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Project Summary

Effects of Livestock Pasturing on Nonpoint Surface Runoff

Richard K. White, Robert W. VanKeuren, Lloyd B. Owens, William M. Edwards, and Robert H. Miller

This study was conducted to evaluate the effects of livestock pasturing in humid regions of the United States on the quality of nonpoint surface runoff. Specific objectives were to establish the contribution of pollutants from nonpoint source pasturing regimes, to establish what happens to hydrologic and water quality parameters related to nonpoint surface runoff from pastures and to identify pasture management practices that affect nonpoint source pollution.

Three pasturing regimes were monitored and evaluated: summer rotational grazing and winter feeding of hay on one pasture; summer rotational grazing with no livestock on pastures in the winter, and winter rotational grazing of autumn regrowth with feeding of field-stored hay.

Winter pasturing and feeding of hay caused a marked increase in the number of runoff events and the volume of runoff as compared to previous meadow practices, and to summer pasturing only. Dormant season (DS) (Nov-Apr) nutrient fluxes were greater than those in the growing season (GS) (May-Oct). Analysis of the soluble and sediment fraction of the runoff samples indicated that the nutrients were principally in the soluble phase.

Analysis of discrete sample data collected throughout a runoff event indicated that nutrient transport was essentially matched with runoff, i.e. a linear relation can be assumed between runoff volume and nutrient delivery. In general, soluble nutrient concentrations are a function of hydrologic variables, e.g. precipitation, rainfall intensity, and antecedent soil moisture; whereas, sediment related nutrient concentrations were affected by pasture management practices.

Microbiological analyses for total coliform (TC), fecal coliform (FC), and fecal streptococci (FS) were conducted. The number of bacteria exceeded water quality criteria for nonpoint source runoff, even from a non-pastured control watershed.

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

Livestock production systems utilizing pastureland are one segment of agriculture production for which the extent of nonpoint source pollution has not yet been clearly defined, and for which best management practices (BMPs) have not yet been designed. Beef cow and calf production is increasing in East Central United States from Pennsylvania, West Virginia, and Virginia across Ohio and Kentucky to Iowa and Missouri. Currently, this area has about ten million head of beef cattle, many of which are raised on small farming operations. In Ohio, for example, about two-thirds of the 1.4 million cattle raised are on farms with 20-99 head. Most cattle in this region are pastured during the summer. In winter, they may be fed in a barn or on an open lot, fed hay out on pasture, or kept on winter pasture of autumn-saved regrowth and field-stored hay. The land used for such cattle production is primarily hilly and susceptible to erosion if cultivated or if the vegetative cover is lost and the soil exposed. This land, in permanent pasture, constitutes a large, important part of the region.

This project was conducted cooperatively by the Ohio Agricultural Research and Development Center, Wooster, Ohio, and the United States Department of Agriculture, Science and Education Administrative-Agricultural Research Service, Coshocton, Ohio. The pastures studied were located on the North Appalachian Experimental Watershed (NAEW), Coshocton, Ohio. Long-term hydrologic records from the experimental watersheds at NAEW provided background data for this study. The three pasture regimes monitored were as follows:

1. Summer rotational grazing was studied using 25 Charolais beef cows with calves on 17.2 ha divided into four pastures seeded to orchard grass. Hay (square bales) was brought to one of the pastures and fed to the herd in the winter. Within this winter pasture (3.1 ha) was a gaged watershed (WS 129) of 1.1 ha. A moderate level of fertility was provided with a spring application of 56 kg nitrogen per hectare (N/ha) and maintenance of available phosphorus (P) and potassium (K) levels at 28 and 168 kg/ha, respectively. Soil pH was maintained at 6.0 to 6.5. Calves were weaned and removed from the study area in October.

2. Summer rotational grazing (no winter feeding) was studied using 40 Charolais beef cows with calves on 13.8 ha divided into four pastures of orchard grass. Within one of the pastures (3.8 ha) was a gaged watershed (WS 110) of 0.86 ha. A high level of fertility was provided with an annual application of 224 kg N/ha (in three applications) and maintenance of available P and K levels at 56 and 336 kg/ha, respectively. Soil pH was maintained at 6.5 to 7.0.

