being the most complex and most manual operation required.

4.7 Conflict of Interest

Conflict of interest happens when fertilizer use is reduced and production land appropriated for non-production use. Grading scale like that of education is used for evaluating conflict of interest with 1 indicating no conflict, 2 indicating some conflict, and 3 indicating major conflict.

4.8 Aesthetics

Drainage water management structure and bioreactors are buried underground. The only source of aesthetic comes from the retention pond, which could be designed to have entertainment and recreation functionalities. The binary scale is used to evaluate aesthetics with 1 indicating retention ponds present and 0 indicating retention ponds not present.

4.9 Likelihood of Adoption

As many survey and extension efforts suggested, there is no single factor can be used to predict landowners' adoption of conservation practices. It is the combination of various factors that push the change. Thus, it would be a valid assumption that the more factors affecting landowners' adoption addressed, the more likely some combination of factors could move landowners and push the change. It is noteworthy that some factors work as shut-off factors. If not properly addressed, they will make landowners' adoption impossible. For example, if construction cost is so high for landowners that it is financially inhibitive to adopt conservation practice, the likelihood of adoption is practically zero. If time used for maintenance is too much, landowners may get tired of it and abandon the practice even if they choose to adopt at the beginning, which also means adoption likelihood to be zero. To estimate the likelihood of adoption, ordinal values are assigned to each configuration under each factor based on their standings. Non-shut-off factors are added while shut-off factors will appear as shut-off functions and multiply to the sum. Shut-off factors include cost, time, and performance.

CHAPTER 5

RESULTS

5.1 Nitrate-N Reduction Performance

Calculations are made with the assumption that the retention pond is designed to hold drainage water from a 1-hour, 50-year precipitation without overflow. Other assumptions are that the woodchip bioreactor is designed to have 1 hour hydraulic retention time (HRT) under the saturated condition, a 2-hour, 50-year precipitation is considered a storm event, and there is no precipitation 72 hours before the storm event. These assumptions are made arbitrarily to demonstrate a heavy precipitation event for ease of calculation.

Drainage Water Management + Retention Pond Configuration (DR): Only drainage water management is contributing to Nitrate-N reduction. As mentioned in the literature review, drainage water management reduces Nitrate-N by 30% on average. This means 30% Nitrate-N loss from drainage is kept in the field. Thus, for DR, there is 30% Nitrate-N reduction (standard), and zero Nitrate-N reduction (minimum). Water in retention pond has 70% Nitrate-N remaining.

Drainage Water Management + Woodchip Bioreactor Configuration (DB): Drainage water management part limits 30% Nitrate-N loss from drainage in the field. Woodchip bioreactor part removes 13.6% Nitrate-N before discharge under normal conditions. Under storm conditions, HRT is typically less than 1 hour, and woodchip bioreactor efficiency is less than 5%. Nitrate-N reduction (standard) is 40%, Nitrate-N reduction (minimum) is less than 5%.

Retention Pond + Woodchip Bioreactor Configuration 1 (RB1): Only woodchip bioreactor is contributing to Nitrate-N reduction. It removes 13.6% Nitrate-N (standard). Under storm conditions, retention pond holds half of the drainage water in the first hour and allows normal condition HRT for woodchip bioreactor and allows 1-hour HRT when overflow occurs. On average, bioreactor removes Nitrate-N at 5% (minimum).

Retention Pond + Woodchip Bioreactor Configuration 2 (RB2): Only woodchip bioreactor is contributing to Nitrate-N reduction. It removes 13.6% Nitrate-N on the first pass and after recycling, dilutes Nitrate-N concentration in retention pond to a minimum of 93%, after the second pass, RB2 can reduce 20% Nitrate-N removal (standard). Under storm conditions, retention pond holds half of the drainage water in the first hour and allows normal condition HRT for woodchip bioreactor and allows 1-hour HRT when overflow occurs. On average, bioreactor removes Nitrate-N at 5% (minimum).

Retention Pond + Woodchip Bioreactor Configuration 3 (RB3): Only woodchip bioreactor is contributing to Nitrate-N reduction. It diverts half of the drainage water to the retention pond and the other half to woodchip bioreactor. It removes 8% Nitrate-N (standard). Under storm conditions, retention pond holds half of drainage water throughout the event, allows 2-hour HRT. Nitrate-N removal (minimum) is 5%.

Retention Pond + Woodchip Bioreactor Configuration 4 (RB4): Only woodchip bioreactor is contributing to Nitrate-N reduction. It diverts half of the drainage water to the retention pond and the other half to woodchip bioreactor. It removes 8% Nitrate-N (standard), and stores processed drainage water in the retention pond with 93% Nitrate-N remaining. Under storm conditions, retention pond holds half of drainage water throughout the event, allows 2-hour HRT. Nitrate-N removal (minimum) is 5%.

