ABSTRACT

COMPUTER SIMULATION MODEL CALIBRATION AND VALIDATION FOR PREDICTION OF WATER QUALITY IMPACTS OF POULTRY WASTE DISPOSAL

Runoff and water quality data collected from two pairs of grazed fields in northwestern Arkansas were analyzed to support efforts to model runoff quality from areas receiving poultry manure and other fertilizer sources. The monitoring period described in this report was September 1, 1991 to April 30, 1993. One of each pair of fields was fertilized with inorganic fertilizer, and the other received either poultry litter or manure. Losses of fertilizer constituents were quite low from an agronomic standpoint, ranging from approximately 2-11 kg N/ha/year and 0.5-4.1 kg PO_4-P/ha/year. Annual losses of fertilizer constituents were dominated by only a small number of runoff events. Concentrations and losses of fertilizer constituents were markedly higher for application relatively close to a runoff event than for application well in advance of a runoff event. Runoff fecal coliform concentrations routinely exceeded primary, as well as secondary, contact standards and appeared not to be strongly related to either grazing or poultry litter/manure application.

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INTRODUCTION

Use of manures from confined animal production is the subject of increasing concern in Arkansas, which leads the nation in broiler production, as well as having significant egg and swine production (Arkansas Agricultural Statistics Service, 1992). Northwestern Arkansas water bodies such as Beaver Lake (the water source for approximately 100,000 persons) and the scenic Illinois River are focal points for such concerns because of the value of the water resources and the dense production of poultry (particularly broilers) in the respective watersheds. Past research has demonstrated potential runoff quality impacts of poultry litter (a combination of manure and bedding material) and manure application to range/pasture land areas (e.g., Westerman et al., 1983; McLeod and Hegg, 1984; Edwards and Daniel, 1992, 1993). There is general agreement on the part of the poultry industry, state and federal agencies, and private citizens that any adverse impacts of poultry litter/manure application in the northwestern Arkansas area should be minimized to the greatest possible extent, subject to applicable constraints.

Effective management options to reduce off-site losses of fertilizer constituents and associated downstream water quality impacts have customarily been identified through classical experimentation. Experimental results, however, are often site specific. It is thus not always possible to extend experimental results to scenarios other than that under which the experimental results were derived. Since the number of variables and permutations of variables influential in runoff transport of fertilizer constituents is simply too large to rely solely on experimental techniques for identification of effective management options, indirect methods must be used to at least some degree as a substitute for direct observations. Simulation modeling is an increasingly accepted method for investigating feasibility of particular management options and for extending experimental results to conditions different than used during the experiment(s).

Model testing, or validation, is a critical consideration when planning for the use of models in identifying, extending, or tailoring management practices for minimizing off-site transport of fertilizer constituents. While models are by their nature reasonably flexible in terms of scenarios that can be accomodated, a model is never fully validated in the sense that its predictions are not evaluated against observations from all conceivable scenarios. Thus, model outputs should be compared to observations from, at the minimum, some scenarios representative of the general context in which the model is to be applied. The confidence that is justified in model outputs will increase if the model can be calibrated as well as validated. Otherwise, a simulation model might faithfully replicate trends and relative differences in data sets while significantly underpredicting or overpredicting numerical values of the outputs.

Lack of suitable observed data is often a limitation to adequate testing of simulation models used to estimate runoff losses of fertilizer constituents. Testing comprehensive models requires a comprehensive data base - in terms of both number of outputs observed as well as length of record. Rigorous model testing also requires data from a variety of general site and management scenarios with which to assess the various capabilities of comprehensive models. Obtaining such a data base is relatively difficult in comparison to controlled, small-scale experiments because the scale is necessarily larger, there is usually less control of the monitored area, and the data are generated at irregular intervals. The practical challenges and the time required to gain data from a range of weather scenarios act to make hydrologic and water quality monitoring quite an expensive proposition if performed properly. Notwithstanding such considerations, the data bases gained from detailed monitoring of realistic (in terms of areal extent, management, etc.) situations are essential to simulation model development and testing, as well as to extending research results from studies performed on areally small scales.

This report describes results from 20 months' monitoring of runoff and runoff quality for four agricultural fields in northwestern Arkansas. A portion of the related activities was conducted to support efforts described in a companion report (Edwards and Daniel, 1993c) to test the performance of a mathematical simulation model that predicts runoff and transport of various fertilizer constituents. The monitoring activities described in this report are also one component of a multi-agency effort to improve the quality of surface waters in the Muddy Fork of the Illinois River basin. The University of Arkansas Cooperative Extension Service and USDA Soil Conservation Service are the lead agencies responsible for public education and technical assistance, respectively. Cost sharing for eligible management practices implemented in the basin has been provided by the USDA Agricultural Stabilization and Conservation Service. The Arkansas Soil and Water Conservation Commission is the lead agency in assessing the effectiveness of the overall program as well as specific elements of the program.

RELATED RESEARCH

As Magette et al. (1988) and Edwards and Daniel (1992a) have noted, poultry manure and litter have not received the same amount of attention from researchers as other agricultural wastes such as dairy manure, swine manure, and others. A comprehensive review of the contribution of agricultural waste to non-point source pollution by Khaleel et al. (1980) contained no mention of the role of poultry waste. However, the body of literature available for assessing potential runoff quality impacts of poultry manure/litter application is increasing and generally indicates that runoff quality degradation is possible, although not necessarily to any greater degree than would be promoted by application of other fertilizer sources.

Giddens and Barnett (1980) analyzed runoff from litter-treated plots for sediment and microbial content. Runoff from bare plots receiving higher application rates contained appreciable coliform bacteria; in some cases, the coliform content exceeded recreational and drinking water standards. The authors concluded that no water quality problems should result from application of "moderate" amounts of poultry waste unless "excessive" rainfall occurs.

McCleod and Hegg (1984) investigated runoff quality impacts of pasture plots treated with municipal sludge, inorganic fertilizer, dairy manure, and poultry manure. Runoff from the plots was analyzed for total suspended solids (TSS), total Kjeldahl N (TKN), ammonium N, nitrate N (NO_3-N), total P (TP), and other parameters. Overall, runoff from plots treated with commercial fertilizer contained the highest concentrations of fertilizer constituents; NO_3-N concentration in runoff from the first rainfall exceeded drinking water standards. Runoff from plots treated with poultry manure had the overall next highest concentrations of fertilizer constituents.

Westerman and Overcash (1980) applied poultry manure to fescue plots and flushed the plots with water at intervals from 1 h to 3 d after application. Runoff concentrations of constituents such as TKN, total P, Cl, and chemical oxygen demand (COD) for the 3 d flush were only about 10% of those observed for the 1 h flush.

Westerman et al. (1983) conducted a factorial experiment to determine the relative importance of variables affecting surface losses of nutrients from land treated with poultry waste. The variables considered were soil type, rainfall intensity, manure type, application rate, and drying time. Losses of poultry litter and manure constituents increased with both rainfall intensity and application rate. Runoff losses of TKN, NH_3-N, and COD decreased with increased drying time.

