Polyacrylamide for coliform bacteria removal from agricultural wastewater

R. Spackman, J.A. Entry, R.E. Sojka, and J.W. Ellsworth

ABSTRACT: Pollution of surface flow and groundwater from animal waste application to soils has been well documented. Polyacrylamide (PAM) has reduced total coliform (TC) and fecal coliform (FC) bacteria in animal waste water flowing in irrigation furrows. We measured efficacy of PAM dissolved in water and as a "patch" application to soil to remove total and fecal coliforms from: 1) water flowing over dairy waste in furrow-irrigated, ungrazed forage production systems; 2) soil water after it flowed through 1 m of soil; and 3) influence of PAM on survival of total and fecal coliforms in surface flow, soil, and soil water. Total coliforms in surface flow did not differ when waste was applied to soil, regardless of PAM treatment or days since waste was applied. Total coliforms in surface flow decreased by tenfold over the 7 days after waste regardless of PAM treatment. Fecal coliforms in surface flow decreased by tenfold over the 7 days after waste application and one hundredfold over the 28 days after waste application regardless of PAM treatment. Total coliforms in soil decreased by tenfold over the 7 days after waste was applied, one hundredfold over the 28 days after waste was applied and one thousandfold over the 63 days after waste was applied, regardless of PAM treatment or soil depth. Total coliforms did not differ in control soils and soils receiving waste, regardless of soil depth or PAM treatment over the 28 and 63 days after dairy waste was applied. Fecal coliforms in soil were greater in the 0 to 5 and 5 to 15 cm soil depths when waste was applied to soil, regardless of soil PAM treatment. Fecal coliforms in all three soil depths decreased as much as one thousandfold over the 28 and 63 days after waste and PAM treatments were applied. In all treatments, except the waste application x PAM patch treatment, total coliforms in soil water showed a tenfold decrease over the 28 and 63 days after waste was applied. PAM may not provide additional protection to surface water from waste applied to ungrazed forage production systems, but the compound does not enhance survival of total or fecal coliforms in soils or water.

Keywords: Anionic polyacrylamide, dairy waste, fecal coliforms, furrow irrigation runoff, soil water, total coliforms

Agriculture is the most widespread source of nonpoint water pollution in the United States (USEPA, 1998). Protection of water from agricultural runoff has focused on soil erosion and related nonpoint sources that contribute to surface-water contamination (Mallin et al., 1997; Mawdsley et al., 1995). The soil-erosion-control literature is voluminous and links to surface-water quality are well-documented. In the last decade, there has been a major shift in animal rearing toward large-scale, confined, animal-feeding operations (CAFOs). CAFOs are a primary source of agricultural pollution and pose many risks to water quality and public health because of the large amount of manure generated (USEPA, 1998). The U.S. Environmental Protection Agency (USEPA) estimates that animal waste production in 1992 was 13 times greater on a dry weight basis than human production. Sources of water pollution from CAFOs include direct discharges, open feedlots, treatment and storage lagoons, manure stockpiles and land application of manure. Pollution of surface flow and groundwater from animal waste applied to soils has been documented (Mallin et al., 1997; Mawdsley et al., 1995; Khaeel

et. al., 1980). Liquid waste discharge onto soil initiates solute and microbe movement into the soil following ground water drainage patterns potentially contaminating adjoining surface water. These same bodies of water are often sources of drinking water or used for recreational activities. Human contact with recreational waters containing intestinal pathogens is an effective method of disease transmission. It is critical to employ appropriate treatment strategies to maintain the quality of lakes and streams and keep them free of intestinal pathogens.

Total and fecal coliforms are sensitive and commonly used indicators of bacterial pathogen contamination of natural waters. Their presence implies the potential presence of microorganisms that are pathogenic to humans. Runoff and groundwater from waste-treated agricultural land shows that total and fecal coliform bacteria numbers follow a pattern:

1) More coliform bacteria in water during spring flows,

2) Fewer coliform bacteria in water during the dry period,

3) Greater numbers of coliform bacteria in water after applying wastewater by irrigation or after additional manure application, and

4) A rapid decline of bacteria counts once manure application is halted (Fraser et al., 1998; Howell et al., 1996; Darling and Coltharp, 1973; Buckhouse and Gifford, 1976).