Retention Pond + Woodchip Bioreactor Configuration 5 (RB5): Only woodchip bioreactor is contributing to Nitrate-N reduction. It diverts half of the drainage water to the retention pond and the other half to woodchip bioreactor. It removes 13.6% Nitrate-N in woodchip bioreactor half and continues to remove 13.6% Nitrate-N in water pumped from the retention pond, making 13.6% Nitrate-N removal (standard). Under storm conditions, retention pond holds half of drainage water throughout the event, allows 2-hour HRT. Nitrate-N removal (minimum) is 10%.

Retention Pond + Woodchip Bioreactor Configuration 6 (RB6): Only woodchip bioreactor is contributing to Nitrate-N reduction. It diverts half of the drainage water to the retention pond and the other half to woodchip bioreactor. It removes 20% Nitrate-N (standard), and stores processed drainage water in the retention pond with 93% Nitrate-N remaining. Under storm conditions, retention pond holds half of drainage water throughout the event, allows 2-hour HRT. Nitrate-N removal (minimum) is 10%.

Drainage Water Management + Retention Pond + Woodchip Bioreactor Configuration 1 (DRB1): Same as RB1 with added drainage water management structure after the main pipe, keeping 30% drained Nitrate-N in the field under normal condition. Water in retention pond has 70% Nitrate-N remaining. Nitrate-N reduction is 40% (standard), and 5% (minimum).

Drainage Water Management + Retention Pond + Woodchip Bioreactor Configuration 2 (DRB2): Same as RB2 with added drainage water management structure after the main pipe, keeping 30% drained Nitrate-N in the field under normal condition. Water in retention pond has 65% Nitrate-N remaining. Nitrate-N reduction is 44% (standard), and 5% (minimum).

Drainage Water Management + Retention Pond + Woodchip Bioreactor Configuration 3 (DRB3): Same as RB3 with added drainage water management structure after the main pipe, keeping 30% drained Nitrate-N in the field under normal condition. Water in retention pond has 70% Nitrate-N remaining. Nitrate-N reduction is 20% (standard), and 5% (minimum).

Drainage Water Management + Retention Pond + Woodchip Bioreactor Configuration 4 (DRB4): Same as RB4 with added drainage water management structure after the main pipe, keeping 30% drained Nitrate-N in the field under normal condition. Water in retention pond has 65% Nitrate-N remaining. Nitrate-N reduction is 20% (standard), and 5% (minimum).

Drainage Water Management + Retention Pond + Woodchip Bioreactor Configuration 5 (DRB5): Same as RB5 with added drainage water management structure after the main pipe, keeping 30% drained Nitrate-N in the field under normal condition. Water in retention pond has 70% Nitrate-N remaining. Nitrate-N reduction is 40% (standard), and 10% (minimum).

Drainage Water Management + Retention Pond + Woodchip Bioreactor Configuration 6 (DRB6): Same as RB6 with added drainage water management structure after the main pipe, keeping 30% drained Nitrate-N in the field under normal condition. Water in retention pond has 65% Nitrate-N remaining. Nitrate-N reduction is 44% (standard), and 10% (minimum).

5.2 Construction Cost

Before starting to estimate construction cost, it is noteworthy that the Natural Resources Conservation Service (NRCS) provides cost-share for construction of conservation practices under their Environmental Quality Incentives Program, which might reduce the actual construction cost for some conservation practices. Ponds and drainage water management are included in this program (Natural Resources Conservation Service, 2017).

The following costs are estimated for a 100-acre farmland to avoid missing data from the larger scale. For larger scale applications, these estimates might not be accurate. Costs are not discounted to present value as the discount rate is equal for all configurations and does not alter the results. It would be an unnecessary complication in this analysis.

A concrete-bottom retention pond costs $100,000 in total to construct, resulting in 1 acre of farmland out of production (Delaware Department of Natural Resources, 2008). There are other cheaper alternatives with non-solid bottoms, which can be used to reduce construction cost if price associated with the concrete bottom is proven to be economically prohibitive to use. However, due to a significantly higher range of overall cost for a retention pond (between $30,000 to $100,000) (Newport, 2014) compare to other conservation practices included for combination, a different number will not affect overall results.

Drainage water management requires 20 hours' design at $40/hour (Christianson et al., 2013c). Five control structures needed at $1000 each, including transportation. Installation requires 8 hours at $100/hour. Cost for building drainage water management structures that serve 100-acre farmland is $6,400.

Woodchip bioreactors require two control structures at $1000 each. $2000 of woodchips transported by four trucks at $100 each. 20 design hours at $40/hour. Estimated construction time of 30 hours at $100/hour. $200 for internal piping. Cost for building woodchip bioreactor that serves 100-acre farmland is $8,400.

A heavy-duty water pump cost $1000 with $100 shipping, plus 1 hour installation time at $100/hour, it costs $1,200.