3. Winter rotational grazing of fall regrowth and feeding of field-stored hay (round bales) was studied using 40 Charolais cows (those from the second regime) on 10.1 ha divided into four pastures. The pastures were seeded to tall fescue. Within one of these pastures was a gaged watershed (WS 106) of 0.63 ha. The same high level of fertility as in the second pasturing regime was provided here.

A forested non-pastured watershed (WS 172) of 17.6 ha was monitored as a control.

Surface runoff from the watersheds was measured by precalibrated H-flumes. Precipitation was measured on each of the watersheds by corresponding recording rain gages. Topsoil moisture was measured biweekly. Intervening soil moistures were calculated using a method based upon precipitation measurements and depletion curves developed from field data on soil moisture.

Proportional runoff samples were collected by using an offset Coshocton wheel sampler located at the outfall of the flume. The collected runoff was delivered to a temperature-controlled (4°C) storage shed. The flow was collected in a series of 14 buckets (approximately 5L each) and a final collecting drum for collecting runoff from an exceptionally large event. Event markers on the water stage recorders noted when the sampling device advanced to the next container.

Using vacuum filtration or centrifugation, samples were separated into a liquid fraction (for analysis of soluble plant nutrients) and a sediment fraction (for analysis of attached nutrients). The sediment fraction was air-dried and stored for subsequent analysis. The liquid fraction was stored at 4°C until analyzed. The N, P, and K concentrations were determined for the soluble fraction and the sediment. Also, the runoff sample was analyzed for TOC, COD, and periodically, for BOD_5.

Conclusions

Evaluation of three pasture regimes indicated that winter pasturing increased the surface runoff. Where winter feeding of cattle on one watershed (WS 129) occurred, the runoff volume was threefold that of a predicted volume based on 23 years of previous hydrologic record. Winter rotational grazing and feeding of field-stored hay (WS 106) increased the runoff by 75 percent more than predicted. Summer rotational grazing only (WS 110) increased the observed runoff by 17 percent more than predicted. The increased runoff volumes were primarily associated with the dormant season, winter feeding, and pasturing.

Average DS, November through April, nutrient fluxes were greater than those in the GS, May through October, for all three pasturing regimes. The flux of total potassium (Tot K), 143 kg/ha, during the study period was larger than total nitrogen (Tot N) or phosphorus (Tot P), 73 and 14 kg/ha, respectively. The flux of sediment nitrogen (Sed N) was larger than sediment potassium (Sed K) or sediment phosphorus (Sed P) by a factor of three to six. The sediment-to-soluble-flux ratio was largest for P and least for K, so that P transport is associated more with sediment than are N or K. A comparison of nutrient fluxes from the control watershed with the pasture watersheds showed that N and K were two to ten times larger, and that P flux was larger by three to ten orders of magnitude for pasture watersheds.

Periodic samplers were utilized to partition runoff samples during storms and the discrete samples were analyzed separately. Normalized flux scatter plots indicated that N and K tended toward early delivery (ED) as related to runoff volume. Phosphorus tended toward late delivery (LD). Analysis of the nutrient flux plots, using 90 percent confidence intervals, indicated that nutrient delivery was essentially matched with runoff, i.e. a linear relation can be assumed between runoff volume and nutrient delivery.

Linear regression was used to identify variables that contribute to nutrient flux in runoff. In general, soluble nutrient concentrations are a function of hydrologic variables such as precipitation, rainfall intensity, and antecedent soil moisture; whereas, sediment-related nutrient concentrations were affected by pasture management, specifically cattle occupancy and time of occupancy.

The pasture management regimes are related to water quality in surface runoff in the following order with the first practice causing the least flux of nutrients: (1) summer rotational pasturing only, (2) winter rotational pasturing on autumn regrowth and field-stored hay, and (3) summer rotational pasturing and winter feeding with hay brought to the cattle on one watershed.

Microbiological analyses for TC, FC, and FS confirmed previous studies that showed water quality criteria were exceeded for coliform in runoff from pastures. Ratio of FC to FS for pastured watersheds and a non-pastured, forested control varied to the extent that the source of fecal material, either cattle or wildlife, was not evident. Analyses showed little difference in the number of bacteria in runoff water collected early in a storm event from water collected near the end of a storm event. Therefore, bacteriological water quality criteria may be inappropriate for characterizing pasture runoff.

