Economic Analysis of Management Practices to Reduce Phosphorus Load to Lake Eucha and Spavinaw

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Abstract:

Changes in management practices are often proposed to reduce phosphorus loading from a watershed due to over application of poultry litter. This study determines the choice, location, and level of each best management practice in the watershed to meet a Total Maximum Daily Load and margins of safety at least cost.

Keywords: best management practice, phosphorus runoff, poultry litter, Target MOTAD

Introduction:

In recent years there has been a growing concern about the quality of drinking water, especially in areas where there are a large number of animal feeding operations. Many watersheds experienced eutrophication which is attributed to excess phosphorus runoff from poultry litter application on farmland. The Eucha-Spavinaw watershed is of interest because the city of Tulsa, Oklahoma receives most of its drinking water from this watershed. The City of Tulsa built reservoirs Spavinaw and Eucha to guarantee a constant supply of clean water. Before 1980 there were very few poultry houses in this area. Most of the land in the watershed was used for cattle grazing while very little was used for row crop agriculture. However, in the 1980s and 1990s poultry farming in this area increased dramatically. With the increase in poultry houses, there was an increase in poultry litter. Since poultry litter is an inexpensive fertilizer, and readily available in the watershed, farmers in the watershed began applying it to their fields. When the poultry litter is applied to meet nitrogen needs, more phosphorus is applied than plants will utilize. Consequently, extra phosphorus builds up on or near the soil surface and during a storm event, runoff and soil erosion carries with it phosphorus to an offsite location. The phosphorus then ends up in the water supply, which promotes eutrophication. As a result, the City of Tulsa, in the past few years, has had taste and odor problems in their drinking water. Consequently, consumer complaints increased dramatically, which prompted the City of Tulsa to provide additional treatment to the drinking water and contact researchers to find the cause of the water problem. The focus of this study is to determine which BMPs should be used at each location in the watershed to meet possible TMDLs at least cost and minimize future taste and order problems.

Objectives:

The overall objective of this research is to determine which best management practices reduce nonpoint phosphorus loss at least cost to the public. Specific objectives are to, a) determine the choice and level of best management practice (BMP) implementation for each spatial location in the watershed to meet possible phosphorus total maximum daily loads (TMDLs) at least cost, b) for each TMDL determine whether the margin of safety (MOS) can be met most efficiently by changing practices and/or by further reducing average annual phosphorus loss, c) compare the economics of switching from cow-calf to stocker operations on the cost of meeting phosphorus TMDLs, and d) determine the most cost effective pasture management BMP for each soil type-land use area in the watershed.

Contributions:

Past research determined the effect of different soil types and management practices on phosphorus (P) loss (Marumo 2007). We will go one step further and find the most cost effective livestock/pasture management BMP for each soil type-land use. Previous research analyzed transportation patterns for poultry litter and possible litter to energy power plants under various P-loading and margins of safety targets (Ancev 2003, Marumo 2007, Machooka, 2007). We will incorporate previous research in to this research and investigates if the margin of safety is being met by changes in management practices and/or if it is due to reducing the average annual P loss further. Previous research showed a least cost mix, location, and magnitude of grazing management practices to reduce P loading (Marumo 2007). We will find the level of best management practice to implement for each location to meet the phosphorus TMDLs at least cost.

Literature Review:

There have been several studies on point and nonpoint pollution in groundwater and watersheds (Griffin and Bromley 1982; Milon 1986; Park and Shabman 1982; Whittaker 2005). The best management practice (BMPs) are designed to control the amount of runoff to a lake or stream. Park and Shabman (1982) stated that best management practices are needed to control nonpoint pollution. Their paper gives an empirical case of how linear programming is to determine the tax/compensation scheme in a multi-jurisdictional watershed area. They found that a multi-jurisdictional area may result in benefit-cost allocation that will prohibit the approval of an economically efficient, nonpoint pollution control strategy. Griffin and Bromley (1982) noted that nonpoint pollution exists whenever an agent's contribution cannot be measured by direct monitoring. Therefore, it is impossible to enforce regulations (taxes or subsides) on emissions when the exact sources of pollution cannot be identified. There are three basic economic effects of runoff according to Griffin and Bromley (1982). First, the farmer loses resources when the runoff removes sediment and nutrients from the farmland. Second, when the social discount rate is less than the discount rate facing the farmer, the farmer will use up the soil resource faster than is socially optimal. Finally, the physical resources removed by the runoff are pollutants. The authors noted that social benefits can be gained if policies are implemented for point and nonpoint source. However, nonpoint incentives are standard and are not realistic because it is impossible to monitor nonpoint source pollution.