Edwards and Daniel (1992) applied simulated rainfall to fescue plots 1 d following application of poultry manure. Runoff losses of all constituents investigated increased with simulated rainfall intensity and increased approximately linearly with manure application rate. An analogous experiment using poultry litter as the fertilizer source (Edwards and Daniel, 1993a) yielded similar results.

Previous work has facilitated a basic understanding of how poultry manure/litter application parameters and rainfall parameters affect runoff quality in the very short term (1-7 d) following manure/litter application. Ongoing research in various poultry-producing states will help to better define the runoff quality impacts of other variables such as cover crop, slope, and soil. Such work is essential to developing reasonably comprehensive descriptions of how numerous influential variables act and interact to influence quality of runoff from manure/litter treated areas. One of the larger information gaps at present is in the area of field-scale studies of larger systems in which manure/litter application is only one component. Data from practically scaled and managed experiments will be necessary to provide insight into the runoff quality impacts of many longer-term processes (e.g., plant nutrient uptake and forage removal) and aid in development and testing of comprehensive, generalized simulation models as discussed earlier.

PROCEDURE

Two sets of paired fields were to be monitored. Soil, cover, grazing, and topographic parameters within pairs were to be as comparable as practical. Fertilizer source was to be varied within pairs to provide, to the greatest extent possible, information regarding the water quality impacts of various fertilizer sources. Fields to be monitored were selected by first identifying potential cooperators and then conducting an on-site reconnaissance of their property. Almost all land-owners in the basin were eager to support the project because of a general recognition of the need to gain realistic information to support development/implementation of practical management options for handling animal manures. Cooperative land-owners' property was inspected for suitable potential monitoring sites (i.e., fields of small to moderate size with well-defined outlets), ease of wheeled (all-terrain) vehicle access, and probable security of monitoring instruments. Specific pairs of fields were then selected based on similarity of cover and management. All fields are located in northwestern Arkansas(lat. 36° N long. 94° W) at an elevation of approximately 460 m. The predominant cover for the fields is "tall" fescue (*Festuca arundinacea* Schreb.).

Professional surveyors contracted to prepare topographic maps, with drainage basins delineated, of the monitored fields. Table 1 lists selected characteristics of the monitored fields. As may be inferred from Table 1, there were some differences in field characteristics. Unfortunately, it was not possible to identify identical paired fields,

Table 1
Selected Characteristics of Monitored Fields

Field Name	Area (ha)	Soil[1]	Curve[2] Number	Average Slope	Slope Length (m)	Erodibility[3] (Mg/ha/year)
RA	1.23	Captina silt loam	74	0.03	137	0.97
RB	0.57	Fayetteville fine sandy loam	61	0.02	142	0.54
WA	1.46	Linker Loam	79	0.04	194	0.54
WB	1.06	Hector-Mountainburg stony fine sandy loam/ Allegheny gravelly loam	64	0.04	180	0.49

[1] Harper et al. (1969)
[2] Soil Conservation Service (1986)
[3] Soil Conservation Service (1983)

and the final field selection represents several trade-offs in terms of desirable characteristics.

Monitoring of field runoff began on September 1, 1991. Each monitored field had flow measurement and sampling instrumentation installed at the outlet. Runoff was channeled into type "H" flumes (Agricultural Research Service, 1979) with flume depths of 30.5 cm for fields RB and WB and 45.7 cm for fields RA and WA. Stilling wells were constructed and attached to the flumes. A pressure transducer (model PCDR950, Druck, Inc.*) was placed inside each stilling well to measure water height inside the flume. The stilling wells were constructed so that the pressure transducers were approximately 2 cm beneath the flume floor. Pressure transducer output was measured and recorded at 5-min intervals by data loggers (model CR10 measurement and control modules, Campbell Scientific, Inc.*). Runoff was sampled by automatic water samplers (model 800SL portable liquid sampler, American Sigma) installed at each monitoring point. Sampler intake holders were constructed from a horizontal wooden base to which wooden blocks were attached to form a narrow (2 cm wide, 4 cm deep) channel with one end (toward the flume) of the channel blocked. The sampler intake holders were positioned and secured just below the flume outlets. The sample intake apparatus ensured the collection of well-mixed samples and minimal air pumpage. The water sampler and data logger were interfaced so that when water

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* Mention of a trade name constitutes neither endorsement by the University nor criticism of similar products not mentioned.

height inside the flume reached 2.5 cm, sample (1 L sample volume) collection initiated with samples collected at 5 min intervals until either all 24 sample bottles were filled or flume water height had fallen below 2.5 cm. The data logger received feedback from the sampler that enabled recording of when the samples were actually collected. In addition to the flow measurement/sampling equipment, each pair of fields had a tipping bucket rain gage installed. All instruments were powered by batteries and were operational on an essentially continuous basis over the project duration. Runoff samples were to be collected not later than 24 h following each runoff event. Samples were then transported to the Arkansas Water Resources Center Water Quality Laboratory, prepared for analysis, and analyzed for nitrate nitrogen (NO_3-N), ammonia nitrogen (NH_3-N), total Kjeldahl nitrogen (TKN), ortho-phosphorus (PO_4-P), total phosphorus (TP), chemical oxygen demand (COD), total suspended solids (TSS), fecal coliforms (FC), and fecal streptococci (FS). Standard methods of analysis (Greenberg et al., 1992) were used in all analyses. Ion chromatography was used in analyses of NO_3-N and PO_4-P. The ammonia-selective electrode method was used to determine NH_3-N. The macro-Kjeldahl method was used in TKN analyses. Total P was determined by the ascorbic acid colorimetric method following sulfuric acid-nitric acid digestion. The closed-reflux, colorimetric method was used for COD determinations. The membrane filtration technique was used to analyze runoff concentrations of fecal coliforms and streptococci.

The decision regarding the fertilizer sources that would be used on fields within a particular pair was based on both initial analyses of soil P content and the fertilizer source that had customarily been applied. Inorganic fertilizer (ammonium-nitrate, NH_4-NO_3) was to be applied to the field within a pair having the highest soil P concentration. The remaining field within a pair would receive either poultry litter or manure, whichever had usually been applied to the field. Extractable (Mehlich III; Mehlich, 1984) P contents of the upper 15 cm soil were found to be 156 and 307 mg/kg for fields RA and RB, respectively, based on sample analyses by the University of Arkansas Agricultural Services Laboratory. This finding indicated sustained prior applications of animal manures at rates in excess of plant P requirements. The lower soil P content for field RA was consistent with the land-owner's observations that the field was not as trafficable after rainfall as field RB and thus was not fertilized as often. A similar disparity in soil P contents was found for fields WA and WB. Extractable soil P content of the upper 15 cm of soil was initially found to be 630 mg/kg for field WA (later determined to be more on the order of 400 mg/kg) and 210 mg/kg for field WB. The soil test results again indicated relatively long-term application of animal manures and were consistent with information from the land-owner regarding a one-time, massive application of poultry litter to field WA. Based on the criteria of soil P content and usual fertilizer source, field RA received poultry manure; RB, NH_4-NO_3; WA, NH_4-NO_3; WB, poultry litter.