Several investigators found that fecal coliform bacteria numbers declined rapidly when transported through dispersed soils, indicating that bacterial pollution occurs by transport via water through soil macropores (Abu-Ashour et al., 1998; Howell et al., 1996; Huysman and Verstraete, 1993; Buckhouse and Gifford, 1976).

Since the early 1990s, use of polyacrylamide (PAM) has been shown to be an effective strategy for erosion control and water-quality protection (Lentz and Sojka, 1994). The application of anionic PAM to soils or vegetative treatments could also provide a cost-effective way to reduce bacteria and nutrient loads in animal waste effluent and thereby reduce pollution in surface and ground waters receiving these effluents. Sojka and Entry (2000)

Ross Spackman and **J.W. Ellsworth** are with the University of Idaho's Research and Extension Center in Twin Falls, and **James A. Entry** and **Robert E. Sojka** are with the U.S. Department of Agriculture - Agricultural Research Service, Northwest Irrigation and Soils Research Laboratory in Kimberly, Idaho.

found that after water traveled 1 m (3.28 ft) down a bare furrow at 7.5 and 15.5 L min^{-1} (2 and 4 gal min^{-1}), PAM treatment reduced algae, total bacterial and microbial biomass, and total fungal biomass relative to the control treatment. After water traveled 40 meters at 7.5, 15.5, and 22.5 L min^{-1} (2, 4 and 6 gal min^{-1}), PAM treatment reduced algae, active and total bacteria, active and total fungal length, total bacterial biomass, and total fungal biomass relative to the control treatment. In a study to determine the efficacy of PAM to remove enteric bacteria and nutrients from animal wastewater, Entry and Sojka (2000) found that PAM+Al(SO$_4$)$_3$ and PAM+CaO mixtures reduced populations of total and fecal coliforms and fecal streptococci in cattle, fish, and swine wastewater leachate and surface runoff by approximately one hundred to one thousandfold compared with no treatment. Entry et al. (2002) found that PAM reduced populations of total and fecal coliforms in swine dairy waste leachate from columns containing four different soil types, ranging from sand to clay, by at least tenfold compared with soil columns without PAM. In the same study, PAM+Al(SO$_4$)$_3$ and PAM+CaO treatments reduced populations of total and fecal coliforms in the same leachate from ten to one hundredfold in all three dairy waste sources compared with the control. PAM is effective at reducing erosion, nutrients, and bacteria in surface flow over a 1 m (3.28 ft) distance, and its effectiveness increases as water flows down a furrow to a distance of at least 40 m (130 ft). These studies indicate that PAM application may be used to reduce contaminant loads in waste water entering streams and lakes.

Survival of total and fecal coliforms in soil and soil water on irrigated, ungrazed, forage production systems with several years of waste application needs to be investigated. Because ungrazed forage production systems are vegetation, they may perform similarly to vegetated filter strips. Vegetation acts as a filter and removes total and fecal coliforms, and nutrients through both soil and surface-water pathways (Entry et al., 2000a, 2000b; Fajardo et al., 2002; Hubbard et al., 1998; Snyder et al., 1998; Jordan et al., 1993). Coyne et al. (1995), Walker et al. (1990), and Young et al. (1980) concluded that 10 m (32.8 ft) wide grass filter strips can reduce fecal coliforms in surface runoff by as much as 70%.

In studies where animal waste has been continually applied for several years enteric

bacteria are found in soils and groundwater (Entry et al., 2000a, 2000b; Entry et al., 2002). Pathogen survival time in the soil varies from 4 to 160 days (Abu-Ashour et al., 1998; Sjogren, 1994). Survival of pathogenic bacteria first reflects the organisms' ability to respond to nonparasitic and adverse environmental conditions. Obligate parasites usually only live a few minutes outside the host, but many pathogenic organisms can live in groundwater and soil for months (Entry et al., 2000a, 2000b; Sorber and Moore, 1987). Several factors influence the survival of pathogens in soil after waste materials are applied. Soil moisture and temperature seem to be the most important of these factors (Sjogren, 1994; Crane and Moore, 1986). Survival of bacteria that are pathogenic to humans in soil increases when the soil is moist and temperatures are warm (Entry et al., 2000a, 2000b). Although further research is necessary when waste is continually applied to forage production systems, at least a 60-day period between waste applications, to let enteric bacteria die, is usually advisable. The opportunity for transfer of these organisms from soils, after land application of animal waste to surface and groundwater, and ultimately humans, will depend in part on their ability to survive in the soil environment.