12-Inch * 20ft plastic pipe cost $150 per unit. Installation time for 10 unit is 1 hour at $100/hour, the cost for plastic pipes is at $1600/10 units.

Using these information, construction cost for each configuration on a 100-acre farmland can be calculated as follows:

DR: Drainage water management + Retention pond + 20 units of pipe = $109,600

DB: Drainage water management + Woodchip bioreactor + 10 units of pipe = $16,400

RB1: Retention pond + Woodchip bioreactor + 20 units of pipe = $111,600

RB2: Retention pond + Woodchip bioreactor + 70 units of pipe + 1 Pump = $120,800

RB3: Retention pond + Woodchip bioreactor + 30 units of pipe = $113,200

RB4: Retention pond + Woodchip bioreactor + 50 units of pipe + 1 Pump = $117,600

RB5: Retention pond + Woodchip bioreactor + 50 units of pipe + 1 Pump = $117,600

RB6: Retention pond + Woodchip bioreactor + 70 units of pipe + 2 Pumps = $122,000

DRB1: Drainage water management + Retention pond + Woodchip bioreactor + 20 units of pipe = $118,000

DRB2: Drainage water management + Retention pond + Woodchip bioreactor + 70 units of pipe + 1 Pump = $127,200

DRB3: Drainage water management + Retention pond + Woodchip bioreactor + 30 units of pipe = $119,600

DRB4: Drainage water management + Retention pond + Woodchip bioreactor + 50 units of pipe + 1 Pump = $124,000

DRB5: Drainage water management + Retention pond + Woodchip bioreactor + 50 units of pipe + 1 Pump = $124,000

DRB6: Drainage water management + Retention pond + Woodchip bioreactor + 70 units of pipe + 2 Pumps = $128,400

5.3 Construction Time

Construction of drainage water management structure involves 8-hour nominal installation time and is considered very time-saving. Time factor of 1 is assigned.

Construction of retention pond requires significant digging and building with heavy machinery involved. Construction time can take up to weeks. Time factor of 3 is assigned.

Construction of woodchip bioreactor requires 30-hour nominal installation time. It takes some time, but not as much as that retention pond takes. Time factor of 2 is assigned.

Installation of the water pump is a job to be finished in one day. Time factor of 1 is assigned.

Installation of connecting pipes is like the construction of drainage water management structure. Even with the most pipe installation requirement of DRB6, installation time is still under 10 hours. Thus, a time factor of 1 is assigned.

Using these estimated time factors, nominal construction time for each configuration on a 100-acre farmland can be calculated as follows:

DR: Drainage water management + Retention pond + Pipe = 5
DB: Drainage water management + Woodchip bioreactor + Pipe = 4
RB1: Retention pond + Woodchip bioreactor + Pipe = 6
RB2: Retention pond + Woodchip bioreactor + Pipe + Pump = 7
RB3: Retention pond + Woodchip bioreactor + Pipe = 6
RB4: Retention pond + Woodchip bioreactor + Pipe + Pump = 7
RB5: Retention pond + Woodchip bioreactor + Pipe + Pump = 7
RB6: Retention pond + Woodchip bioreactor + Pipe + Pump = 7
DRB1: Drainage water management + Retention pond + Woodchip bioreactor + Pipe = 7

DRB2: Drainage water management + Retention pond + Woodchip bioreactor + Pipe + Pump = 8

DRB3: Drainage water management + Retention pond + Woodchip bioreactor + Pipe = 7

DRB4: Drainage water management + Retention pond + Woodchip bioreactor + Pipe + Pump = 8

DRB5: Drainage water management + Retention pond + Woodchip bioreactor + Pipe + Pump = 8

DRB6: Drainage water management + Retention pond + Woodchip bioreactor + Pipe + Pump = 8

5.4 Maintenance Cost

The maintenance of drainage water management is cheap. Labor cost includes raise and lower gate for four times a year, 4 hours each time, at $20/hour. Gate will need to be replaced every eight years, five control structures with five gates each, at $15. Total annual cost for maintaining drainage water management structures on a 100-acre farmland is $366.88.

Maintenance of retention pond is very dependent on what is happening to the pond. Since retention pond is a long-term structure, a lot of input will be added to the maintenance effort over the years. A good estimation of annual maintenance cost is 3-5% of its construction cost. In our case, this means $4,000 annually for a retention pond on 100-acre farmland.

Other than regular mowing, which cost about $200 annually, woodchip bioreactor is maintenance-free during its lifespan. But woodchip degrades over time, and the suggested term of use for woodchip bioreactor is 10 to 15 years. For defensive estimation, assume useful life for a woodchip bioreactor is 10 years. Annualized maintenance cost for woodchip bioreactor on a 100-acre farmland is thus $860.

Plastic Pipes are non-biodegradable and can be used for hundreds of years without major problems. Thus, maintenance cost for pipes is trivial.

