Effectiveness and Cost-Benefit Analysis of Agricultural Conservation Buffer BMPs to Address Water Quality: A Literature Based Study

Prepared by:

Kenton Beal

Abstract

Agriculture is a tremendous source of non-point pollution resulting in stressed water quality in waterbodies throughout the world. Conservation buffer best management practices (conservation buffer) are becoming better utilized to protect water quality in agricultural settings. Extensive literature sources suggest that conservation buffers can be beneficial in decreasing water quality stress by capturing nutrients and sediment but little literature is present discussing the cost efficiency and cost effectiveness of implementation. The effectiveness of conservation buffers is highly dependent on factors such as climate, topography, integrity, density, continuity, and soil composition in addition to buffer type and size. The land adjacent to streams and wetlands is typically very productive farm land and removal of this land from production can be a complicated subject for most farmers. The implementation of conservation buffers often results in a monetary loss to farmers unless government programs are in place to compensate farmers for conservation efforts. Furthermore, there may be a reoccurring loss due to land being removed from production in perpetuity. In some cases there may be an increase in income for farmers when government programs are advanced. This review analyzes and summarizes effectiveness and costs associated with the implementation and maintenance of conservation buffers.

(i) Introduction

Water quality issues related to agriculture has surpassed the early stages of recognition and theorizing with practical solutions now being implemented during the development or retrofit of farms. Farming is an integral part of society that is necessary for sustaining our population. Historically, farms were worked intensively with little concern for environmental impacts due to the simple fact that the impacts were not well understood. In present day we better understand the impacts of intensive farming including water quality issues associated with aggregate runoff. Today, according to the EPA, agricultural nonpoint pollution is considered the leading source of water quality impact on surveyed rivers and streams, the third largest source for lakes, the second largest source of impairments to wetlands, and a major contributor to contamination of surveyed estuaries and groundwater (EPA 2017). As an example, more than 70% of the delivered nitrogen and phosphorous in the Mississippi River Basin is contributed from the adjacent agricultural lands (EPA 2017). Intensive farming typically leads to water quality issues from the input of nutrients including nitrogen, phosphorous, pesticides, fecal bacteria and sediment.

Conservation buffer best management practices (conservation buffers) are considered effective techniques to protect waterbodies by acting as physical barriers to sediment, nutrient and pesticides. Conservation buffers may also reduce the flux of soluble nutrients by hosting uptake into growing plants and supporting environmental conditions that favor transformation such as denitrification (Hickey 2004). While conservation buffers are generally considered effective for the protection of water quality there may be variability in the true measurable effectiveness.

It has been suggested that current conservation guidance has been set forth by political backing that has some justification from scientific studies or the expectations of what may be given up by farmers (Hickey 2004). This method may not be adequate in order to properly onboard farmers that are uncertain if buffers can work for them. Hesitation from farmers may be present due to the worry associated with the removal of viable farm land from production to establish buffers that could have negative impacts of other productive farm land. Furthermore, worry may arise from the questioning of what sort of economic loss may be incurred by implementing conservation buffers. In many instances the land removed from production in riparian areas is some of the most productive on farms. There may be situations where the implementation of a suggested riparian buffer takes high quality soils out of production or the buffer introduces shade to crops or undesirable weeds. But is it possible that the removal of farm land from production for the implementation of conservation buffers can be financially worthwhile for farmers? More importantly, what are the characteristics of a cost effective conservation buffer BMP that adequately protects water quality?

(ii) Literature review approach

The purpose of this literature review is to first analyze the effectiveness of conservation buffers in addressing water quality issues and more importantly analyze the cost-benefits associated with the implementation of conservation buffers. This review concentrates on literature related to conservation buffer effectiveness and the costs of implementation. Google Scholar and online access to the UF library was utilized for gathering sources related to the topic. Searches for the review were screened to identify titles related to Best Management Practice (BMP) implementation and performance as well as quantitative monetary measures related to implementation. For this review, conservation buffers are defined as strips of permanent vegetation established as breaks between agricultural activities and waters of the US. Conservation buffers may include riparian wooded buffers or filter strips.

(iii) Results

The actual benefit of conservation buffers varies in literature but buffer effectiveness is generally attributed to the integrity, density, and continuity of a buffer. Variation in the range of effectiveness is likely attributed to specific site conditions that include factors such as topography and climate.