The efficacy of PAM in reducing coliform bacteria in water flowing from forage production systems that have been treated with dairy waste has not been investigated. Vegetation may inhibit direct water flow and cause bacteria to be deposited on the soil surface or on the vegetation itself. In addition, the effect of PAM on survival of coliform bacteria in soil has not been investigated. The amide group side chain on the PAM molecule could supply nitrogen (N) to bacteria, enhancing bacterial growth. Bacterial enrichment cultures, derived from PAM-treated field soils, were capable of growth with PAM as a sole source of nitrogen but could not grow with PAM as sole source of carbon (C) (Kay-Shoemake et al., 1998a, 1998b). Therefore, addition of PAM to soil via irrigation or runoff water may increase survival of enteric bacteria in soil. The objectives of this study were: 1) to determine the efficacy of PAM application dissolved in water or as a "patch" application to soil in removing coliform bacteria from surface flow and shallow soil water in irrigated, ungrazed, forage-production systems, and 2) to determine whether PAM affects survival of coliform bacteria in soil or soil water.

Methods and Materials

Study site. The study was conducted at the College of Southern Idaho field site at Twin Falls, Idaho. The soil from the test field was Portneuf silt loam (coarse-silty, mixed, superactive, mesic Durinodic Xeric Haplocalcid), with 10% to 21% clay, 60% to 75% silt, and organic matter of approximately 13 g kg^{-1} (1.3%). Saturated paste extract electrical conductivity (EC) of this soil ranges from 0.7 to 1.3 dS mmho cm^{-1}, exchangeable sodium percentage (ESP) of 1.4 to 1.7, pH of 7.6 to 8.0, and a CaCO$_3$ equivalent of 2% to 8%. Slope on this site was approximately 1.5%. The site was planted with orchardgrass (*Dactylis glomerta* L.) that produced 14,228 kg dry grass ha^{-1} yr^{-1} (10,120 lbs ac^{-1} yr^{-1}).

Experimental design. The study was arranged in a randomized complete block design consisting of four treatments:
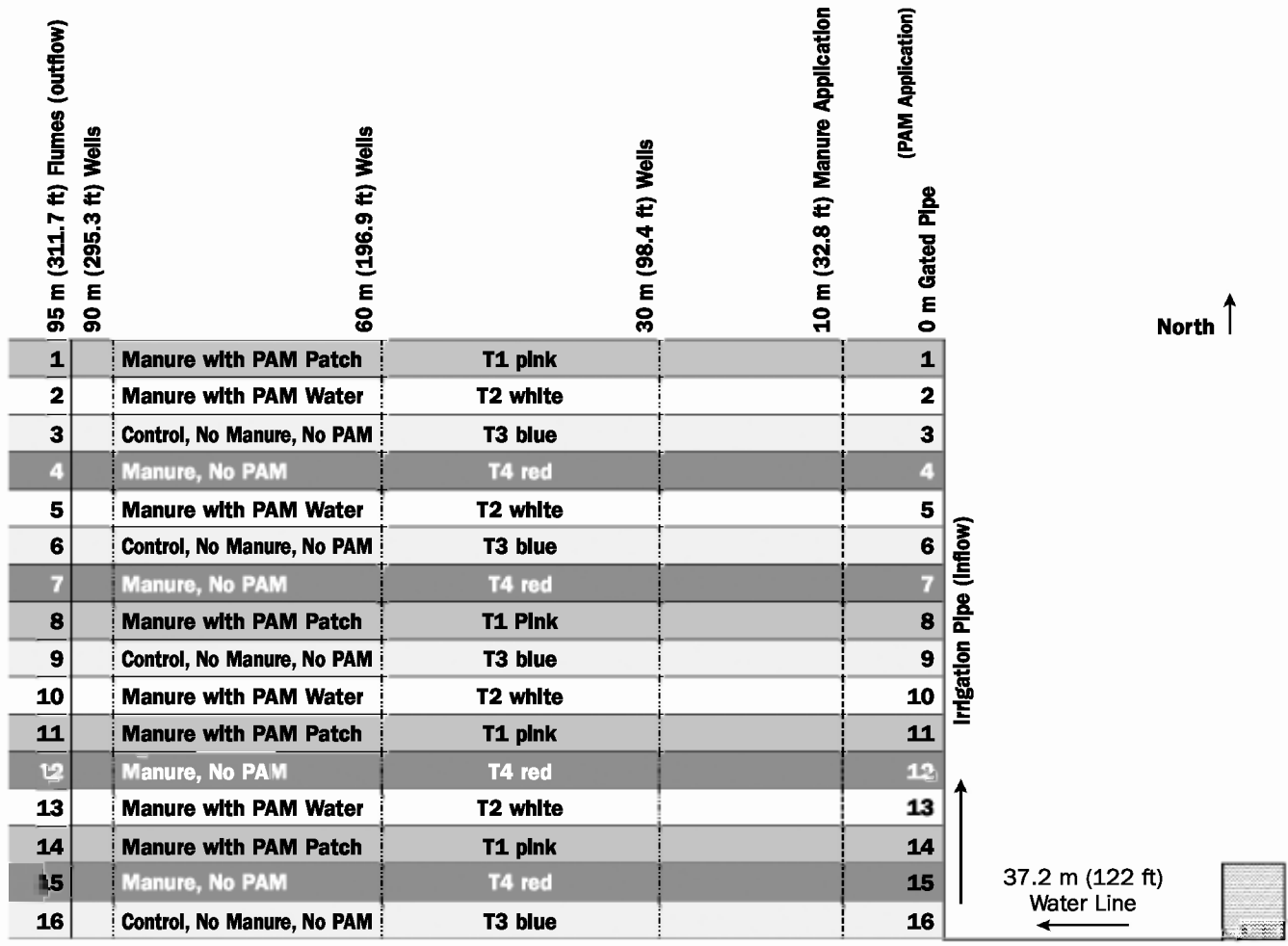
1) Dairy waste without PAM application,