There have been a number of studies that have investigated nonpoint source pollution policies which work to maximize net returns at least cost (Johnson, Adams, and Perry 1991; Mapp et al. 1994; Larson, Helfand, and House 1996; Qui and Prato 1999; Whittaker 2005). There have also been several studies that have utilized the target MOTAD approach (Tauer

1983) to incorporate environmental risk (Teague, Bernardo, and Mapp 1995) and/or economic risk (Qui, Prato, and Kaylen 1998; Qui, and Prato 1999) in an agricultural watershed to maximize expected returns. Qui, Prato, and Kaylen (1998) extended the application of the Target MOTAD model by Teague, Bernardo, and Mapp (1995) to take into account economic risk in agricultural watersheds associated with the changes in crop yield. Instead of the net return deviation being below the target return level for the nature, they modified the model such that the average pollutant deviations above the target or the environmental indicator are to be minimized. They calculated annual net returns for a farming system in different soil types, because crop yields differ by soil type. They also estimated the environmental indicators using the agricultural non-point source pollution model by Young and colleagues (1987). These results indicated that economic risk had very limited impact on tradeoffs between total watershed net returns and nitrogen runoff under conditions of economic risk neutrality and risk aversion. There was only a slight difference between economic risk neutrality and economic risk aversion. They stated that this result can be explained by the fact that environmental impacts are associated with and overshadow the economic impacts.

Research at OSU utilizing SWAT and MOTAD to evaluate Lakes Eucha and Spavinaw:

Ancev (2003) determined an optimal level of phosphorus abatement for the Eucha-Spavinaw watershed. This was done by minimizing the sum of costs to reduce phosphorus loading from point and non-point sources and the cost for environmental damages as measured by costs of public water treatment and from recreation losses due to phosphorus loading. To reduce phosphorus loading, he also determined the most cost effective technologies and polices. Finally he looked the optimal spatial allocation of waste management practices. Machooka (2007) determined the costs of meeting different TMDLs when rainfall / phosphorus runoff varied. She determined the poultry application rates to each land class, such that the TMDLs were met by varying the rate of application. Marumo (2007) determined the least cost mix, location, and magnitude of BMPs to meet phosphorus loading targets and within specified margins of safety or average deviations over the runoff target. His analysis determined possible management practices of converting litter to energy, adding alum to poultry litter, pasture management, and litter within an from the watershed.

SWAT Data:

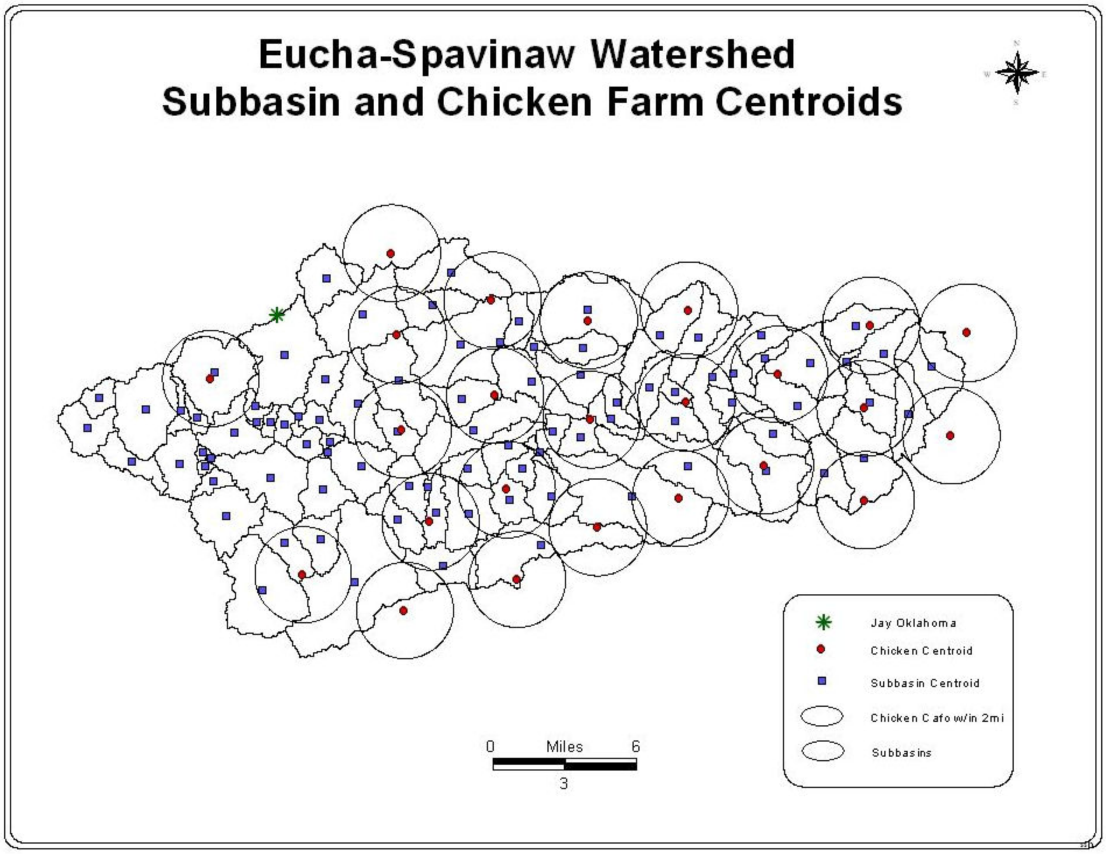
A calibrated SWAT simulation model for the Eucha-Spavinaw watershed was utilized (Storm, et.al 2001). The 93.1 thousand hectare (tha) watershed was divided up into 2400 soil type-land use areas (HRUs). The four largest land uses are forest (47.4tha), pasture (35.9tha), crop (1.7tha), and urban (1.7tha). Forty-nine management practices were simulated on the 35.9 thousand ha of pasture. These included applying 0 to 5 Mg of litter per hectare and/or 0 to 200 kg of commercial nitrogen. Three stocking rates for both cow-calf and stocker operations were 0.86, 1.00 and 1.24 animal units/stocking rates per hectare and three levels of biomass left after grazing of 1.1, 1.6, and 2.0 Mg per hectare were considered. SWAT was used to simulate biomass yield and phosphorus loss from each pasture HRU using 55 years of daily temperature and rainfall. Each SWAT simulation consisted of 13 years of weather data. In each simulation weather from 1993-1995 were used to initialize the SWAT model ten additional weather years from the 1950 – 2005 weather (daily rainfall and temperature) years were randomly selected (without replacement) to create data for the 13 year simulation run. The first 3 years of the SWAT simulation run were used as warm up years for the model and only data from the last 10 years were used in the analysis. The process was repeated using 6 weather sets, so that data from 60 (6 weathers * 10 years) years of simulation were available.

OSU Cow-Calf Budget Data:

Monthly estimates of biomass consumed were obtained from the SWAT simulation. Estimation of the economic value of biomass consumed is problematic because the monthly production varies and forage is produced only during a few months each year. A cow-calf unit requires forage throughout the year and a stocker requires forage for the few months that it is on the land. This problem was addressed by utilizing a linear programming model (Smith, 1999) that allowed carry-over and/or hay harvesting to transfer unconsumed forage from one month to the next. The net value of biomass consumed was taken from the LP model after allowances from costs of inter-year transferring of forage by stockpiling, bailing, and/or protein supplementing.