Grassed Buffers vs Riparian Buffers

McKergow et al. (2004) studied the effectiveness of grass and riparian buffers in the rainforest of Australia to determine dense grass buffers were more effective at trapping significant amounts of bedload, suspended solids, and total phosphorous than riparian buffers. Although the riparian buffer was not very effective in trapping pollutants it is still suggested that a riparian buffer should be present to protect and stabilize stream banks, an important component of heightened water quality. Abu-Zreig et. al (2004) also suggests grassed buffers were highly effective in sediment trapping and that performance was found to be directly related to filter length. The optimum filter length was found to be 10 m (32.8 feet). The increase of the filter length to 15 m (49.2 feet) did not improve its performance (Abu Zreif et al. 2004).

Separate studies by Wilson (1967), Choi (1992), and Van Diik et al. (1996) all reported that the type of vegetation, height and density significantly affect the performance of buffers. Abu-Zreig et. al (2004) takes this information a step further and suggests uniformity in flow was found to be a determinant of sediment trapping effectiveness in addition to the composition of vegetation cover. Flow patterns were dependent on topographic relief but were also be affected by vegetation age and composition. Pearce et al. (1997) reported that vegetation height is not a significant variable in grassed buffer performance as long as submergence did not occur.

A literature review performed by Clark (2015) used statistical analysis to determine contaminant load reductions. The study suggests almost all contaminants of concern (suspended particles, ammonium-nitrogen, nitrate-nitrogen, total nitrogen, dissolved phosphorous, total phosphorous) had an 80% load reduction with an 80 foot filter strip and suspended particles, total nitrogen and total phosphorus nearly achieve this load reduction with a 70 foot wide filter strip. Furthermore, is was determined that a 50 foot wide filter strip had considerably lower treatment levels for nitrogen and phosphorus than the wider widths, but with lower intensity use of adjacent contributing land areas. Most importantly, the statistically based recommendation include the use of a 30 foot woody zone for stream bank stabilization and 40-50 foot herbaceous zone for water quality protection. Wossnick and Osmond (2002) also suggests nitrate reduction was most effective using a combination of 30 feet of trees and 20 feet of grasses for the Piedmont and Upper/Middle coastal plain of North Carolina.

Cost-Benefit Analysis

The cost of conservation buffer implementation is variant across sources and is likely attributed to geographic location of implementation and surrounding land use. For example, a rural watershed with low land opportunity costs will involve less money than a more urban or suburban watershed. Furthermore, a certain soil type may be more advantageous for higher value crops resulting in higher land opportunity cost.

Bracmort et al. suggests that year 2000 grassed waterway establishment costs for the Black Creek Project in the Smith Fry watershed, Indiana was $755/acre. For implementation of grassed waterways, this value is very contrary to $168-400 as suggested by Lynch et al. (1999) in Maryland and $153-206 as suggested by Wossnick and Osmond (2002) in North Carolina.

Lynch et al. (1999) suggests a landowners decision whether or not to adopt a buffer will have to be based on his or her individual circumstances. This decision will be heavily determined by the costs to implement BMPs and reduction in income resulting from land removal from production. The removal of land from farming production and implementation costs are hefty values that many farmers may struggle to justify. The resulting change in production quantity may be uneconomical for a farmer unless cost share programs are in place such as Conservation Reserve Enhanced Program (CREP) (Lynch et al. 1999). Implementation costs and monetary benefits observed by a study by Lynch et al (1999) are shown in Tables 1, 2, and 3.

Table 1. Tree Buffer Costs (436-550 trees/a)

Task	Cost per acre
Plant by machine	$75-130
Plant by hand	$60-174
Plant material	$60-275
Site preparation (herbicide)	
Band	$30-50
Broadcast	$80-120
Replanting	$56-100
Maintenance	
Herbicides	$30-60
Mowing	$12-60
Total	**$218-729**

Table 2. Grass Buffer Costs

Task	Cost per acre
Planting	$10-50
Seeds	$100-225
Site preparation	$18-40
Fertilizer/lime	$30-50
Maintenance	
Mowing or herbicide	$10-60
Total	**$168-400**

Table 3. Change in net income

Proposed Change	Establish riparian buffer on 10 acres of land and enroll in CREP
Total income increases and cost reductions	$58,655
Total income reductions and cost increases	$52,700
Change in net income	$5,955

A study by Wossnick and Osmond (2002) breaks down conservation buffer costs into different categories. The first category of costs only occur in the first year and include seed and fertilizer. Other costs such as opportunity costs, labor cost and equipment costs may occur over the life of the BMP. This study was completed for the case of BMPs mandated for nitrogen control in the Neuse River Bain in North Carolina. The study identified the economic differences of BMP implementation across three regions of the state (Piedmont, Upper and Middle Coastal