Recommendations

This report established the contribution of nutrients and pollutants from nonpoint source pasturing regimes in the cool, humid region of East Central United States. Three years of detailed hydrologic data, water quality data, and livestock-pasture management data were collected. The nutrient transport was principally in the soluble form versus the sediment form and more transport occurred during the DS than during the GS. A marked increase due to livestock pasturing, in the volume of runoff occurred during the DS. The results support the following recommendations:

1. Watershed modeling efforts should include the impact of livestock pasturing on the hydrology, nutrient flux, and pollutant transport.

2. Composite, proportional samples of runoff should be used to measure nutrient flux from meadow and pastured watersheds.

3. Alternative winter livestock management practices should be evaluated to identify BMPs for winter pasturing.

4. Bacteriological water quality criteria should not be used as a principal parameter to identify sources of nonpoint pollution.

Results and Discussion

The average precipitation for the GS during this study was 25 percent greater than the long-term mean. In particular, the GS in 1978 and 1979 were much wetter than normal. The average precipitation for the DS was only 4 percent less than the long-term mean.

Effects on Hydrology

Using a linear regression stepwise analysis procedure, a predictive equation for runoff volume based on precipitation, a precipitation intensity factor, and soil moisture was developed using prior meadow year data. A predicted runoff (Q_p) was calculated using this equation and data from the three-year pasture study. Table 1 gives a comparison of Q_p and the observed runoff (Q_o) during the pasture study. A comparison of Q_p with Q_o on WS 110 (summer rotational grazing only) does not indicate a marked change in hydrology, observed flow being only 1.2 times greater than predicted. WS 106 (winter rotational grazing on autumn regrowth and feeding field stored hay) had an observed flow 1.8 times that predicted. WS 129 (summer rotational grazing and winter feeding of hay) had an observed flow three times larger than predicted. It was during the DS that the marked increase in flow occurred on WS 129 and to a lesser degree on WS 106. Therefore, winter pasturing of livestock has a marked effect on increasing the runoff. A similar conclusion was obtained by using an analysis of optimized curve numbers.

Table 1. *Predicted and Observed Runoff Volumes for WS 106, 110, and 129*

Season*	Q_p (mm)	Q_o (mm)	No. of Events
WS 106			
1977	14.6	6.3	13
1977-78 DS	15.5	13.9	21
1978 GS	16.1	10.5	29
1978-79 DS	22.5	63.1	20
1979 GS	14.9	53.8	16
Study period	83.6	147.6	
WS 110			
1977 GS	30.6	14.8	14
1977-78 DS	14.9	28.3	12
1978 GS	36.0	20.9	17
1978-79 DS	24.4	24.4	12
1979 GS	48.8	96.0	11
Study period	154.7	184.4	
WS 129			
1977 GS	33.0	57.0	38
1977-78 DS	7.2	79.1	30
1978 GS	33.8	99.3	40
1978-79 DS	8.5	49.4	27
1979 GS	37.7	114.4	19
Study period	120.2	399.2	

**GS is May-Oct. DS is Nov-Apr.*

Nutrient Concentrations and Flux

The mean concentration of the nutrients N, P, and K in the runoff from the pastures and the control watersheds is given in Table 2. A comparison of concentrations for the GS indicates a higher concentration on those pastures with a higher fertilization rate, WS 106 and WS 110. During the DS, those pastures with livestock had a higher concentration of nutrients in the runoff.

Runoff samples were partitioned into soluble and sediment fractions for the analysis of N, P, and K. Figure 1 shows the nutrient fluxes for the three pastures and the control. Certain trends are evident from this flux data:

1. Soluble nutrient flux was largest for K and least for P.

2. Sediment nutrient flux was largest for N and least for K as shown by shading on the bars.

3. The total nutrient flux (both soluble and sediment) was largest for year-round cattle occupancy (WS 129) and least for summer rotational grazing (WS 110) except for the very wet 1979 GS.