2) Dairy waste with PAM dissolved in irrigation water (the Natural Resources Conservation Service [NRCS] method),

3) Dairy waste with PAM applied to soil as a patch application, and

4) Control (no dairy waste or PAM applied). Dairy waste was applied once on day zero, June 24, 2001. Plots were irrigated on a 10 to 14 day interval throughout the study. In this study, grazing animals had not been present on this land for more than ten years before this study.

Treatment application. Plots were 12.2 m wide x 95 m long (40 ft wide x 311.6 ft long) with 16 furrows spaced 76 cm (2.5 ft) apart (Figure 1). Furrows were prepared with weighted 75° shaping tools. Furrows were 0.1 m wide x 0.1 m deep x 95 m long (0.3 ft wide x 0.3 ft deep x 311.6 ft long). A larger furrow, 30 cm wide x 30 cm deep x 95 m long (1.0 ft wide x 1.0 ft deep x 311.6 ft long), was formed between plots to prevent irrigation water from flowing from one treatment to another treatment. We placed 77.6 L^{-1} (20.5 gal) of solid, wet dairy waste 3.0 m (9.84 ft) from the water inflow point in 1.0 m long (3.3 ft long) area in each furrow (Figures 1 and 2). Irrigation water from the Snake River via Twin Falls Canal Company was applied to individual furrows at 23.1 L^{-1} min^{-1} (6.1 gal^{-1} min^{-1}) using gated plastic pipe. Spigots controlled inflow rates to each furrow.

PAM was applied as a patch treatment or was metered (NRCS method) into irrigation water. Stock PAM solutions of 0.61 g PAM

Figure 1

Plot diagram showing surface water and soil sampling points and soil water suction lysimeters.