The management operations for fields RA and RB over the monitored period consisted of grazing and fertilizer application. The grazing parameters for the two fields were the same, because the fields are adjacent with no separating fence. Grazing density for the two fields was 5 animal units (AU)/ha from September 1991 through March 1992 and 3.6 animal units from September 1992 through April 1993. The fields were ungrazed from April through August 1992. The management of the two fields differed in terms of fertilizer application parameters. Poultry manure from a laying hen facility was applied to field RA (unmanaged) on March 15, 1992 at 363 kg N/ha and 120 kg P/ha while field RB (nutrient-managed) received inorganic fertilizer NH_4-NO_3 on March 23, 1992 at 67 kg N/ha. On April 25, 1993, field RB received NH_4-NO_3 at 115 kg N/ha. Poultry manure was not applied to field RA in spring 1993 due to unusually wet weather and untrafficability of the field.

Fields WA and WB varied in terms of fertilizer application parameters with some variation in other management parameters. Ammonium nitrate was applied to field WA (nutrient managed) at 138 kg N/ha on March 23, 1992 and at 226 kg N/ha on April 13, 1993. Field WB (unmanaged) received poultry litter at a rate of 195 kg/ha N and 63 kg/ha P on March 23, 1992. Poultry litter was again applied to field WB on April 13, 1993 at 158 kg N/ha and 52 kg P/ha. Only field WA was cut for hay (on July 7, 1992). Both fields were grazed but with differences in grazing parameters. Field WA was grazed at 0.8 AU/ha from September 1991 through January 1992 and at 2.6 AU/ha from September 1992 through December 1992. Field WB was grazed continuously with densities of 0.8

AU/ha from September 1991 through January 1992, 2.4 AU/ha from February through June 1992, 4.1 AU/ha from July through August 1992, 2.6 AU/ha from September through December 1992, and 3.7 AU/ha from January through April 30, 1993.

RESULTS

Tables 2 through 5 summarize flow-weighted mean storm concentrations of water quality parameters for the four fields. Flow-weighted means of the parameters over the 20-month study period are given in Table 6. Nitrate concentrations were initially relatively high for all fields except RA and were quite high for field WA. The TP analyses that were performed for fields RA, WA, and WB are not reflected in Tables 2, 4, and 5, respectively (as well as in subsequent tables) because of unfavorable PO_4-P to TP ratios that might have been due to inadequacies in the analytical method. The TP data shown for field RB (Table 3) are included because they consistently indicated a high ratio (on average, approximately 0.8) of PO_4-P to TP as has been demonstrated in earlier studies for local soils disposed to pasture/range (e.g., Edwards and Daniel, 1992, 1993). Runoff PO_4-P (and TP for field RB) concentrations were relatively high for all fields throughout the study period. Concentrations of other parameters were highly variable; concentrations of TSS and COD varied within a field by as much as two orders of magnitude during the study period.

The data in Tables 2-5 suggest that the application of fertilizer is detectable in runoff for at least the first few storms following application. Runoff concentrations of most parameters increased perceptibly during the storms occurring in May-June 1992 (Tables 2-5) but decreased quickly thereafter. The 1993 application of fertilizers to fields WA and WB was followed by a severe storm the next day (April 14). The April 14, 1993 runoff concentration data for field WA

Table 2
Summarized flow-weighted mean storm concentration data for field RA

Mo	Day	Year	P^1	Q^2	NO_3-N	PO_4-P	NH_3-N	TKN	TSS	COD
			mm		mg/L					
10	24	91	63.3	0.24	0.617	2.289	0.114	2.397	32.546	37.117
10	26	91	54.9	16.78	0.147	0.995	0.177	2.782	103.653	44.725
10	29	91	14.2	0.03	*	*	*	*	*	*
10	31	91	26.4	4.56	0.141	1.899	0.359	2.101	2.983	11.652
12	12	91	10.4	8.76	0.160	1.373	0.192	2.454	59.267	102.556
5	11	92	57.4	6.46	0.165	4.196	1.871	24.399	7.267	69.586
5	28	92	32.5	1.60	0.028	5.221	1.921	20.877	7.962	86.835
6	2	92	13.2	0.73	0.086	3.097	0.955	26.718	7.075	88.327
6	6	92	37.3	17.00	0.096	3.130	1.781	20.866	8.439	62.464
7	5	92	44.2	7.56	0.942	3.662	0.192	2.232	39.684	52.049
7	16	92	47.8	0.19	0.366	3.742	0.000	3.429	25.803	44.722
7	30	92	58.9	17.82	0.251	2.612	0.168	2.043	59.566	30.017
8	4	92	48.8	17.82	0.135	2.714	0.137	1.560	17.441	20.089
8	5	92	5.8	0.85	0.061	2.998	0.046	2.154	3.608	48.921
9	22	92	89.2	38.43	0.287	2.563	0.110	1.469	154.042	87.006
11	11	92	43.4	7.10	0.099	4.116	0.050	2.185	24.813	76.212
11	12	93	28.5	15.27	0.039	3.358	0.088	1.835	38.801	43.635
11	20	92	34.4	9.44	0.025	2.889	0.040	1.419	*	*
11	21	92	51.1	40.05	*	*	*	*	*	*
12	9	92	31.8	12.26	0.098	2.479	0.034	1.418	13.605	77.595
12	15	93	100.1	70.20	0.040	1.741	0.059	0.668	9.791	35.869
1	4	93	37.6	24.83	0.091	1.474	0.103	1.617	122.786	82.222
1	9	93	23.9	3.50	*	*	*	*	*	*
3	19	93	22.9	2.69	0.078	1.084	0.839	6.450	60.398	115.671
3	30	93	22.1	1.23	*	*	*	*	*	*
4	3	93	28.2	1.74	0.037	1.122	0.153	2.735	22.859	51.512
4	14	93	73.4	16.51	0.074	1.576	0.170	2.148	29.820	40.195

[1] Rainfall.

[2] Runoff.

* No samples available.