4. Where winter occupancy of cattle was involved (WS 129 and WS

Table 2. Summary of Mean ($\bar{x}$) Concentration of Nutrients in Runoff from the Pasture and Control Watersheds

Season and Watershed	Tot N, mg/l	Tot P, mg/l	K, mg/l
Growing Seasons			
WS 106	6.3	1.13	20.7
WS 110	10.7	1.24	20.7
WS 129	6.4	1.87	9.9
WS 172	2.3	0.05	2.1
Dormant Seasons			
WS 106	13.2	0.69	15.2
WS 110	5.4	0.49	7.6
WS 129	21.5	2.02	45.2
WS 172	1.5	0.02	1.6
Water Year			
WS 106	9.8	0.91	17.9
WS 110	8.2	0.88	14.5
WS 129	12.9	1.93	25.1
WS 172	1.9	0.03	1.8

106), the trend was toward greater nutrient fluxes during the DS.

A sediment-nutrient-flux to soluble-nutrient-flux ratio was calculated for each runoff event. The sediment-to-soluble-flux ratio values for WS 129 were significantly larger than for WS 106 or WS 110.

Relation Between Nutrient Flux and Runoff

Runoff was sampled periodically throughout each storm event. Normalized plots of percent cumulative nutrient flux versus percent cumulative runoff volume were constructed for runoff events that had five or more discrete subsamples. Figure 2 shows a scatter plot for percent cumulative nitrogen flux in all runoff events from WS 129. The nitrogen flux slightly preceded the runoff in the majority of the samples. By use of 90 percent confidence intervals of the flux, the time of delivery of the nutrients in the runoff volume was evaluated. Table 3 summarizes the nutrient flux delivery data. Event data were grouped in ten different ways to determine if ED, matched delivery (MD), or LD of nutrients with runoff occurred. In most of the data groupings, MD was observed. The confidence intervals that excluded MD did so by only a small amount (3 percent or less of the total flux for an event). Therefore, even when ED is found, it did not differ greatly from MD and a linear relation between nutrient flux and runoff volume could be assumed for the conditions in this study.

Variables Affecting Nutrient Transport

Regression analysis was used to identify statistically significant hydrologic and pasture management variables. Analyses were conducted for both the soluble and sediment N, P, and K. Independent variables regressed against the nutrient concentration means were: runoff volume, amount of precipitation, precipitation intensity factor, soil moisture, sediment flux, time after fertilizer application, percent vegetation, cattle on or off pasture, and time factor with cattle on or off pasture. Soluble N, P, and K showed no consistent pattern of the independent variables correlated with the dependent variable for WS 106, 110, or 129. For the sediment nutrients, a time factor of cattle on and off the pasture correlated with the nutrient means for all three watersheds.

A second procedure used to identify significant independent variables was stepwise regression with significance set at the 10 percent level. The soluble nutrient concentration means were a function of the hydrological variables of precipitation amount, precipitation intensity, and antecedent soil moisture. The sediment nutrient concentrations means were a function of cattle occupancy variables.

Microbiology of Pasture Runoff

Runoff water samples were collected periodically from the pasture watershed and a control, forested watershed. When possible, water samples were collected at both the beginning and the end of the runoff events. Each water sample was analyzed for numbers of TC, FC, and FS. The numbers of all three indicator bacteria did not provide a clear relationship to animal occupancy. The numbers of indicator bacteria in runoff from WS 129 were consistently higher than those of the other three watersheds.

An evaluation of the FC/FS for the watershed indicated wildlife sources of fecal pollution for WS 172 and WS 106. WS 172 and WS 106 had mean FC/FS ratios of 0.07 and 0.01, respectively. WS 129 and WS 110 had the greatest number of days of cattle occupancy and had mean FC/FS ratios of 0.18 and 0.22, respectively. FC/FS ratios greater than 0.1 are reported characteristics of cattle pastures.

These data which are in close agreement with similar studies elsewhere, support the conclusion that recommended water quality criteria may be inappropriate for characterizing pasture runoff and other nonpoint sources of potential water pollution.