Water pump under normal operation lasts about 20 years. It consumes gasoline, requires oil change and repair when necessary, and require labor to service. From a typical water pump specification sheet, this number is about $400 (Axthelm and Decker, 1964). Total annualized maintenance cost is $400 + $1000/20 = $450 per water pump.

With estimated maintenance cost for individual components, total maintenance cost for each configuration can be calculated:

DR: Drainage water management + Retention pond = $4366.88

DB: Drainage water management + Woodchip bioreactor = $1226.88

RB1: Retention pond + Woodchip bioreactor = $4860

RB2: Retention pond + Woodchip bioreactor + Pump = $5310

RB3: Retention pond + Woodchip bioreactor = $4860

RB4: Retention pond + Woodchip bioreactor + Pump = $5310

RB5: Retention pond + Woodchip bioreactor + Pump = $5310

RB6: Retention pond + Woodchip bioreactor + 2 Pumps = $5760

DRB1: Drainage water management + Retention pond + Woodchip bioreactor = $5226.88

DRB2: Drainage water management + Retention pond + Woodchip bioreactor + Pump = $5676.88

DRB3: Drainage water management + Retention pond + Woodchip bioreactor = $5226.88

DRB4: Drainage water management + Retention pond + Woodchip bioreactor + Pump = $5676.88

DRB5: Drainage water management + Retention pond + Woodchip bioreactor + Pump = $5676.88

DRB6: Drainage water management + Retention pond + Woodchip bioreactor + 2 Pumps = $6126.88

5.5 Maintenance Time

Drainage water management requires maintenance four times a year for gate rise/lower, once every eight years to replace gates. In total, the number of maintenance required in 50 years for drainage water management structures on 100-acre farmland is 206.25 times.

Retention pond requires two inspections annually, sediment removal every ten years, and some repair work if necessary (California Stormwater Quality Association, 2003). On average, such repair work could happen once a year. In total, the number of maintenance required for a retention pond on 100-acre farmland in 50 years is 155 times.

Woodchip bioreactor requires mowing two times a year. Replacement happens every 20 years. In total, a woodchip bioreactor requires maintenance 102.5 times in 50 years.

Plastic pipes are non-degradable material and require minimal maintenance, which means 0 maintenance in 50 years.

Water pumps require routine maintenance to keep machinery running, which include oil change, inspection, and possible repair. In total, one water pump would expect 150 times in maintenance in 50 years. (fill up gasoline is too simple a job to be called maintenance)

Using these estimations, the number of maintenance in 50 years can be calculated for each configuration on a 100-acre farmland.

DR: Drainage water management + Retention pond = 361.25 times

DB: Drainage water management + Woodchip bioreactor = 308.75 times

RB1: Retention pond + Woodchip bioreactor = 257.5 times

RB2: Retention pond + Woodchip bioreactor + Pump = 407.5 times

RB3: Retention pond + Woodchip bioreactor = 257.5 times

RB4: Retention pond + Woodchip bioreactor + Pump = 407.5 times

RB5: Retention pond + Woodchip bioreactor + Pump = 407.5 times

RB6: Retention pond + Woodchip bioreactor + 2 Pumps = 557.5 times

DRB1: Drainage water management + Retention pond + Woodchip bioreactor = 463.75 times

DRB2: Drainage water management + Retention pond + Woodchip bioreactor + Pump = 613.75 times

DRB3: Drainage water management + Retention pond + Woodchip bioreactor = 463.75 times

DRB4: Drainage water management + Retention pond + Woodchip bioreactor + Pump = 613.75 times

DRB5: Drainage water management + Retention pond + Woodchip bioreactor + Pump = 613.75 times

DRB6: Drainage water management + Retention pond + Woodchip bioreactor + 2 Pumps = 763.75 times

5.6 Education

DR: Simple structure but some manual work of rising and lowering gates need to be done. Education difficulty is on a nominal scale of 2.

DB: Simple structure but some manual work of rising and lowering gates need to be done. Education difficulty is given a nominal scale of 2.

RB1: A simple structure without manual work necessary. Education difficulty is on a nominal scale of 1.

RB2: Internal recycling structure with pumping needed sometimes. Education difficulty is given a nominal scale of 2.

RB3: A simple structure without manual work necessary. Education difficulty is given a nominal scale of 1.

RB4: Internal recycling structure with pumping needed sometimes. Education difficulty is given a nominal scale of 2.

RB5: Internal recycling structure with pumping needed sometimes. Education difficulty is given a nominal scale of 2.

RB6: Extensive internal recycling with two pumps needed to operate. Education difficulty is given a nominal scale of 3.

DRB1: A simple structure with manual work of rising and lowering gates need to be done. Education difficulty is given a nominal scale of 2.

