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Project Summary

Reducing Runoff Pollution Using Vegetated Borderland for Manure Application Sites

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The objective of this study was to evaluate the mechanisms and effectiveness of vegetated buffer zones or borderland areas in reducing pollutional impact of rainfall runoff from sites used for land application of livestock or poultry manure. The effect of grass buffer-zone length on the reduction of pollutant concentration and mass in runoff from land application areas was studied over a nine-month period for several different buffer-area length/application-area length ratios. Also, one-dimensional mathematical models were developed to investigate the effects of dilution and infiltration.

The field study consisted of measuring rainfall runoff pollutional characteristics at various distances downslope from areas where caged-layer poultry manure was applied regularly. Evaluation of nutrients and solids in runoff samples revealed that grass buffer zones effectively reduced the pollutional concentrations and that the amount of reduction increased with an increase in the ratio of buffer-area length to application-area length.

The model and experimental results suggest that infiltration is the major factor affecting buffer-zone length. Soils having greater infiltration rates will require shorter buffer lengths to obtain the same percent reduction of pollution potential. The results also indicate that required buffer-area length is a function of the application-area length. Application areas having longer slopes require longer buffer lengths to obtain the same percent reduction of the pollution potential. The pollution potential of the application area likewise affects buffer length because a greater percent reduction is required to obtain a desired water quality standard if the application area runoff pollution potential is larger.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Land application of animal manure has long been recognized as an efficient means of waste disposal and as a means of manure utilization for crop nutrients and soil amendment. In recent years land application of municipal and industrial wastes has increased. Although the experimental part of this study evaluates runoff pollution from land application sites receiving animal manure, many of the principles discussed apply to land application sites receiving other wastes, especially wastes which have high runoff pollution potential for nutrients or oxygen demand. Such wastes are municipal sludge, poultry processing wastes, fermentation sludges, and meat processing wastes.

Land application sites are a potential source of nonpoint source water pollution. Section 208 of the Federal Water Pollution Control Act Amendments of 1972, Public Law No. 92-500, specifies the development of water quality management plans to control nonpoint source pollution. The U.S. Environmental Protection Agency (EPA) proposes the use of Best Management Practices (BMPs). These are defined for agriculture as management practices which best reduce nonpoint source pollution while being consistent with sound agricultural principles. Such BMPs are to be used, in lieu of runoff collection and treatment prior to stream discharge, as the only feasible nonpoint source control measures.

Grass buffer zones are one of the possible BMPs. Other terms used almost interchangeably with grass buffer zone are filter strip, grass filtration area, field borders, or borderland areas. Land application sites near streams, ditches, waterways, or water impoundments can particularly benefit from buffer zones which reduce runoff pollution potential. Mechanisms acting in the buffer area to reduce pollution potential include dilution due to rainfall, infiltration, and settling or filtering of materials. These mechanisms in turn depend upon the vegetation, soil surface condition, soil hydrologic properties, topography and rainfall-runoff conditions. However, very little research has been conducted to determine the size of buffer zone needed for a specified reduction in runoff pollution potential.

The total amount of land required for a complete land application system increases as the buffer-area size increases. Buffer zone research is essential since regulations establishing arbitrary buffer distance can have a tremendous impact on land-based waste treatment system costs.

The objectives of this research were: (1) to develop models based on hydraulic processes to predict reductions of the pollution potential for a land application/buffer zone system and (2) to experimentally determine effectiveness of various buffer lengths based on reduction of runoff pollution concentrations while maintaining a relatively constant manure load on the land application areas.

Conclusions

Land application of manure to a grass area by surface spreading increased the pollution transported by rainfall runoff considerably when compared to a similar area not receiving manure. Moreover, a high pollution potential was maintained by frequent manure applications (normally every two to three weeks), and this allowed evaluation of buffer areas under maximum pollution potential conditions.

Grass buffer areas effectively reduced pollutional concentrations of nutrients (such as total phosphorus (P) and total Kjeldahl nitrogen (TKN)), organic material (total organic carbon (TOC)), and solids in runoff from manured areas. However, to reduce concentrations to within 10% of the concentrations in runoff from a similar area not receiving manure may require a buffer area as large as the manure-application area for soils with low infiltration capacity. The pollution concentration reduction per unit length of buffer zone was greatest for shortest buffer lengths. Thus, a cost-benefit analysis of buffer zones should consider that as the buffer zone increases, there is less improvement in water quality per unit length increase in buffer zone.