Plain, and the Lower Coastal Plain. Establishment costs were between $153-207/acre for grassed buffers and around $70/acre for a loblolly pine buffer. The study determined that the profitability of conservation buffers differs by region and is highly dependent upon crop choice, crop rotation, current agricultural conditions and the type of CREP contract in place whether it be 10, 15, 30 years, or permanent. The study suggests when tobacco and cotton are rotated and grown close to streams (high opportunity cost) any type of buffer has a negative net profit in the upper and middle coastal plain. Contrary, if the same crop rotation occurs without planting near streams and ditches (low opportunity costs) grass buffers are not profitable but forest buffers are. Table 4 summarizes the economic profitablility findings from Wossnick and Osmond (2002). In general, the profitability of buffers is highly dependent on the opportunity costs of the land (rotation, planting method, planting proximity to streams and ditches) and the type of CREP contract in place.

Table 4. Summary of the farm economic profitability of CREP cost-shared buffer and filter strips, Neuse River basin -5% interest.

	Total net profit ($/a) and Annual Profit ($/a)		
BMP	**Permentant Contract**	**30-year contract**	**15-year contract**
Piedmont(Opp. Cost land $53/a)[1]			
Forested buffer	832 (80)	588 (57)	411 (40)
Fescue-bahia grass buffer/filter strip	158 (15)	-66 (-6)	-232 (-22)
Switchgrass buffer/ filter strip	125 (12)	-98 (-9)	-264 (-25)
Upper and Middle Coastal Plain(Opp. Cost land $70/a)[2]			
Forested buffer			
Fescue-bahia grass buffer/filter strip	655 (63)	411 (40)	235 (23)
Switchgrass buffer/ filter strip	-18(-2)	-242 (-23)	-408 (-39)
Shrub buffer	-50(-5)	-275 (-26)	-411 (-42)
Upper and Middle Coastal Plain(Opp. Cost land $630/a)[3]			
Forested buffer	-5,157(-497)	-5,401(-520)	-5,578(-537)
Fescue-bahia grass buffer/filter strip	-5,831(-562)	-6,055(-583)	-6,221(-599)
Switchgrass buffer/ filter strip	-5,863(-565)	-6,087(-586)	-6,253(-602)

[1] Two-year rotation of wheat conventional-till and tobacco; tobacco NOT grown close to streams.

[2] Three-year rotation of tobacco, wheat, and soybeans; tobacco NOT grown close to streams and ditches.

[3] Three-year rotation of tobacco, wheat, and soybeans; tobacco grown close to streams and ditches.

Lui et al. (2013) compared multiple conservation buffer options and found that reforestation practice involved the least cost for implementation and the most appreciated benefits. Most investments associated with reforestation last 2-3 years with little investment following (Lui et al. (2013). The Cost effectiveness ratio of reforestation on the reduction of Total Phosporous and Total Nitrogen were 8% and 4% in 10 years, respectively (Lui et al. 2013).

Qui (2003) studied the cost effectiveness of installing buffers in Missouri. During the study private costs were tied into land and opportunity cost and buffer installation costs. The study found that when a government subsidy was available to a producer there was a net benefit to the producer but otherwise the implementation of buffers was a cost burden. They considered the private costs to be associated with land opportunity cost and buffer installation cost. From this, the annualized cost of the buffer was $62.4/ac.

A study by Rein 1999 suggests the installation of conservation buffers results in costs to the grower including removal of some agricultural benefits and installation but are outweighed by the benefits of minimizing agricultural related erosion. The study determined that farmers may experience a net benefit of $1,488 in the first year and $6,171 over five years for a 36 acre system (Rein 1999).

Epp and Hamlett evaluated changes in field costs and revenues with seven conservation best management practices and two nutrient management programs at three sites in Pennsylvania. The study found that strip crop with waterway was typically the only or most profitable BMP at each site.

Economic benefits to society may be observed when considering the lowered quantity of sediment reaching waterbodies resulting from the implementation of conservation buffers. Although this topic extends beyond the focus of this review it should be considered when analyzing a cost-benefit analysis for societal well-being. Santhi et al. (2001) evaluated the estimated annual economic impact of implementing 2 million miles of buffer. Net costs of buffers were reduced supply for consumers, program payment to landowners, federal technical assistance cost, and producer's net gain from higher prices due to reduced supply. The net cost was compared to the value of water quality improvements from Ribaudo et al. (1999). It was determined that the annual net cost of the 2 million mile buffer goal was $793 million and the value of water quality improvements was $3288 million for a benefit cost ratio of 4.1. The study determined that buffers would be a benefit to society economically and environmentally.