95 m (311.7 ft) Flumes (outflow)	90 m (295.3 ft) Wells	60 m (196.9 ft) Wells	30 m (98.4 ft) Wells	10 m (32.8 ft) Manure Application	0 m Gated Pipe (PAM Application)
1	Manure with PAM Patch	T1 pink			1
2	Manure with PAM Water	T2 white			2
3	Control, No Manure, No PAM	T3 blue			3
4	Manure, No PAM	T4 red			4
5	Manure with PAM Water	T2 white			5
6	Control, No Manure, No PAM	T3 blue			6
7	Manure, No PAM	T4 red			7
8	Manure with PAM Patch	T1 Pink			8
9	Control, No Manure, No PAM	T3 blue			9
10	Manure with PAM Water	T2 white			10
11	Manure with PAM Patch	T1 pink			11
12	Manure, No PAM	T4 red			12
13	Manure with PAM Water	T2 white			13
14	Manure with PAM Patch	T1 pink			14
15	Manure, No PAM	T4 red			15
16	Control, No Manure, No PAM	T3 blue			16

North

Irrigation Pipe (Inflow)

37.2 m (122 ft) Water Line

L^{-1} (0.08 oz PAM gal^{-1}) water were prepared 1 to 2 days before each irrigation and were metered into the head of each furrow with a positive displacement pump connected to a tube manifold. Turbulence created by incoming irrigation water mixed and dispersed the aqueous PAM stock solution into the flow at a concentration of 2 mg PAM in 1,000 L^{-1} water (7.5 x 10^{-1} oz PAM 1,000 gal water). In the PAM patch method, 16 g (0.6 oz) of PAM was placed in a 1.0 m long (3.3 ft) area (Figures 1 and 2). Water flowed 0.5 m (1.6 ft) from the inflow point and then flowed over a 0.1 m wide x 0.1 m deep x 1.0 m long (0.3 ft wide x 0.3 ft deep x 3.3 ft long) area containing the PAM applied as a patch, and then over a 0.1 m wide x 0.1 m deep x 1.0 m long (0.3 ft wide x 0.3 ft deep x 3.3 ft long) area containing 77.4 L^{-1} (20.5 gal) of solid wet dairy waste (Figures 1 and 2). PAM when

applied as a patch treatment or when metered (NRCS method) at 10 µg L^{-1} (10 ppm) into irrigation water does not dilute to the point the efficacy is lost at 100 m (108 ft) (Lentz et al., 2002).

Surface flow samples. Surface flow was sampled at the inflow point and at 30, 60, and 90 m (98.4, 196.8, and 295.2 ft) down slope of treatments (Figure 1), with time increments during irrigation (0.5, 2.5, and 5 hr). We sampled soil at 0 to 5 cm, 5 to 15 cm, and 15 to 30 cm (0 to 2.0, 2.0 to 5.9, and 5.9 to 11.8 inches respectively) depths and soil water at 1.0 m (3.28 ft) deep at 1, 7, 28, and 63 days after treatments were applied. We analyzed three subsamples for total and fecal coliforms from each sample to account for sampling error (Kirk 1982). We took 576 surface-flow samples for the study (4 treatments x 4 sampling points along each furrow x 3 sampling times during each irri-