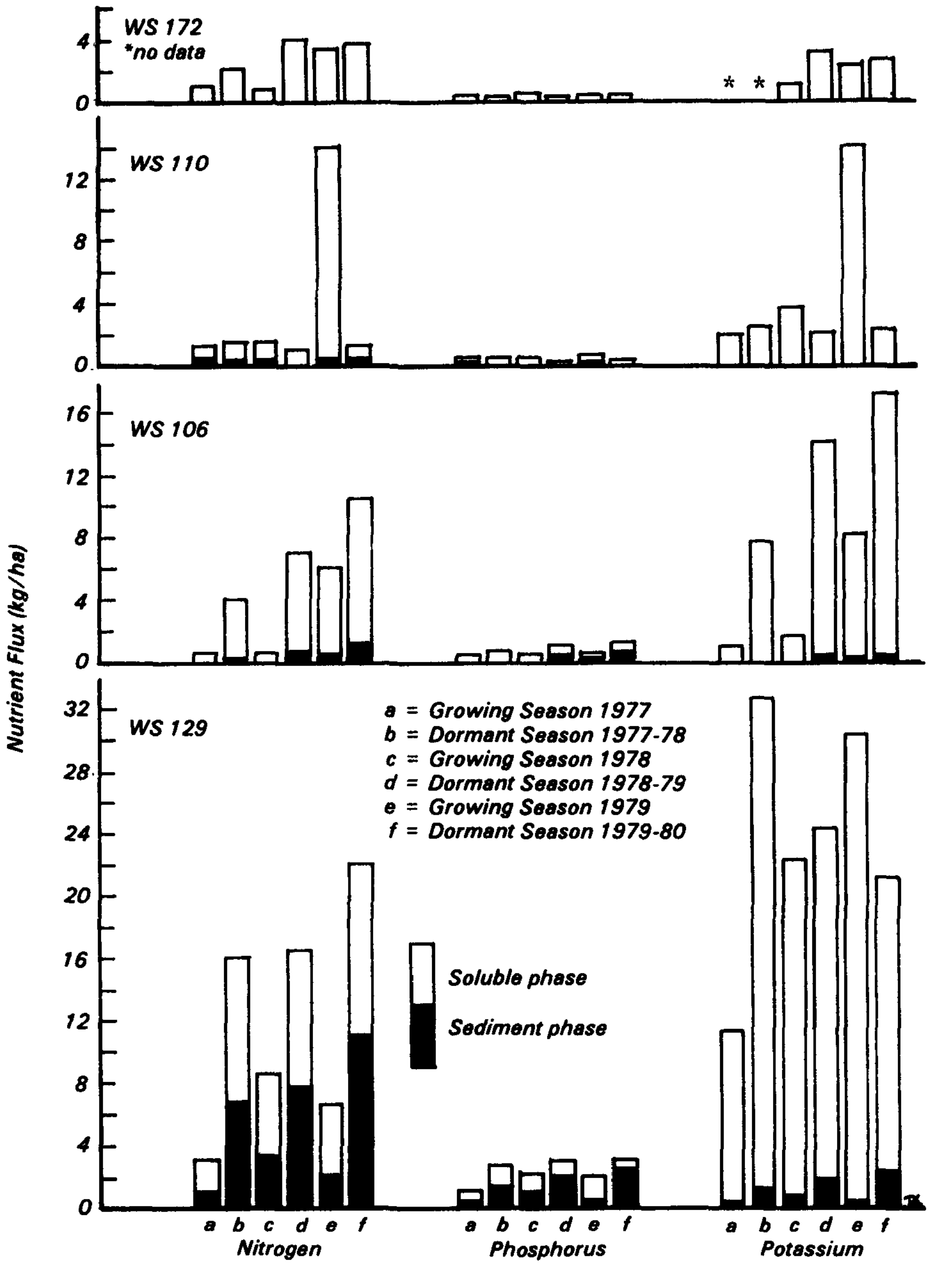

Figure 1. Total nutrient flux for watersheds for May 1977 - March 1980.