Table 3
Summarized flow-weighted mean storm concentration data for field RB

Mo	Day	Year	P[1]	Q[2]	NO_3-N	PO_4-P	TP	NH_3-N	TKN	TSS	COD
			mm	mm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
10	24	91	63.3	0.01	*	*	*	*	*	*	*
10	26	91	54.9	4.28	0.582	1.433	2.513	1.325	9.856	714.072	192.265
11	17	91	15.8	0.04	1.649	2.794	2.565	1.237	6.733	201.621	28.397
12	12	91	10.4	0.02	1.483	2.224	3.986	0.371	9.639	773.558	198.997
5	11	92	57.4	1.88	0.461	1.927	2.177	2.971	24.524	114.480	47.554
5	17	92	21.3	0.83	0.668	1.553	1.914	0.000	38.501	137.750	132.158
6	6	92	37.3	0.52	0.535	2.401	2.803	3.243	26.400	29.919	97.671
7	5	92	44.2	2.93	1.464	2.695	3.454	0.364	3.949	123.807	123.807
7	30	92	58.9	5.24	0.384	1.001	1.283	0.077	1.593	13.679	8.922
8	4	92	48.8	2.24	0.355	1.300	1.630	0.024	1.899	8.345	21.408
9	21	92	89.2	13.75	0.721	1.378	1.532	0.302	1.627	18.819	68.798
10	14	92	45.7	3.74	0.240	0.134	0.129	0.049	0.269	1.271	6.871
11	11	92	63.3	2.15	0.822	2.435	3.061	0.315	3.199	175.239	90.406
11	21	92	51.1	7.78	*	*	*	*	*	*	*
12	9	92	31.8	0.12	*	*	*	*	*	*	*
12	15	92	100.1	12.63	0.267	1.191	1.377	0.042	1.011	25.299	53.725
1	4	93	37.6	3.56	0.243	0.664	1.627	0.464	4.270	237.745	94.922
3	30	93	22.1	0.89	0.549	0.795	1.434	0.639	4.729	105.296	76.409
4	3	93	28.2	0.91	0.122	0.929	1.058	0.164	2.107	20.583	41.410
4	14	93	73.4	12.60	0.155	0.996	0.796	0.201	2.456	18.421	43.549

[1] Rainfall.

[2] Runoff.

* No samples available.

Table 4
Summarized flow-weighted mean storm concentration data for field WA

Mo	Day	Year	P[1]	Q[2]	NO_3-N	PO_4-P	NH_3-N	TKN	TSS	COD
			mm		mg/L					
10	24	91	90.7	1.88	3.538	3.199	0.360	2.746	20.130	59.592
10	26	91	58.9	31.14	2.660	2.351	0.168	3.551	309.815	108.797
10	28	91	36.1	16.39	3.792	2.347	0.217	3.449	29.572	60.949
10	30	91	11.2	0.28	*	*	*	*	*	*
10	31	91	30.5	19.40	3.865	2.203	0.123	1.963	14.524	39.242
11	17	91	70.6	15.45	5.119	2.614	0.881	3.892	5.023	115.482
11	19	91	12.2	1.26	4.349	1.806	1.461	4.923	8.059	192.383
12	12	91	18.0	0.27	3.045	1.239	0.427	2.589	88.254	57.880
6	6	92	40.9	15.81	2.477	3.233	2.534	26.373	20.191	61.010
7	5	92	44.5	0.67	1.636	2.071	0.317	3.099	63.896	32.696
7	30	92	95.5	28.78	0.457	1.280	0.038	3.547	457.922	87.530
8	5	92	69.9	24.31	0.152	1.750	0.001	1.614	14.150	243.348
8	11	92	19.8	0.10	0.692	2.055	0.212	3.248	14.899	85.703
11	11	92	69.9	8.84	0.525	2.070	0.083	1.449	15.289	38.179
11	21	92	45.7	40.92	0.313	1.706	0.114	1.249	*	*
12	9	92	38.1	1.79	0.257	1.330	0.200	1.367	20.010	29.936
12	14	92	117.9	67.85	0.130	0.912	0.037	0.652	23.183	20.845
12	16	92	5.3	0.45	*	*	*	*	*	*
1	4	93	25.2	1.58	0.239	0.868	0.148	1.678	46.919	38.264
1	9	93	21.6	2.50	*	*	*	*	*	*
4	14	93	70.4	17.56	13.904	0.927	10.759	15.336	10.489	5.960

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[1] Rainfall.
[2] Runoff.
* No samples available.

Table 5
Summarized flow-weighted mean storm concentration data for field WB

Mo	Day	Year	P^1	Q^2	NO_3-N	PO_4-P	NH_3-N	TKN	TSS	COD
			mm		mg/L					
10	24	91	90.7	4.30	0.306	1.515	0.250	1.462	36.321	34.447
10	26	91	58.9	3.75	0.457	1.417	0.303	5.215	562.720	105.776
10	29	91	36.1	0.57	0.454	3.021	0.050	4.666	17.623	51.563
10	31	91	34.8	3.40	1.208	2.621	0.115	2.090	18.433	44.433
11	17	91	21.1	2.22	0.841	2.378	1.075	5.136	44.701	71.546
6	2	92	29.2	0.02	0.520	4.325	2.190	40.350	34.766	70.572
6	6	92	40.9	3.54	0.306	3.618	3.651	34.268	32.699	104.370
6	20	92	1.8	0.03	0.520	2.041	4.026	4.278	34.810	53.180
7	5	92	44.5	3.32	0.570	2.030	0.393	2.970	42.788	67.912
7	31	92	95.5	19.61	0.335	1.102	0.114	2.148	240.290	31.797
8	4	92	51.8	6.88	0.435	1.867	0.253	2.387	35.684	37.364
8	5	92	18.0	0.82	0.292	1.833	0.234	3.208	61.629	76.164
8	10	92	19.1	0.02	1.097	1.796	0.249	3.242	26.385	61.499
10	15	92	38.6	0.23	0.024	0.061	0.000	0.098	0.530	1.915
11	11	92	68.3	1.79	0.332	3.701	0.225	2.422	41.515	78.099
12	9	92	38.1	0.79	0.701	2.024	0.719	4.276	126.722	108.541
12	13	92	59.4	16.42	0.359	1.312	0.376	3.008	178.020	94.430
12	14	92	8.4	0.28	*	*	*	*	*	*
12	15	92	50.0	11.16	0.198	1.542	0.212	1.774	39.548	83.573
1	9	93	21.6	2.18	0.362	1.367	0.487	5.400	329.231	180.626
1	20	93	23.9	0.89	0.289	1.025	0.308	3.657	211.345	124.632
2	25	93	37.3	2.26	*	*	*	*	*	*
3	18	93	24.1	0.08	0.522	1.471	0.571	5.719	89.684	196.644
4	4	93	29.2	1.03	0.149	1.325	0.163	3.742	73.628	100.375
4	14	93	70.4	9.98	0.875	11.097	15.373	38.934	73.352	252.126

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[1] Rainfall.
[2] Runoff.
* No samples available.

Table 6
Overall flow-weighted mean runoff concentrations

Field	NO_3-N	PO_4-P	TP	NH_3-N	TKN	TSS	COD
	mg/L						
RA[1]	0.14	2.28	-	0.26	3.35	53.40	53.16
RB[2]	0.45	1.25	1.50	0.37	3.72	88.39	64.10
WA[3]	2.18	1.72	-	0.91	4.15	104.52	63.61
WB[4]	0.44	2.65	-	2.02	7.80	139.42	88.95

[1] Computations based on sampling 87% of all runoff occurring, except for TSS (based on sampling 84% of all runoff occurring).