DRB2: Internal recycling structure with pumping and gate operations needed. Education difficulty is given a nominal scale of 3.

DRB3: A simple structure with manual work if rising and lowering gates need to be done. Education difficulty is given a nominal scale of 2.

DRB4: Internal recycling structure with pumping and gate operations needed. Education difficulty is given a nominal scale of 3.

DRB5: Internal recycling structure with pumping and gate operations needed. Education difficulty is given a nominal scale of 3.

DRB6: Internal recycling structure with 2 pumps to operate and gate operations as well. Education difficulty is given a nominal scale of 3+.

5.7 Conflict of Interest

Conflict of interest arises from two sources: First, if land is taken out of production, there is potential conflict of interest between conservation practice and landowners; second, if more Nitrate-N is available for recycling, fertilizer dealers will have longer inventory turnover and loss liquidity in the short run and fertilizer manufacturers will lose revenue, both situations are considered unfavorable, especially when fertilizer dealers exerts significant pressure on landowners' decision.

DR: With retention pond present, taking away production land, and a major part of Nitrate-N from drainage water left, conflict of interest scale is 2.

DB: Without retention pond taking away production land and no drainage water collected. There is no obvious conflict of interest. Conflict of interest scale is 1.

RB1: With retention pond present, taking away production land, and Nitrate-N from drainage water left untreated, conflict of interest scale is 3.

RB2: With retention pond present, taking away production land, and Nitrate-N from drainage water left untreated, conflict of interest scale is 3.

RB3: With retention pond present, taking away production land, and Nitrate-N from drainage water left untreated, conflict of interest scale is 3

RB4: With retention pond present, taking away production land, and Nitrate-N from drainage water left untreated, conflict of interest scale is 3

RB5: With retention pond present, taking away production land, and Nitrate-N from drainage water left untreated, conflict of interest scale is 3.

RB6: With retention pond present, taking away production land, and Nitrate-N from drainage water left untreated, conflict of interest scale is 3.

DRB1: With retention pond present, taking away production land, and a major part of Nitrate-N from drainage water left, conflict of interest scale is 2.

DRB2: With retention pond present, taking away production land, and a major part of Nitrate-N from drainage water left, conflict of interest scale is 2.

DRB3: With retention pond present, taking away production land, and a major part of Nitrate-N from drainage water left, conflict of interest scale is 2.

DRB4: With retention pond present, taking away production land, and a major part of Nitrate-N from drainage water left, conflict of interest scale is 2.

DRB5: With retention pond present, taking away production land, and a major part of Nitrate-N from drainage water left, conflict of interest scale is 2.

DRB6: With retention pond present, taking away production land, and a major part of Nitrate-N from drainage water left, conflict of interest scale is 2.

5.8 Aesthetics

Retention pond is present in all configurations except for DB, indicating all but DB satisfy aesthetics criteria as described in the method section.

5.9 Likelihood of Adoption

Apparently, while contributing greatly to the aesthetic part of design, retention pond is a component that cost a lot to construct and maintain, which made DB stand out from the 14 configurations. Compare to other configurations, DB has an overwhelming advantage in cost that is less than ¼ of the average. Other than the cost and time advantage of DB, however, differences between every configuration are not very significant, making shut-off function unnecessary. Summary of calculations is shown in Table. 1.

Table. 1 Summary of Calculations for each Configuration and Their Performances

	Perfor-mance (Std.)	Perfor-mance (min.)	Nitrate-N in Pond	Construction Cost ($)	Construction Time (factor)	Maintenance Cost ($/yr.)	Maintenance Time (#s in 50 years)	Education (Difficulty)	Conflict of Interest	Aesthetics
DR	30%	0	70%	109600	5	4366.88	361.25	2	2	1
DB	40%	3%	0	26400	4	1226.88	308.75	2	1	0
RB1	14%	5%	100%	111600	6	4860	257.5	1	3	1
RB2	20%	5%	93%	120800	7	5310	407.5	2	3	1
RB3	8%	5%	100%	113200	6	4860	257.5	1	3	1
RB4	8%	5%	93%	117600	7	5310	407.5	2	3	1
RB5	14%	10%	100%	117600	7	5310	407.5	2	3	1
RB6	20%	10%	93%	122000	7	5760	557.5	3	3	1
DRB1	40%	5%	70%	118000	7	5226.88	463.75	2	2	1
DRB2	44%	5%	65%	127200	8	5676.88	613.75	3	2	1
DRB3	20%	5%	70%	119600	7	5226.88	463.75	2	2	1
DRB4	20%	5%	65%	124000	8	5676.88	613.75	3	2	1
DRB5	40%	10%	70%	124000	8	5676.88	613.75	3	2	1
DRB6	44%	10%	65%	128400	8	6126.88	763.75	4	2	1