Methodology to Obtain the Poultry House Centroids:

The transportation matrix was based on four distance calculations. The 300 poultry farms were divided into 24 groups such that no poultry farm was more than two miles from a group centroid as represented by circles on the map. This was necessary to limit the amount of litter sources points in the linear model. The first distance, was obtained by an ArcView 3.3® script which determined the average distance from each poultry farm to the centroid of that group. This average distance was needed, since not all the farms were exactly two miles away from the poultry farm centroid. Then a nearest feature algorithm was used to determine the distance from each poultry farm centroid to the nearest road. The next distance was determined by utilizing a multi-path script, which started from the point on the road nearest each poultry farm centroid and went to the point on the road nearest each subbasin centroid. The final distance required was the distance from the road to the subbasin centroid, in which the nearest feature algorithm was again utilized. By placing each distance in a matrix we were able to obtain the distance from each of the 24 poultry farm centroids to each of the 92 subbasin centroids, which resulted in 2160 transportation distances. This same process was utilized to create the transportation matrix from each poultry farm centroid to a proposed litter to energy plant in Jay Oklahoma. Transportation prices were obtained through correspondence via internet and email. “Currently BMPs, Inc. is coordinating all transactions between the buyers, sellers, and haulers” (Oklahoma Litter Market, 2005). Through correspondence with Sheri Herron at BMPs, Inc., loading, hauling, and spreading prices were obtained. The cost for loading and coordinating a haul ranged from $7.50 to $8.00 per ton. The cost of hauling ranged from $3.25 to $3.50 per loaded mile per truckload with truck averaging 23 tons per load and the loaded mileage is one way distance. The cost of spreading was $6 per ton.



Methodology:

The following methodology was used to select BMP's to meet possible TMDLs within a specified MOS. This required determining the most cost effective pasture management BMP for each soil type-land use. Target MOTAD is a modification of MOTAD model. Target MOTAD was developed to be computationally efficient and to generate solutions that met the second-degree stochastic dominance (SSD) test (Tauer, 1983). For the proof that Target MOTAD is SSD refer to Tauer, 1983. The objective function of the Target MOTAD model was to maximize net farm income subject to a set of resource constraints and a set of constrains that require the income not to fall below a target value. Teague, Bernardo, and Mapp made some modifications to the Target MOTAD model to incorporate the effect of environmental risk. Qiu, Prato, and Kaylen made further modifications to the Target MOTAD model by Teague, Bernardo, and Mapp to account for both economic and environmental risk.

This paper will utilize the modified Target MOTAD by Qiu, Prato, and Kaylen (1998).

1. $Max\ E(z) = \sum_h \sum_j I_{hj}\, x_{hj} - \sum_c \sum_h s_{ch} L_{ch} - \sum_c s_{co} L_{co}$ (max. farm grazing income)

   $h = 1, \ldots, 2400 \quad j = 1, \ldots, 49 \quad c = 1, \ldots, 24$

subject to

2. $\sum_j x_j \leq b_h$ (area in each HRU)
3. $\sum_h \sum_j a_{hj}\ x_{hj} - \sum_c \sum_h L_{ch} = 0$
4. $\sum_c \sum_h L_{ch} + \sum_c L_{co} = QL_c$ *(Total Quantity of Litter*
5. $\sum_h \sum_j \overline{p}_{hj} x_{hj} \leq T_e$ *(ave. ann. P loss < TMDL)*
6. $T_e - \sum_h \sum_j v_{hjr}\, x_{hj} + d_r \geq 0$ $r = 1, \ldots, 60$
7. $\sum_r p_r\, d_r = \lambda_e$ $\lambda_e = M \rightarrow 0$ (reduce MOS)

for all x_j and $L_j \geq 0$, where E(z) is the expected return from the watershed; I_{hj} is the expected per hectare income from management practice *j* on HRU *h*; x_{hj} is the level of management practice *j* on HRU *h*; s_{ch} is the cost to ship a ton of litter from poultry centroid *c* to HRU *h*; L_{ch} is the quantity of litter shipped from poultry centroid *c* to HRU *h*; s_{co} is the cost to ship a ton of litter from poultry centroid *c* to outside the watershed *o*; L_{co} is the quantity of litter shipped from poultry centroid *c* to outside the watershed *o*; a_{hj} is the amount of resource *h* used per unit of activity *j*; b_h is the land area in HRU *h*; *Te* is the target identified for average phosphorus loss from the watershed, v_{hj} is the actual phosphorus loss in year from HRU h when MP_j is selected (or in this study the maximum average annual phosphorus loading from the watershed); d_r is the deviation above T_e in year *r* (or in this study the average amount of phosphorus loss over the target); p_r is the probability of year *r*; and λ_e is the expected value of average deviations above an environmental target.