[2] Computations based on sampling 90% of all runoff occuring.

[3] Computations based on sampling 99% of all runoff occurring, except for TSS (based on sampling 86% of all runoff occurring).

[4] Computations based on sampling 97% of all runoff occurring.

(Table 4) clearly indicate the increased transport of NO_3-N and NH_3-N, as well as TKN, which is consistent with the recent application of NH_4-NO_3 fertilizer. Similarly, the April 14 runoff concentration data for field WB (Table 5) indicate greatly increased content of P, NH_3-N, TKN, and COD, which is consistent with the application of poultry litter shortly prior to the storm. The runoff concentration data for fields WA and WB demonstrate rather clearly the benefits of avoiding runoff-producing rainfall in the near future following fertilizer application regardless of the fertilizer source.

Mass losses (amounts transported off the fields via runoff) of water quality parameters are summarized by storm in Tables 7-10 and for the study period in Table 11. The TKN mass loss data for the May-June, 1992 storms (Tables 7-10) reflect the application of fertilizer in 1992. Mass losses of other analysis parameters, however, appeared not to be very sensitive to fertilizer application and appeared instead to be much more dependent on runoff amounts than on fertilizer application. The 1993 application of fertilizer to fields WA and WB, in contrast, did reflect the recent application of NH_4-NO_3 and poultry litter, respectively (Tables 9 and 10).

The majority of mass losses of parameters occurred during only a few storms, as is characteristic of nonpoint source pollution. On field WA, for example, two storms accounted for 86% of observed sediment loss during the study period. On field WB, 82% of all observed NH_3-N loss during the study period occurred in association with one storm. Four runoff events accounted for almost 70% of TP loss from field RB.

Table 7
Summarized mass loss data for field RA

Mo	Day	Year	P[1]	Q[2]	NO_3-N	PO_4-P	NH_3-N	TKN	TSS	COD
			mm		kg/ha					
10	24	91	63.3	0.24	0.001	0.005	0.000	0.006	0.077	0.087
10	26	91	54.9	16.78	0.025	0.167	0.030	0.467	17.391	7.504
10	29	91	14.2	0.03	*	*	*	*	*	*
10	31	91	26.4	4.56	0.006	0.087	0.016	0.096	0.136	0.531
12	12	91	10.4	8.76	0.014	0.120	0.017	0.215	5.192	8.985
5	11	92	57.4	6.46	0.011	0.271	0.121	1.575	0.469	4.492
5	28	92	32.5	1.60	0.000	0.084	0.031	0.335	0.128	1.393
6	2	92	13.2	0.73	0.001	0.023	0.007	0.194	0.051	0.642
6	6	92	37.3	17.00	0.016	0.532	0.303	3.546	1.434	10.616
7	5	92	44.2	7.56	0.071	0.277	0.015	0.169	2.999	3.933
7	16	92	47.8	0.19	0.001	0.007	0.000	0.006	0.048	0.083
7	30	92	58.9	17.82	0.045	0.465	0.030	0.364	10.613	5.348
8	4	92	48.8	17.82	0.024	0.484	0.024	0.278	3.109	3.581
8	5	92	5.8	0.85	0.001	0.025	0.000	0.018	0.031	0.416
9	22	92	89.2	38.43	0.110	0.985	0.042	0.564	59.204	33.440
11	11	92	43.4	7.10	0.007	0.292	0.004	0.155	1.762	5.412
11	12	93	28.5	15.27	0.006	0.513	0.013	0.280	5.923	6.661
11	20	92	34.4	9.44	0.002	0.273	0.004	0.134	*	5.384
11	21	92	51.1	40.05	*	*	*	*	*	*
12	9	92	31.8	12.26	0.012	0.304	0.004	0.174	1.668	9.510
12	15	93	100.1	70.20	0.028	1.222	0.042	0.469	6.874	25.181
1	4	93	37.6	24.83	0.023	0.366	0.026	0.401	30.484	20.413
1	9	93	23.9	3.50	*	*	*	*	*	*
3	19	93	22.9	2.69	0.002	0.029	0.023	0.174	1.625	3.112
3	30	93	22.1	1.23	*	*	*	*	*	*
4	3	93	28.2	1.74	0.001	0.020	0.003	0.048	0.398	0.897
4	14	93	73.4	16.51	0.012	0.260	0.028	0.355	4.924	6.637
Sum				343.62	0.419	6.810	0.781	10.023	154.538	158.875

[1] Rainfall.
[2] Runoff.
* No samples available.

Table 8
Summarized mass loss data for field RB

Mo	Day	Year	P[1]	Q[2]	NO_3-N	PO_4-P	TP	NH_3-N	TKN	TSS	COD
			mm		kg/ha						
10	24	91	63.3	0.01	*	*	*	*	*	*	*
10	26	91	54.9	4.28	0.025	0.061	0.108	0.057	0.422	30.573	8.232
11	17	91	15.8	0.04	0.001	0.001	0.001	0.000	0.003	0.078	0.011
12	12	91	10.4	0.02	0.000	0.000	0.001	0.000	0.002	0.147	0.038
5	11	92	57.4	1.88	0.009	0.036	0.041	0.056	0.460	2.148	0.892
5	17	92	21.3	0.83	0.006	0.013	0.016	0.000	0.320	1.146	1.099
6	6	92	37.3	0.52	0.003	0.012	0.015	0.017	0.137	0.155	0.506
7	5	92	44.2	2.93	0.043	0.079	0.101	0.011	0.116	3.625	3.625
7	30	92	58.9	5.24	0.020	0.052	0.067	0.004	0.083	0.717	0.468
8	4	92	48.8	2.24	0.008	0.029	0.037	0.001	0.043	0.187	0.480
9	21	92	89.2	13.75	0.099	0.189	0.211	0.041	0.224	2.587	9.457
10	14	92	45.7	3.74	0.009	0.005	0.005	0.002	0.010	0.047	0.257
11	11	92	63.3	2.15	0.018	0.052	0.066	0.007	0.069	3.776	1.948
11	21	92	51.1	7.78	*	*	*	*	*	*	*
12	9	92	31.8	0.12	*	*	*	*	*	*	*
12	15	92	100.1	12.63	0.034	0.150	0.174	0.005	0.128	3.194	6.783
1	4	93	37.6	3.56	0.009	0.024	0.058	0.017	0.152	8.468	3.381
3	30	93	22.1	0.89	0.005	0.007	0.013	0.006	0.042	0.937	0.680
4	3	93	28.2	0.91	0.001	0.008	0.010	0.002	0.019	0.188	0.378
4	14	93	73.4	12.60	0.020	0.125	0.100	0.025	0.309	2.321	5.487
Sum				76.12	0.31	0.85	1.02	0.25	2.54	60.29	43.72

[1] Rainfall.
[2] Runoff.
* No samples available.