DR = Drainage water management + Retention Pond Configuration; DB = Drainage water management + Woodchip Bioreactor Configuration;
RB1 = Retention Pond + Woodchip Bioreactor Configuration 1; RB2 = Retention Pond + Woodchip Bioreactor Configuration 2;
RB3 = Retention Pond + Woodchip Bioreactor Configuration 3; RB4 = Retention Pond + Woodchip Bioreactor Configuration 4;
RB5 = Retention Pond + Woodchip Bioreactor Configuration 5; RB6 = Retention Pond + Woodchip Bioreactor Configuration 6;
DRB1 = Drainage water management + Retention Pond + Woodchip Bioreactor Configuration 1;
DRB2 = Drainage water management + Retention Pond + Woodchip Bioreactor Configuration 2;
DRB3 = Drainage water management + Retention Pond + Woodchip Bioreactor Configuration 3;
DRB4 = Drainage water management + Retention Pond + Woodchip Bioreactor Configuration 4;
DRB5 = Drainage water management + Retention Pond + Woodchip Bioreactor Configuration 5;
DRB6 = Drainage water management + Retention Pond + Woodchip Bioreactor Configuration 6;
For education, 1 is the easiest and 4 is the most difficult; For conflict of interest, 0 means no conflict, 3 means major conflict;
For aesthetics, 0 means no aesthetic element present, 1 means aesthetic element present.

To combine all factors and give an estimate for the likelihood of adoption, previous calculations need to be transformed into the same ranking system. For performance, cost, and time, an ordinal value from 1 to 4 (with 1 being the best and 4 the worst) is assigned to the actual number based on its range. This transformation also eliminates any outliers in previous calculations. The transformed values are shown in Table. 2.

All the ordinal values of a configuration are added using Equation 3 to assess the likelihood of adoption, as shown in Table. 3. The lower the grade, the more likely landowners are to adopt the configuration.

Likelihood = (Standard Performance + Minimum Performance)/2 + (Construction Cost + Maintenance Cost)/2 + (Construction Time + Maintenance Time)/2 + Education + Conflict of Interest + Aesthetics

(Equation. 3)

Table. 2 Summary of Calculations for each Configuration and Their Performance after Ordinal Value Transformation

	Perfor-mance (Std.)	Perfor-mance (min.)	Nitrate-N in Pond	Construction Cost ($)	Construction Time	Maintenance Cost ($/yr.)	Maintenance Time	Education	Conflict of Interest	Aesthetics
DR	2	4		1	1	1	1	2	3	1
DB	1	4		1	1	1	1	2	2	4
RB1	4	3		1	2	2	1	1	4	1
RB2	3	3		3	3	3	2	2	4	1
RB3	4	3		1	2	2	1	1	4	1
RB4	4	3		2	3	3	2	2	4	1
RB5	4	1		2	3	3	2	2	4	1
RB6	3	1		3	3	4	3	3	4	1
DRB1	1	3		2	3	2	3	2	3	1
DRB2	1	3		4	4	3	4	3	3	1
DRB3	3	3		3	3	2	3	2	3	1
DRB4	3	3		4	4	3	4	3	3	1
DRB5	1	1		4	4	3	4	3	3	1
DRB6	1	1		4	4	4	4	4	3	1

Table.3 Likelihood of Adoption for each Configuration

	DR	DB	RB1	RB2	RB3	RB4	RB5	RB6	DRB1	DRB2	DRB3	DRB4	DRB5	DRB6
Score	11	12.5	12.5	15.5	12.5	15.5	14.5	16.5	13	16.5	14.5	17.5	15.5	17
Rank	1	2	2	8	2	8	6	11	5	11	6	14	8	13

Top 6 configurations in the likelihood of adoption are:

#1 DR, #2 DB, RB1, RB3, #5 DRB1, #6 RB5, DRB3

From the environmental perspective, RB1 and RB3 cannot be recommended to landowners, due to Nitrate-N reduction capacity being too low. The other five configurations are good practices with high adoption potential and could be promoted to landowners in future extension effort.

5.10 Further Interpretation

Current research effort in conservation practices primarily focuses on their ability to improve the environment. However, this study shows that better performance regarding Nitrate-N reduction will likely result in a lower adoption potential. As shown in Fig. 25, although the linear relationship is not strong, the upward slope of the regression line indicates higher Nitrate-N performance tend to relate with lower adoption potential (larger number in ranking means lower adoption potential). The reason is better performance almost always comes with more complicated structure, more capital investment, more conflict of interest, and these factors will add lots of complications to a conservation practice, making a state-of-art practice less desirable. Performance must compromise with real-world complications to produce the best possible practice that is likely to be adopted and make real improvements to the environment.