One-dimensional overland flow models that were developed were useful in predicting reductions of concentration and mass in a buffer zone. The models are simple in nature, and the results can be generalized in a family of curves. The theoretical model for predicting reduction in pollution concentration is simple because it considers only dilution and infiltration as the pollution-reduction mechanisms. The mass model considers loss of chemical constituents due only to infiltration. Complete mixing of pollutants in overland flow of surface water and infiltrating water is assumed, and the results indicate that these assumptions are reasonable.

The models can be generalized by plotting percent reduction of pollution potential (above background conditions) versus the ratio of buffer-area length to application-area length. This can be done for concentration and for mass, resulting in a family of curves for various values of the ratio of rainfall rate to infiltration rate. Thus, the graphs are easy to use if the rainfall and infiltration rates can be quantified for the period of concern. The infiltration rate is dependent on soil types; thus, there is some justification for basing buffer length on soil hydrologic groups such as the four groups defined by the Soil Conservation Service (SCS). Soils with high infiltration rates would require less buffer length.

Experimental results indicated that all pollution parameters which were measured were reduced at similar rates through the buffer zones. Thus, the theoretical model can be applied to all nutrients even though the assumptions used in developing the model seem more appropriate for soluble pollutants than for insoluble pollutants. The theoretical model predicted reductions similar to the experimental results.

The experimental results should not be applied to sites with much longer application area lengths without further research. However, the theoretical model would indicate similar results for larger application areas. Both the experimental results and theoretical model results apply only to when the application area and buffer area are similar in vegetative cover, soil surface condition, topography, and hydrologic properties.

The results of this research provide some guidelines which can be used in determining the amount of buffer area needed to reach a predetermined acceptable level of pollution potential of runoff from land application areas. The results of the dilution-infiltration model can be used in evaluating the cost-effectiveness of changing the buffer-zone length.

Recommendations

More research should be conducted on the effectiveness of buffer zones in reducing pollution potential of runoff from land application sites of various larger sizes and sites loaded at various rates of manure application. The results of this study indicate that to reduce the concentration of pollutants in runoff from land application sites to near that of similar surrounding areas receiving no manure requires a buffer-zone length about equal to the application-area length. This is more buffer zone than is normally being recommended. If settling, vegetative adsorption or other additional factors besides dilution and infiltration are acting to reduce the pollution in the runoff, then less buffer zone may be needed. Additional research is needed on the mechanisms acting in the buffer zone.

In order to use the dilution-infiltration models on an event-by-event basis, more research is needed on characterizing the effective infiltration rate/rainfall rate ratio, especially for events of highly varying rainfall rates. Also, the capability to predict pollution potential of manure-application sites for different manure types, application rates and soil-vegetation systems needs further development. Effect of relative amounts of manure adhering to leaves and vegetation compared to that which is in contact with soil needs to be evaluated in terms of affecting the runoff pollution potential of the land application site.

Effectiveness of using alternating strips of application areas and buffer areas needs further research. This method may prove to be a more efficient use of land than having one wide buffer area downslope of the manure area because the initial part of the buffer zone seems most effective in reducing pollutants. Also, the effect of type of vegetation in the buffer area needs further research.

Experimental Study

A nine-month field study using caged-layer poultry manure and tall fescue buffer areas was conducted to evaluate several buffer-area length/application-area length ratios over the range from 0.2 to 2.6. An application area with no buffer area and a control plot were also included. The general representation of a buffer area is shown in Figure 1.

Runoff amount and concentrations of total solids (TS), volatile solids (VS), TOC, chemical oxygen demand (COD), P, TKN, nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), and chloride (Cl^-) were measured for all rainfall events but only the large rainfall events were reported.

A high pollution potential was maintained by frequent applications of manure. The concentrations of pollutants which were measured in runoff from nine of the largest rainfall-runoff events were greater than concentrations in background runoff (from similar plots not receiving manure) by 58% for TOC, 98% for TKN, and 613% for P. The portion of the solids transport attributed to manure solids was estimated using VS/TS ratios and was between 30% and 50% for two selected runoff events. However, filtering of some runoff samples with Whatman 41 filter paper also indicated that the total nutrient transport could be reduced only 34% for P, 26% for TKN, and less for other nutrients by filtering. Thus, considerable portions of the nutrients in runoff were in soluble forms.

Concentration reductions increased with increasing buffer-area length to manure-area length ratio. However, to reduce concentrations to within 10% of the concentrations in background runoff required a buffer area about equal in length to the application area, where the range of manure application areas was 8.7 m to 13 m long.