Table 9
Summarized mass loss data for field WA

Mo	Day	Year	P^1	Q^2	NO_3-N	PO_4-P	NH_3-N	TKN	TSS	COD
			mm		kg/ha					
10	24	91	90.7	1.88	0.066	0.060	0.007	0.052	0.378	1.120
10	26	91	58.9	31.14	0.828	0.732	0.052	1.106	96.483	33.882
10	28	91	36.1	16.39	0.621	0.385	0.036	0.565	4.846	9.987
10	30	91	11.2	0.28	*	*	*	*	*	*
10	31	91	30.5	19.40	0.750	0.427	0.024	0.381	2.818	7.613
11	17	91	70.6	15.45	0.791	0.404	0.136	0.601	0.776	17.837
11	19	91	12.2	1.26	0.055	0.023	0.018	0.062	0.101	2.419
12	12	91	18.0	0.27	0.008	0.003	0.001	0.007	0.238	0.156
6	6	92	40.9	15.81	0.392	0.511	0.401	4.169	3.192	9.644
7	5	92	44.5	0.67	0.011	0.014	0.002	0.021	0.425	0.218
7	30	92	95.5	28.78	0.132	0.368	0.011	1.021	131.794	25.192
8	5	92	69.9	24.31	0.037	0.425	0.000	0.392	3.440	59.164
8	11	92	19.8	0.10	0.001	0.002	0.000	0.003	0.014	0.083
11	11	92	69.9	8.84	0.046	0.183	0.007	0.128	1.352	3.376
11	21	92	45.7	40.92	0.128	0.698	0.047	0.511	*	15.382
12	9	92	38.1	1.79	0.005	0.024	0.004	0.024	0.358	0.536
12	14	92	117.9	67.85	0.088	0.619	0.025	0.443	15.730	14.144
12	16	92	5.3	0.45	*	*	*	*	*	*
1	4	93	25.2	1.58	0.004	0.014	0.002	0.027	0.741	0.605
1	9	93	21.6	2.50	*	*	*	*	*	*
4	14	93	70.4	17.56	2.442	0.163	1.890	2.693	1.842	1.047
Sum				297.23	6.40	5.06	2.66	12.21	264.53	187.02

[1] Rainfall.
[2] Runoff.
* No samples available.

Table 10
Summarized mass loss data for field WB

Mo	Day	Year	P^1	Q^2	NO_3-N	PO_4-P	NH_3-N	TKN	TSS	COD
			mm		kg/ha					
10	24	91	90.7	4.30	0.013	0.065	0.011	0.063	1.561	1.480
10	26	91	58.9	3.75	0.017	0.053	0.011	0.196	21.118	3.970
10	29	91	36.1	0.57	0.003	0.017	0.000	0.026	0.100	0.292
10	31	91	34.8	3.40	0.041	0.089	0.004	0.071	0.626	1.510
11	17	91	21.1	2.22	0.019	0.053	0.024	0.114	0.992	1.588
6	2	92	29.2	0.02	0.000	0.001	0.000	0.007	0.006	0.012
6	6	92	40.9	3.54	0.011	0.128	0.129	1.212	1.156	3.691
6	20	92	1.8	0.03	0.000	0.001	0.001	0.001	0.012	0.018
7	5	92	44.5	3.32	0.019	0.067	0.013	0.098	1.419	2.251
7	31	92	95.5	19.61	0.066	0.216	0.022	0.421	47.129	6.236
8	4	92	51.8	6.88	0.030	0.128	0.017	0.164	2.454	2.569
8	5	92	18.0	0.82	0.002	0.015	0.002	0.026	0.507	0.626
8	10	92	19.1	0.02	0.000	0.000	0.000	0.001	0.005	0.012
10	15	92	38.6	0.23	0.000	0.000	0.000	0.000	0.001	0.004
11	11	92	68.3	1.79	0.006	0.066	0.004	0.043	0.743	1.398
12	9	92	38.1	0.79	0.006	0.016	0.006	0.034	1.000	0.857
12	13	92	59.4	16.42	0.059	0.215	0.062	0.494	29.227	15.504
12	14	92	8.4	0.28	*	*	*	*	*	*
12	15	92	50.0	11.16	0.022	0.172	0.024	0.198	4.412	9.323
1	9	93	21.6	2.18	0.008	0.030	0.011	0.117	7.161	3.929
1	20	93	23.9	0.89	0.003	0.009	0.003	0.033	1.887	1.113
2	25	93	37.3	2.26	*	*	*	*	*	*
3	18	93	24.1	0.08	0.000	0.001	0.000	0.005	0.072	0.157
4	4	93	29.2	1.03	0.002	0.014	0.002	0.039	0.761	1.038
4	14	93	70.4	9.98	0.087	1.107	1.534	3.884	7.318	25.154
Sum				95.55	0.41	2.46	1.88	7.25	129.67	82.73

[1] Rainfall.
[2] Runoff.
* No samples available.

Table 11
Overall runoff losses

Field	Unit Loss						
	NO_3-N	PO_4-P	TP	NH_3-N	TKN	TSS	COD
	kg/ha/year						
RA[1]	0.25	4.09	-	0.47	6.01	92.72[2]	95.33
RB[2]	0.19	0.51	0.61	0.15	1.52	36.17	26.23
WA[3]	3.84	3.04	-	1.60	7.33	158.72	112.2
WB	0.25	1.48	-	1.13	4.35	77.80	49.64

[1] Computations based on sampling 87% of all runoff occurring, except for TSS (based on sampling 84% of all runoff occurring).

[2] Computations based on sampling 90% of all runoff occuring.

[3] Computations based on sampling 99% of all runoff occurring, except for TSS (based on sampling 86% of all runoff occurring).

[4] Computations based on sampling 97% of all runoff occurring.

Table 11 points out that observed mass losses of nutrients were quite small and probably agronomically insignificant for all fields. Since the threat of appreciably diminished crop yields appears unlikely to drive efforts to minimize losses of pollutants, measures to decrease pollutant transport might only be justifiable solely on the grounds of potential downstream impacts. If so, then it is imperative to define acceptable loading to water bodies and to translate those loadings to "edge-of-field" losses so that edge-of-field losses will have some meaning in an environmental context.

Fecal coliform analyses of the runoff samples provided very interesting results. Figs. 1-4 show flow-weighted mean runoff fecal coliform concentrations observed through the study period. Periods of grazing and dates of fertilizer application are also indicated. Fecal coliform concentrations appear not to be related to either grazing (for fields RA, RB, and WA) or application of poultry litter/manure (fields RA and WB). Runoff fecal coliform concentrations were virtually always in excess of Arkansas' primary contact standard (200 col./100 ml) and usually in excess of Arkansas secondary contact standard (1000 col./100 ml). Data from this project suggest that high fecal coliform concentrations are an inherent characteristic of runoff from pasture land in northwestern Arkansas when the methods described earlier are used to assess the concentrations. Sources of bacteria other than cattle and poultry litter/manure (e.g., wild animals) appear to have been present in sufficient quantity to maintain high runoff fecal coliform concentrations throughout the study period.