Contrary, a study by Bracmort et al. (1999) suggests a negative benefit cost ratio for society. This was determine through the simulation of a SWAT project to quantify sediment and Total P reduction occurring as a result of BMP (Best Management Practice) implementation. Monetary values were assignment to water quality improvements expressed in year 2000 dollars. Establishment costs were obtained from project records. The study suggests that the cost of establishment and maintenance of grass swales outweighed the benefits as predicted by SWAT when analyzing the net contribution to society's overall well-being.

(iv) Discussion

From a review of the literature, it is evident that conservation buffers do provide water quality benefits but the actual benefits vary significantly across sources. Furthermore, landowners may not always see cost-benefits from the implementation of conservation buffers. The cost-benefit effectiveness of conservation buffers cannot be generalized but should only be determined through site specific analysis. Furthermore, the effectiveness of a conservation buffer is generally dependent on the integrity, density and continuity of a buffer. Density and continuity of conservation buffers will be directly related to physiographic conditions and the most suitable vegetative composition for the scenario. Physiographic conditions and/or current farming practices cause variation of the environmental benefits and costs of implementation for conservation buffers. The vast variation in results can make the development of generalizations complicated. Due to the need to discuss suggestions with land owners and farmers for the purpose of implementation in would be helpful to have reliable generalizations for local physiographic conditions. The current cooperative and extension systems tends to give farmers educational tools and options for implementation but farmers tend to make decisions based on monetary inclusion instead of choosing options most suitable for their farm. The likelihood of BMP adoption by farmers was studied by Paudel et al. 2008. This study was completed using a logistic regression procedure to assess socioeconomic attributes on adoption decisions by Louisiana dairy farmers relative to cost-share and fixed incentive payments. The study found that the BMPs with the highest rates of adoption were directly correlated to the average cost of adoption rates and cost-share percentage associated with the BMP. It was also determined that visitation with an NRCS staff was the most critical action step in the BMP adoption decision process. With this knowledge NRCS agents should be working closely with farmers to discuss options. The implementation of conservation buffer should follow generalities but the actual cost effectiveness will always be site specific. For an appropriate economic assessment of effective conservation buffers, environmental economists need to work closely with agronomic and water-quality experts to account for differences in local physiographic conditions and in farm-level characteristics. This information can lead to site specific cost-benefit analyses. In many circumstances the costs for implementation will be nearly fixed. Major variation in opportunity costs will be present due to site specific traits. Land use opportunity values will vary depending on climate and geographic position. Some crops will be better suited for particular soil types.

(v) Conclusions and Recommendations

Among the most surprising results from this study is the fact that there is tremendous variation in the cost-effectiveness of conservation buffer implementations on farms. Furthermore, the findings from this review suggest that the generalization of conservation buffers may not be a cost effective or physically effective way to approach the implementation process due to variation between sites. Physical geography may be the driving factor of variation. Among the many sub-branches of physical geography is soil composition which can be considered a determinant of the vegetative composition of a conservation buffer. Also, a very important component of soil composition is the potential productivity of the soil and the value of the crop most suitable for it. In general land opportunity costs will be greatly driven by the suggested value of land and the crop produced on it. This cost is certainly variable across sites but trends may be present based on region, soil type and historic farm practices. In order to narrowly understand the cost-effectiveness of a buffer these factors must be taken into consideration.

All studies examined during this review suggest conservation buffers are effective for water quality protection but there is variability in the measurable effectiveness of conservation buffers. Variability is typically traced back to width and vegetative composition. While effective widths may vary based on site specific conditions literature consistently suggests a minimum 50 foot buffer for water quality protection constructed using a combination of a grassed area and a riparian buffer. The riparian buffer provides stability to stream banks and adds shading to water bodies. The grass buffer can effectively capture nutrients and sediment if the planted area moves water in a uniform manner. Furthermore, farmers can maintain the grass buffer and the shading of crops is minimized.

The process of conservation buffer implementation may include but is not limited to site identification, site selection, discussions with farmers, bmp selection, and construction. Presenting generalizations can be troublesome because of the vast differences that may be present between sites. Land use values should always be weighted heavily before implementation to verify cost-effectiveness for farmers. Government involvement is necessary for implementation of conservation buffers through the collection and distribution of funds for cost share programs that make conservation buffers possible. In general, conservation buffer implementation is not feasible for farmers unless there are cost share and incentive options available.

(vi) References

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