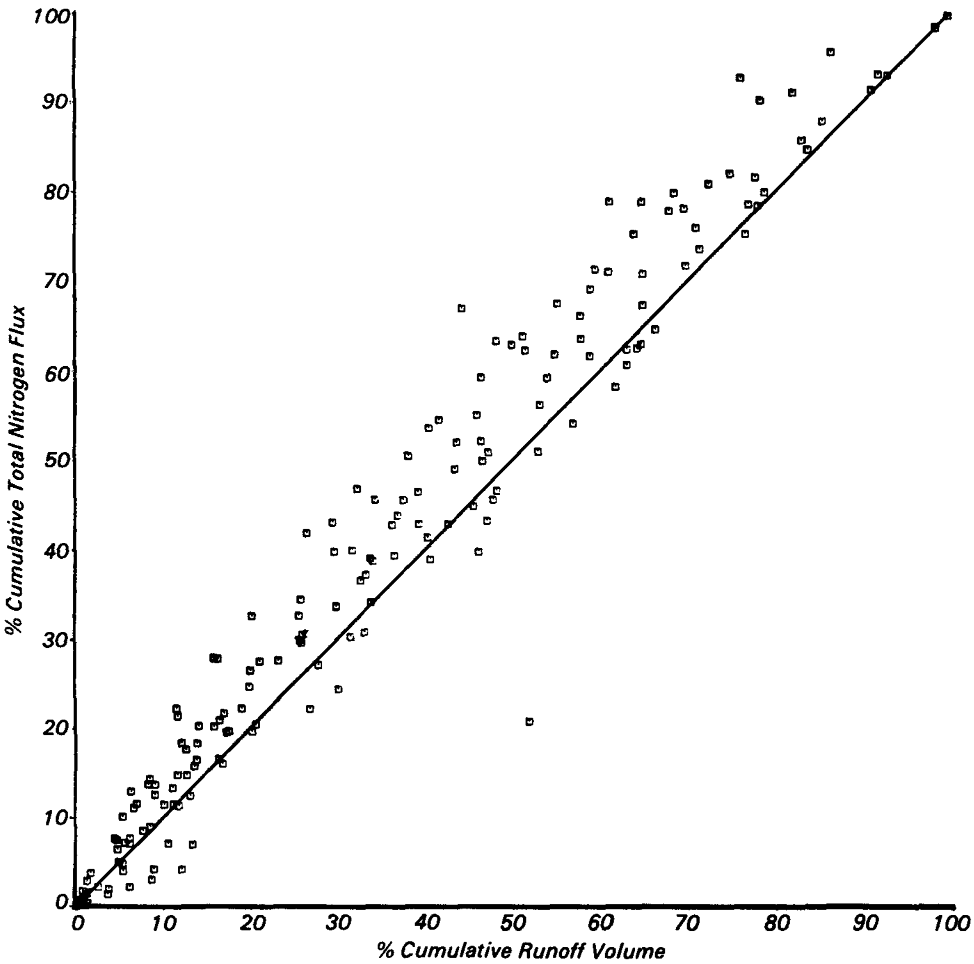

Figure 2. Total nitrogen flux scatter plot for all discrete samples in all selected runoff events from WS 129 during study period.

Table 3. Apparent Trends in the Nutrient Flux Delivery as Related to Time of Delivery*

Nutrient	Watershed	Delivery
Tot N	106	Mainly MD
	110	Mainly MD
	129	Mainly MD
P	106	MD
	110	MD
	129	MD
K	106	MD
	110	Mainly ED
	129	Mainly MD

*Based on a 90 percent confidence interval for MD. MD = matched delivery of nutrients with runoff.

Richard K. White, Robert W. VanKeuren, and Robert H. Miller are with the Ohio Agricultural and Development Center, Wooster, OH 44691 and Ohio State University, Columbus, OH 43210; Lloyd B. Owens and William M. Edwards are with the USDA-SEA-ARS, North Appalachian Experimental Watershed, Coshocton, OH 43812.

R. Douglas Kreis is the EPA Project Officer (see below).

The complete report, entitled "Effects of Livestock Pasturing on Nonpoint Surface Runoff," (Order No. PB 83-165 456; Cost: $11.50, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Robert S. Kerr Environmental Research Laboratory
U.S. Environmental Protection Agency
P.O. Box 1198
Ada, OK 74820

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