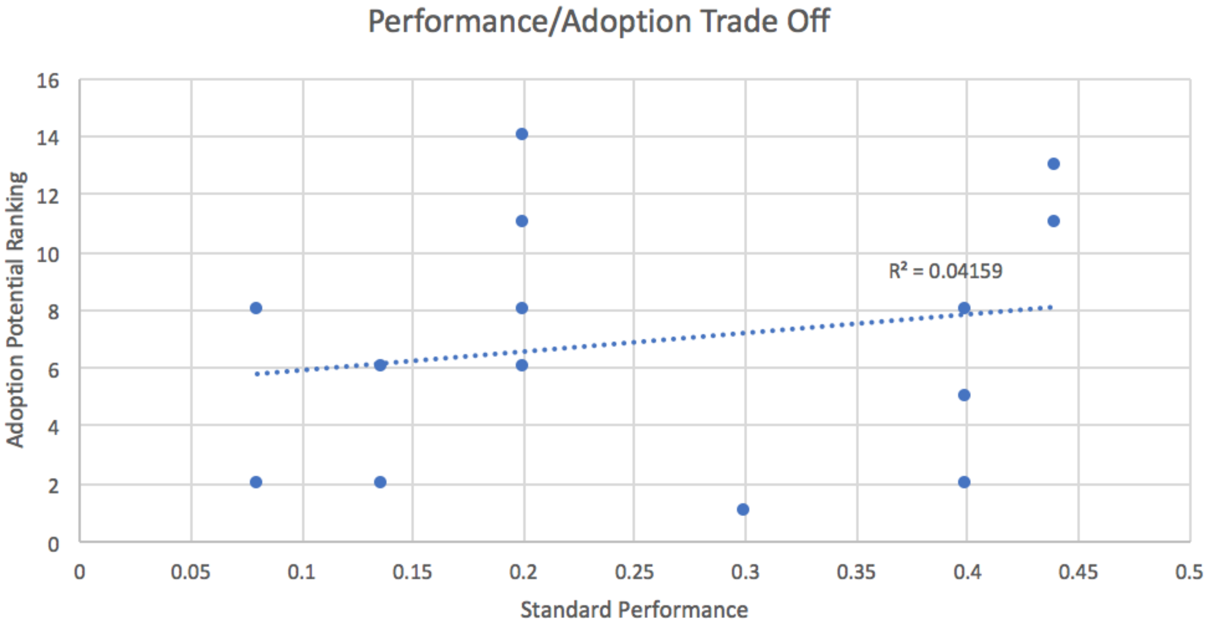

Fig. 25 Trade-Off between Performance and Adoption Potential

This study provides a guideline for finding the ideal bargain between performance and adoption potential. By adding ordinal grades of different factors for different practices, researchers can have a more thorough view of all aspects of their developed practices. Sometimes the worst practice performance-wise could make it to the top of the list due to financial savings and limited complications. This situation should be spotted and eliminated because although good practice without adoption is as good as none, adoption of a bad practice is a waste of money, and promoting bad practices reduces credibility at the same time, which may negatively impact future promotional effort.

This study also shows that internal recycling indeed produces better overall Nitrate-N reduction capacity, shown in Fig. 26. In this case, linear relationship between Nitrate-N removal performance and internal recycling mechanism is strong, and the slope of the regression line is steep upwards, indicating a strong positive relation between internal recycling and Nitrate-N removal capacity. For the fourteen configurations, the eight with internal recycling produce better Nitrate-N reduction capacity than the six without internal recycling. Configurations with internal recycling become undesirable because of the added maintenance effort and complexity, which could be addressed by better design and better pumping option. Internal recycling should be considered whenever Nitrate-N removal efficiency is a priority. It should be noted that one of the configurations with internal recycling make it to the top 6, which means with proper design and engineering, it is possible for internal recycling to be desirable.