The programming model will select the BMP for each of the 1300 soil-pasture land areas. Alternative solutions are obtained such that average annual P loss from the watershed would be less than of 40, 35, 30, 25, or 20 Mg/yr. The farmer's income will be maximized under each set of restrictions for average annual phosphorus losses of 40, 35, 30, 25, and 20 Mg and for each allowable deviation. As the restrictions increase the maximum income will decrease. The cost of reducing the average P loss is the change in the income from the previous restriction. The program will also require average deviations above the mean or target phosphorus loss be within a margin of safety. The deviations above a stated MOS may being met by changing of management practices and/or by further reducing the average annual phosphorus loss.

Understanding Margin of Safety

For example let the limit of average annual phosphorus loss is set at 30Mg/yr. If the P loss for 1 year is 40 Mg and then next year is 20 Mg, then average phosphorus loss is 30 Mg per year. As a result, the average deviation of phosphorus loss over the mean for the 2 years is 5 Mg per year. However, if the average deviation over the mean (5Mg/yr) is not acceptable, then either a change in management practices to decrease the deviation over the mean must occur or the mean annual phosphorus loss must be decreased below 30Mg/yr. In this study, we parametrically set alternative limits on the average deviation of phosphorus runoff above the average target to determine the cost and changes to management practices to reduce variability over the mean.

Results:

The management practices compared below, represent those which are the least costly for producers to adopt to meet increasingly restrictive average phosphorus losses (40 to 30 to 20 Mg/yr) when cow-calf and then stocker operations are considered. The Lp solution for meeting a given phosphorus loss target at least cost satisfies the requirement that marginal abatement costs be equated throughout the watershed.

Whether it is in the overall interest for a producer to change from one management practice to another depends on both the change in profits and the reduction in P loss. The objective here is to meet a watershed target with the minimum cost to all producers. Assume the producer is using MP_1 with met return of Π_1 and a phosphorus loss of P_1 kg/ha. If the producer changes to MP_2 with net returns of Π_2 and a phosphorus loss of P_2 kg/ha, where $P_2 < P_1$, the cost per kg of P loss abated is $(\Pi_1 - \Pi_2)/(P_1 - P_2)$. The marginal abatement cost depends on the change in net revenue divided by the change in phosphorus loss.

Comparison of intense grazing and minimum pasture cover while using cow-calf operation:

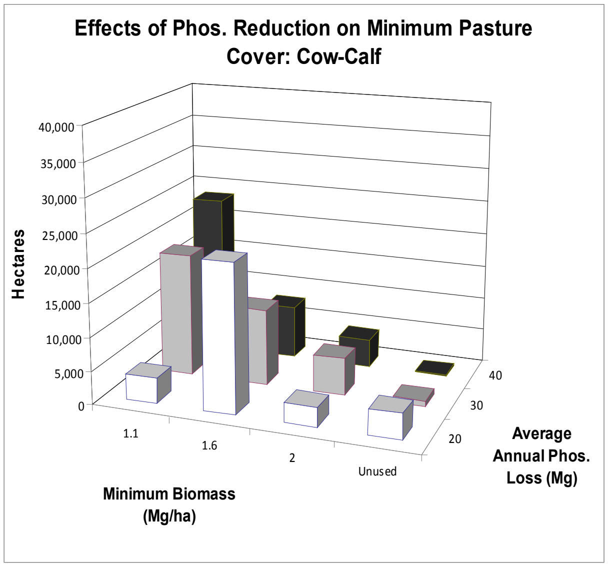


Figure 1

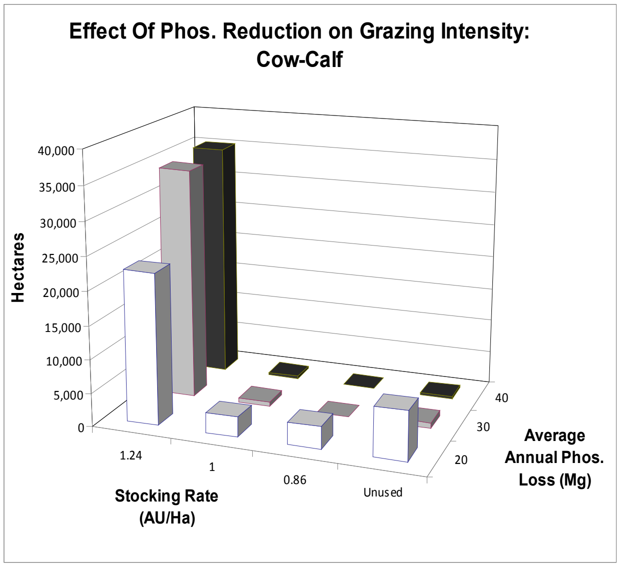


Figure 2

Figure 1 shows, that as the average allowable phosphorus loses are reduced from 40 to 30 to 20 Mg per year that the least costly treatment is for producers to leave more biomass after grazing. The number of hectares with only 1.1 Mg/ha declines from approximately 22,000 to less than 5,000 while the number of hectares with 1.6 and 2 Mg of biomass remaining after grazing increases as the phosphorus runoff limit is reduced. Figure2 shows similar effect with stocking rate. When allowable P loss is 40 Mg, most of the watershed is grazed at a rate of 1.24 au/ha. As the allowable P loss is reduced more of the watershed has lower stocking rates and some of the pasture goes unused. However the number of hectares where it was least costly to increase minimum biomass after grazing exceeds the number of hectares on which the stocking rates were reduced. It should be noted that management different practices are used in different part of the watershed. No single management is used throughout the watershed.

Comparison of intense grazing and minimum pasture cover while using stocker operation:

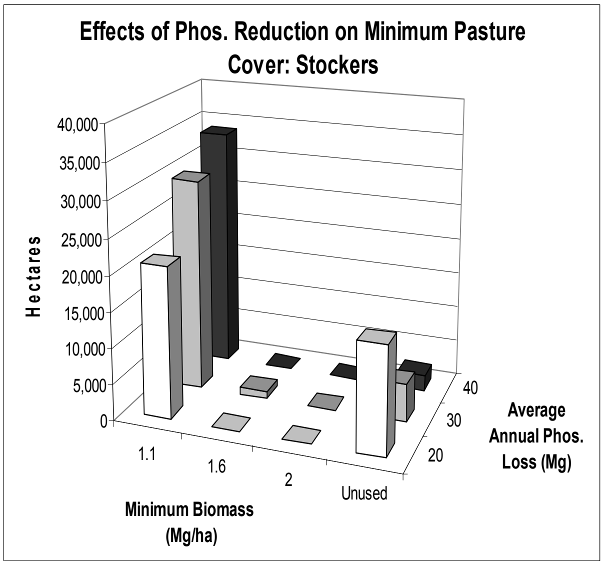


Figure 3

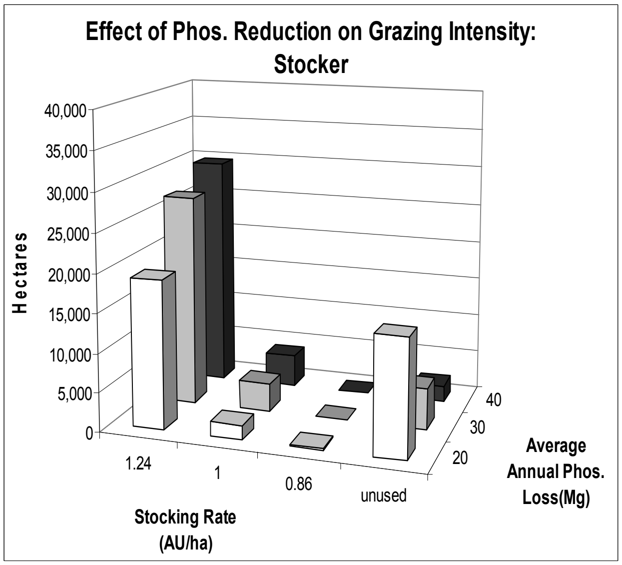


Figure 4

There is less increase in minimum pasture cover/biomass and grazing intensity/stocking rate when stocker operations are employed rather than cow-calf enterprises are used. Figure 3 shows, as the average annual phosphorous loss is decreased from 40Mg to 20Mg, the amount of land with low pasture cover (1.1 Mg/ha) decreases, from approximately 33,700ha to 21,000ha. When the average annual phosphorous loss is limited to 20Mg about half of the land is still intensively grazed with stockers. However some pasture is unused. Figure 4 shows as the average annual phosphorous loss is decreased from 40Mg to 20Mg, the amount of land used with grazing intensity (1.24 AU/ha) decreases from approximately 29,700ha to 19,000ha. When the average annual phosphorus loss was at 20MG, all the land was either used at low to medium grazing intensity or not used at all.