Dilution-Infiltration Equations

One-dimensional overland flow models were developed to predict reductions of concentration and mass in a buffer zone. The model for predicting reduction in pollutant concentration considers only dilution and infiltration as the pollution-reduction mechanisms, and the mass model considers loss of chemical constituents due only to infiltration of runoff liquid. In both cases, complete mixing of pollutants in overland flow of surface water and infiltrating water is assumed. The equation for concentration reduction above a background level is:

$$P_c = (100)\frac{C_o - C_x}{C_o - C_B} = 100\left[1 - \left(\frac{1}{1+K}\right)^{\left(\frac{1}{1-D}\right)}\right] \quad (1)$$

where

P_c = percent reduction in concentration above background level

C_o = pollutant concentration in runoff entering the buffer area

C_x = pollutant concentration in runoff at distance x into the buffer zone

C_B = pollutant concentration in runoff for similar area not receiving manure

K = buffer-area length/application-area length ratio, and

D = infiltration rate/rainfall rate ratio.

The equation for percentage mass reduction (above a background level), defined as P_m, is:

$$P_m = 100\left[1 - \left(\frac{1}{1+K}\right)^{\left(\frac{D}{1-D}\right)}\right] \quad (2)$$

As seen in Equations (1) and (2) the percent reduction (above background levels) in concentration and mass is not dependent upon the pollution concentration or mass transport into the buffer area. However, if a certain concentration or mass transport value is chosen as the water quality limitation, then the pollutant concentration and mass transport coming off the application area and the background levels must be known.

The dilution-infiltration models are generalized by plotting percent reduction of pollution potential (above background conditions) versus the ratio of buffer-area length to application-area length. This is done for concentration and mass, resulting in a family of curves for various values of the ratio of rainfall rate to infiltration rate.

The theoretical model would seem to apply better to soluble pollutants than to insoluble pollutants, but the experimental data indicate all pollution parameters which were measured were reduced at similar rates through the buffer zones. The theoretical model for concentration reduction predicted results similar to the experimental results for an average infiltration rate/rainfall rate ratio of 0.7, which was reasonable for the clay loam soil used in the experiment. Experimental results from this research were also in general agreement with other comparable studies.

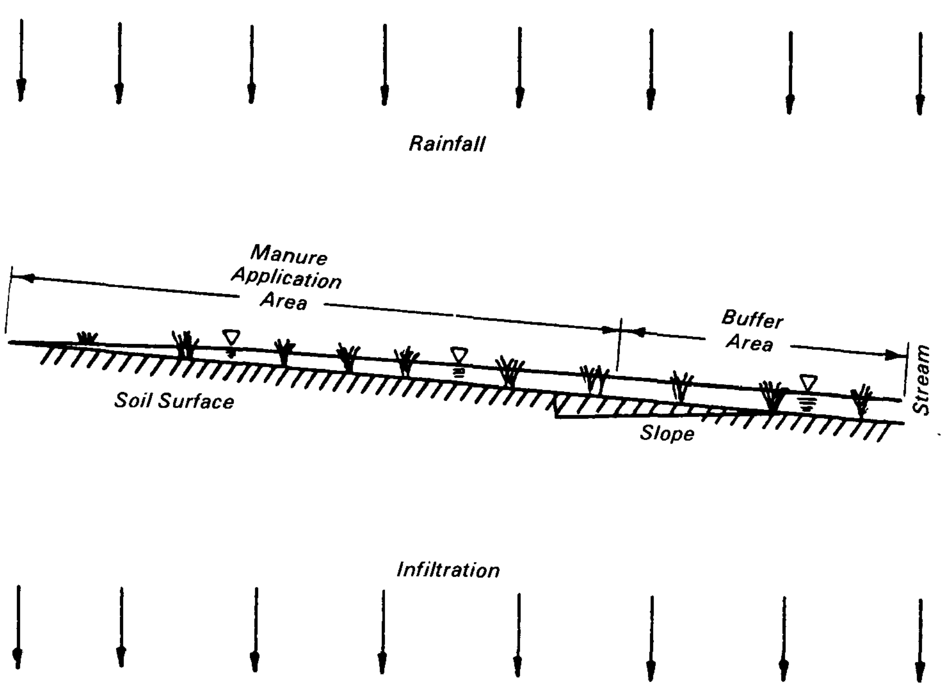

Figure 1. Schematic of manure-application area and buffer area.

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The complete report, entitled "Reducing Runoff Pollution Using Vegetated Borderland for Manure Application Sites," (Order No. PB 83-189 274; Cost: $11.50, subject to change) will be available only from:
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