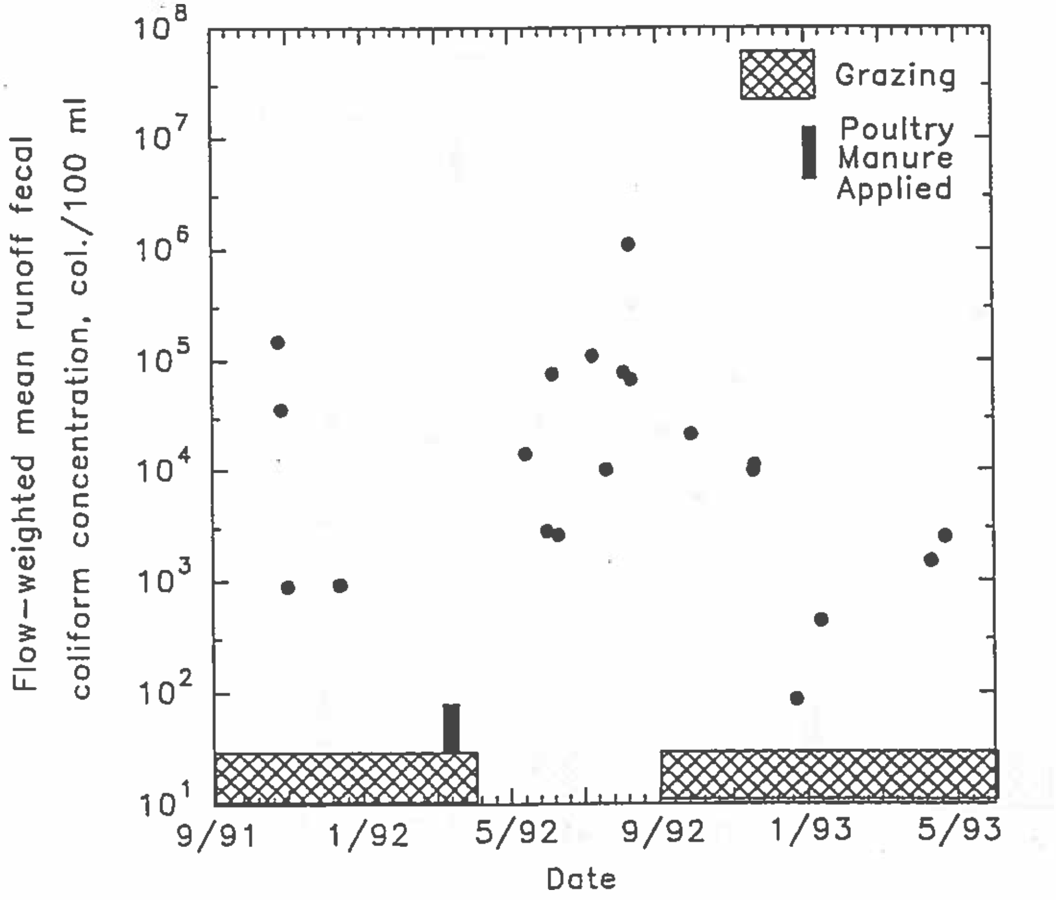

Fig. 1. Mean runoff fecal coliform concentrations for field RA.

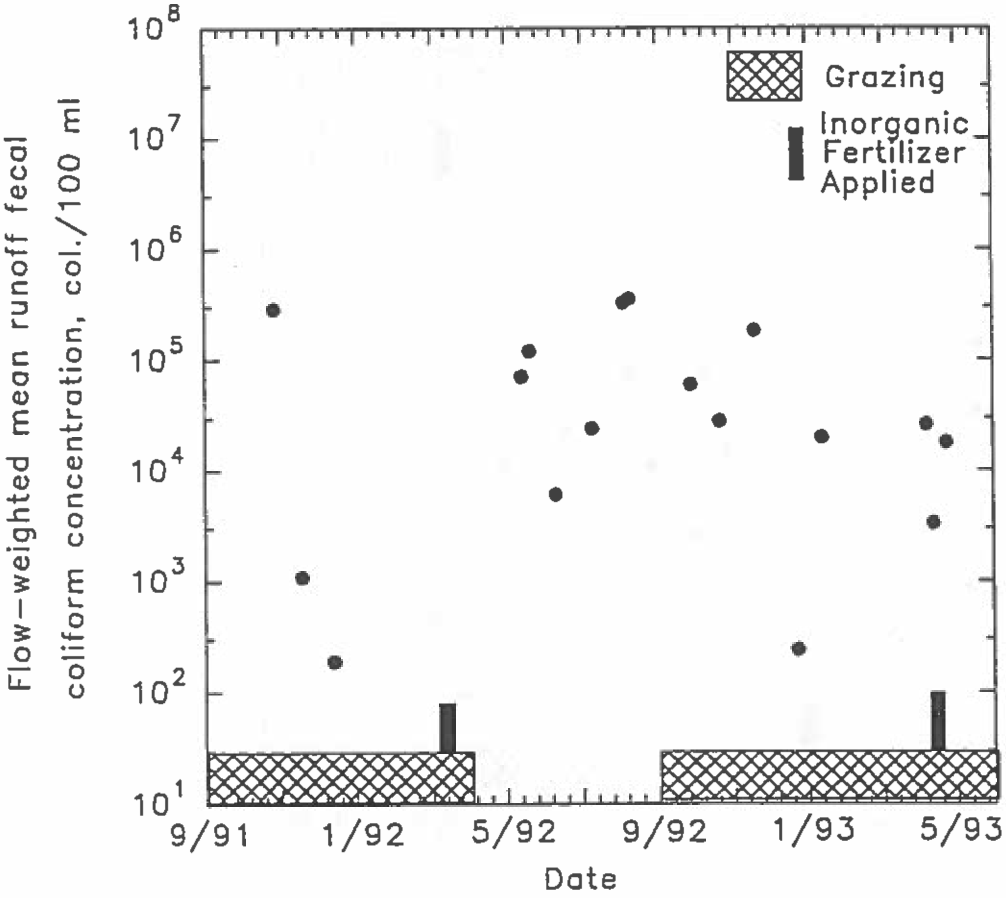

Fig. 2. Mean runoff fecal coliform concentrations for field RB.