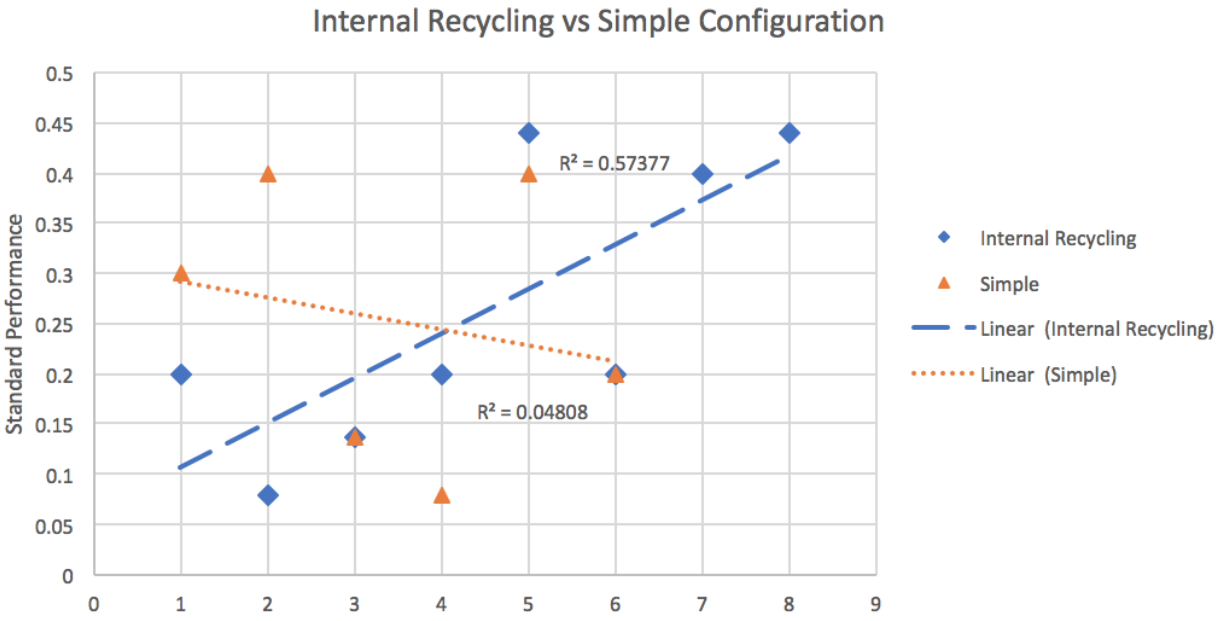

Fig. 26 Performance of Internal Recycling Configurations vs. Simple Configurations

CHAPTER 6

CONCLUSIONS

From literature, it has been shown that structural practices are less likely to be adopted by landowners. When trying to combine structural practices, it turns out internal recycling is not favored as well. Out of the five recommended configurations in the likelihood of adoption, only one configuration (RB5) involves internal recycling. While internal recycling helps increase Nitrate-N removal efficiency (the highest standard performance comes from successful internal recycling in DRB6), it adds too much cost and maintenance effort, making DRB6, the best configuration in term of Nitrate-N removal performance, the configuration that is least likely to be adopted, ranked 13 out of 14. On the other hand, two of the top-ranked practices in terms of adoption potential, RB1 and RB3, produce the least competitive Nitrate-N removal performance.

This study provides a framework test for the Nitrate-N removal performance and adoption potential of conservation practices by combining different conservation practices and calculate their outcomes in Nitrate-N removal and adoption potential. The result confirmed the feasibility of this attempt. Combination of conservation practices multiplies Nitrate-N removing capacity and combines advantages of different conservation practices as well. For example, the top two configurations in adoption potential, DR and DB, also produce promising Nitrate-N removal performance. Drainage water management itself will lose its capacity to reduce Nitrate-N under storm condition. Added woodchip bioreactor can reduce some Nitrate-N in drainage water before it enters waterbody. During normal condition, drainage water management structure works with woodchip bioreactor to produce higher Nitrate-N reduction capacity than individual practice. More attempts at different conservation practices could bring more possibilities.

All available conservation practices still require further studies and combination of conservation practices is not a well-developed strategy. This study illustrated the trade-off between performance improvement and adoption potential. The study was not able to develop a routine to build a model and analyze the effectiveness of different combinations, which would make future studies on the combination of conservation practices much easier. Future studies should focus on developing a model that simulates all available conservation practices and combinations. Adoption potential for conservation practices and combinations is always an important topic and should be addressed whenever new practices and combinations are under development.

CHAPTER 7

RECOMMENDATIONS FOR FURTHER STUDIES

This thesis is a theoretical approach to combine different conservation practices. It would be necessary to build the proposed model in experimental fields and find actual construction time and cost, together with many other complications.

After a real combination project is built, researchers should collect long-term data on yield, profit, Nitrate-N reduction, soil health, and community response from the experiment field.

Build a simulation model that can simulate each conservation practice and their combinations, like Hydromantis GPS-X, which is used to simulate activated sludge system. Such model will greatly improve efficiency in NPS pollution research.

Promote recommended combinations to landowners and continue research to find factors that influence landowners' adoption. More factors known will make likelihood estimate more accurate.

Find the solution for conflict of interest with fertilizer companies. If reduced fertilizer use no longer hurts fertilizer dealers, conservation practices will benefit from fewer restrictions and be easier to promote.

Joint effort to push government subsidy program is inevitable. Even for DB, the least expensive option, building conservation practices is still very expensive for individual farm owners. Without government subsidy, even the most environment-conscious landowners may have to struggle in making the decision. A specialized fund could be established by collecting higher tax for areas contributing more NPS pollution.

Fully developed education program utilizing all leverages to push better adoption rate from landowners.

Nitrate-N reduction capacity of retention pond needs revision. Currently, literature is making contradictory claims on the retention pond. The retention pond is the most expensive practice of the three mentioned. If used only as an intermediate for recycling (which is not very desirable) and entertainment, is not very cost-effective.

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