Cost of decreasing the average annual phosphorous with cow-calf and stocker operations:

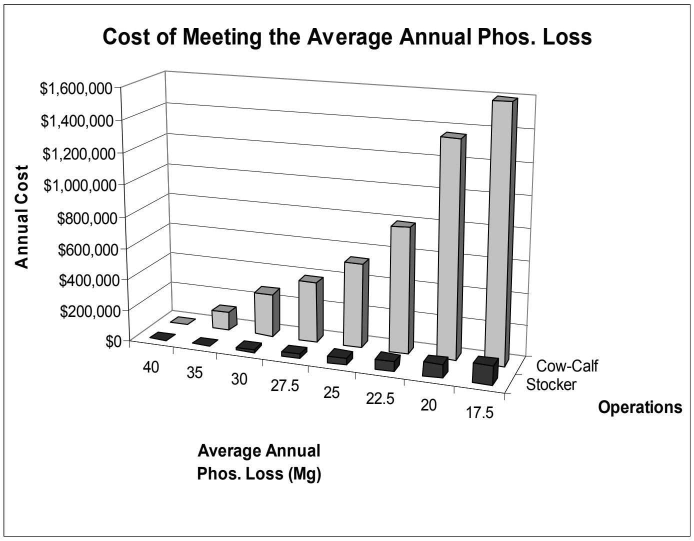


Figure 5

When comparing the annual costs for using a stocker versa a cow-calf operation to reduce the average phosphorous loss; there was a significant decrease in cost at every level of average annual phosphorous loss. When the cow-calf operation was used, the annual cost increase drastically as the average annual phosphorous loss was decreased. The annual cost increased from $206,000 to over $1,566,000, when the average phosphorous loss is decreased from 40Mg to 20Mg, respectfully. When stocker operation was used the costs also increase but only slightly. There was no cost of employing a stocker operation when the average annual phosphorous loss was 40Mg. When the average annual phosphorus loss was decreased to 20Mg then cost only increased to approximately $118,000. This suggests that using a stocker operation would be significantly less costly when decreasing the average annual phosphorus loss of the watershed.

Profits for cow-calf versa stocker operation

Operation	Profits
Stocker	$5,212,612
Cow-Calf	$2,147,594

Findings suggest that stocker operations are more than twice as profitable as cow-calf operations when there are no constraints on phosphorus runoff. Research by Smith (1999) suggests that it is more profitable to retain stockers from a cow-calf operation and purchase additional stockers, then to run a cow-calf operation only. Confirming our results, Terrance Bidwell (2008) stated that in Oklahoma it is more profitable to run a stocker operation over a cow-calf only operation.

Conclusions:

The results are still preliminary. However, results for cow-calf operations showed stocking rates decrease, minimum biomass left after grazing increases, and producer income declines as phosphorus runoff targets were reduced. Results for stocker operations showed that stocking rates decreases slightly, minimum biomass left after grazing did not change, but the amount of land used for grazing decreased, and the producer income declined slightly as phosphorus runoff targets were reduced. The results from this study suggest that running a stocker versa a cow-calf operation is more profitable. Also higher stocking rates and lower minimum biomass per hectare can be employed under a stocker operation, these results can be explained by the fact that stockers are on the land few days of the year; therefore, allow for grass to be taller during non grazing days. The rate of change in management practices varied by major soil type. Some phosphorus load reduction can be obtained for less than $5 per kg of phosphorus but these costs increased exponentially as attempts were made to reduce the annual phosphorus load to the level recommended by the OWRB in 2002. The results imply that those considering implementing BMPs to meet very restrictive TMDLs need to consider a wide range of management practices.

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