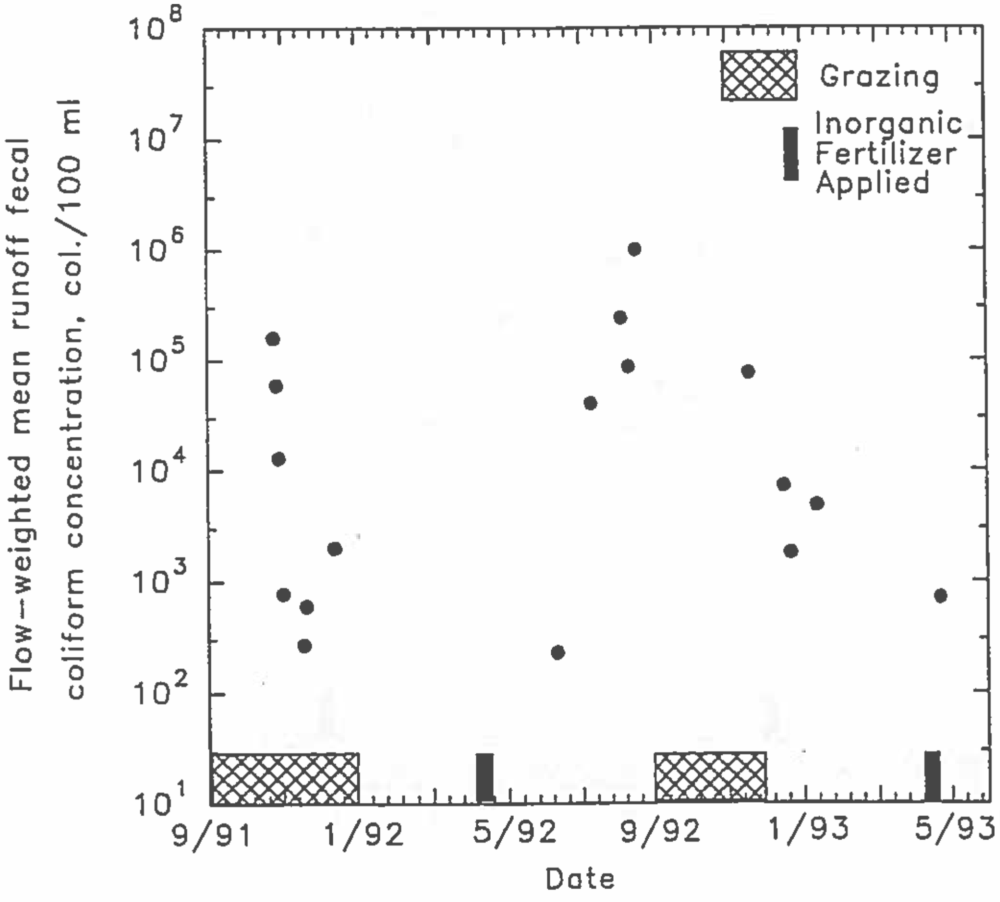

Fig. 3. Mean runoff fecal coliform concentrations for field WA.

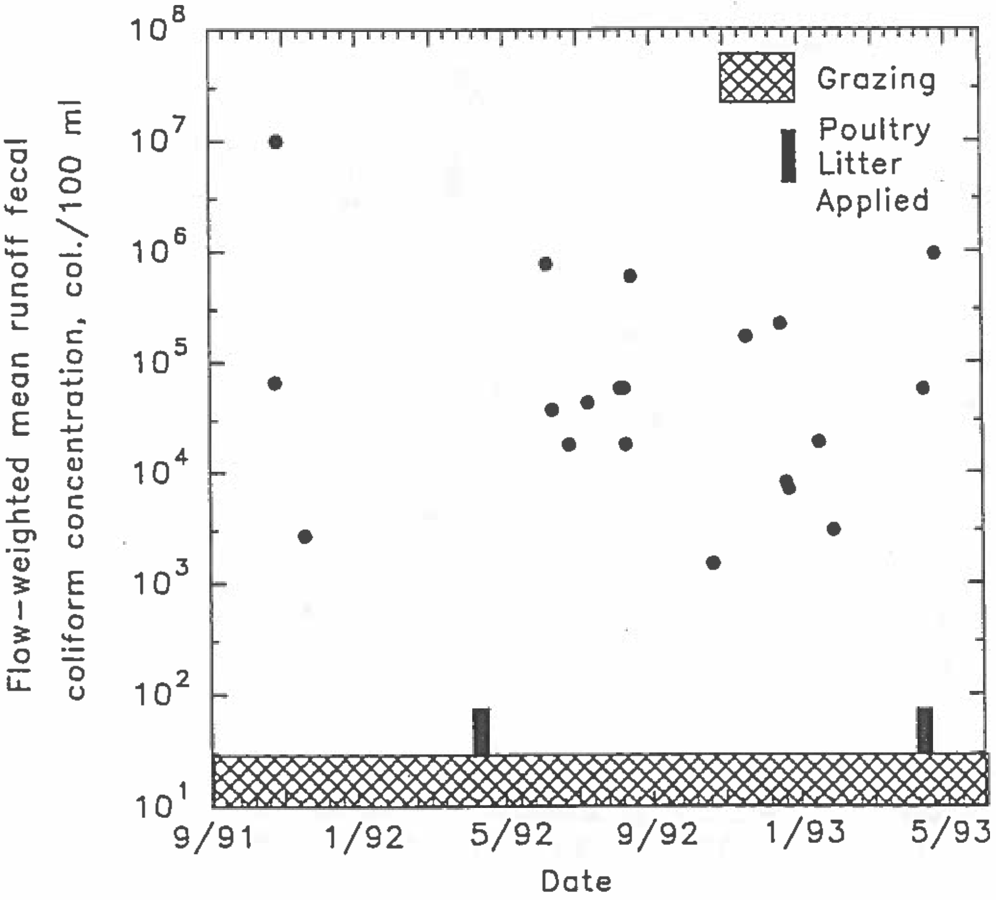

Fig. 4. Mean runoff fecal coliform concentrations for field WB.

It is difficult to draw conclusions from the data regarding runoff quality impacts of fertilizer source and other site/management parameters. Although every effort was made to monitor field pairs that were as similar as possible, the inevitable differences in fields within a pair undoubtedly had a large influence on runoff quality. For example, fields RA and RB had total runoff depths that varied by a factor of 4.5; runoff from fields WA and WB varied by a factor of 3.1. Thus, differences in concentrations and mass losses of analysis parameters can not be ascribed only to management treatment. In terms of runoff quality, the hydrology of the fields appeared to be at least as important as the chemical dynamics near the soil surface.

CONCLUSIONS

Runoff concentrations of analysis parameters were highly variable and depended largely on runoff amounts and timing of fertilizer application. Application of fertilizer just prior to a runoff event was quite evident in the runoff concentration data; when a month or more had elapsed with no runoff event, fertilizer application was less easily detectable. Mass losses of analysis parameters were agronomically small over the study period. A few runoff events were responsible for large proportions of total mass losses of some analysis parameters. Fecal coliform concentrations appeared to be unrelated to either grazing or poultry litter/manure concentrations and usually exceeded Arkansas' secondary contact standard of 1000 col./100 ml.

Results of the study to date do not appear to definitively answer the question of how runoff quality is affected by various fertilizer sources and other management strategies. However, the findings serve as a rather vivid demonstration of the effects of heterogeneities that inevitably increase with size of monitored area.

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