gation x 4 sampling times x 3 samples from each water collection point [Figure 2]).
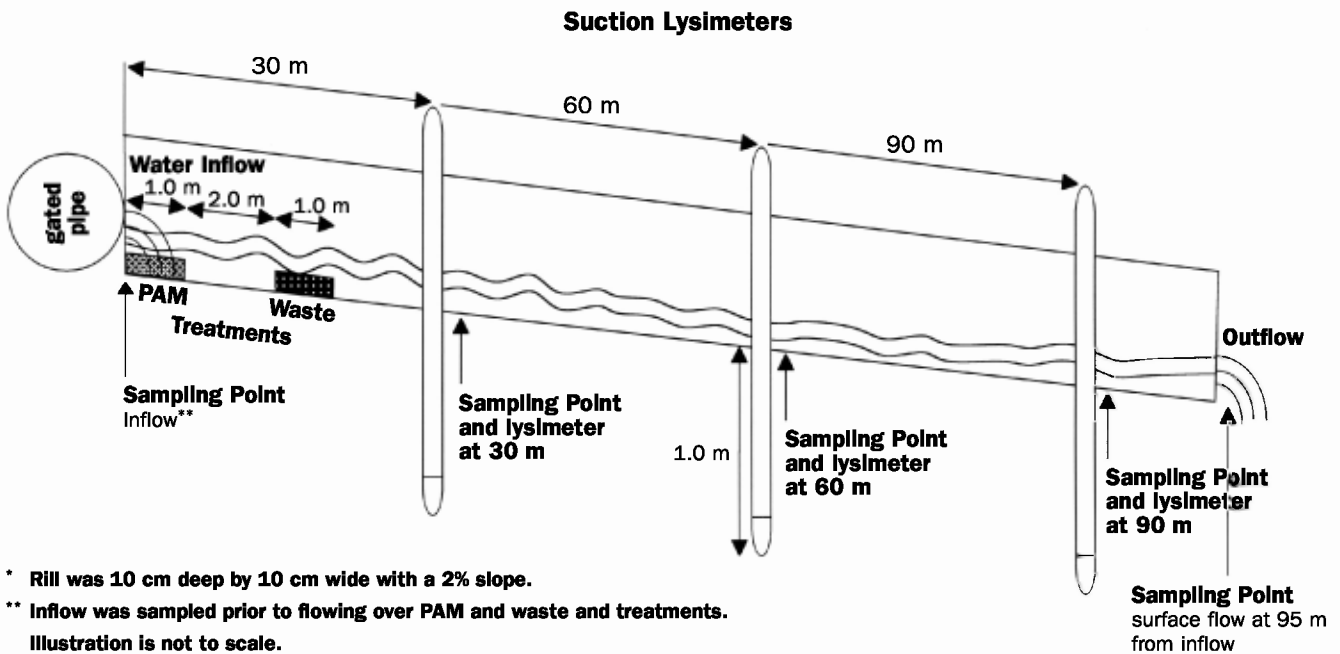
Soil samples. We took 288 soil samples for the study. We had 4 treatments x 3 sampling points (at 30, 60, and 90 m = 98.4, 196.8, and 295.2 ft respectively) along each furrow x 3 depths (0 to 5, 5 to 15, and 15 to 30 cm deep (0 to 2.0, 2.0 to 5.9, and 5.9 to 11.8 inches respectively) x 2 samples from each sampling point as sampling error x 4 sampling times (at 1, 7, 28, and 63 days since dairy waste was applied) (Figure 2).

Soil water samples. We took 144 soil water samples for the study (4 treatments x 3 sampling points along each furrow x 3 samples from each sampling point x 4 sampling times (days since dairy waste was applied) (Figure 2).

Bacterial sample collection. Samples were collected and analyzed for total and fecal coliforms. Surface flow and soil water were

Figure 2

Diagram of furrow in irrigated, ungrazed, forage-production systems showing dairy irrigation water flowing over dairy waste, then a PAM treatment with collection points at inflow (o), 30, 60, and 90 m from the inflow point.

Suction Lysimeters

30 m

60 m

90 m

Water Inflow
1.0 m
2.0 m
1.0 m

gated pipe

PAM

Waste Treatments

Sampling Point
Inflow**

Sampling Point
and lysimeter
at 30 m

1.0 m

Sampling Point
and lysimeter
at 60 m

Outflow

Sampling Point
and lysimeter
at 90 m

Sampling Point
surface flow at 95 m
from inflow

* Rill was 10 cm deep by 10 cm wide with a 2% slope.
** Inflow was sampled prior to flowing over PAM and waste and treatments.
Illustration is not to scale.

collected and stored in airtight and watertight 500 ml plastic bottles and prepared for coliform testing within 2 hours of collection (Greenberg et al., 1992). Surface flow and soil water samples tested for active bacteria and fungi were stored at 4° C and analyzed within 24 hours of collection (West et al., 1986) to minimize the effects of storage on microbial activity. Survival of total and fecal coliforms in surface flow in each treatment was determined at 0 (inflow), 30, 60, and 90 m (98.4, 196.8, and 295.2 ft respectively) from the inflow point at 1, 7, 28, and 63 days after application of wastewater. Survival of total and fecal coliforms in soil water in each treatment was determined at 0 (inflow), 30, 60, and 90 m (98.4, 196.8, and 295.2 ft respectively) from the inflow point at 2, 8, 29, and 64 days after application of wastewater. Survival of total and fecal coliforms in soil in each treatment was determined at 30, 60, and 90 m (98.4, 196.8, and 295.2 ft respectively) at the 0 to 5, (0 to 2.0 inches), 5 to 15 (2.0 to 5.9 inches), and 15 to 30 cm (0 to 2.0, 2.0 to 5.9, and 5.9 to 11.8 inches) soil depths at 2, 8, 29, and 64 days after application of wastewater.

Coliform procedures. Total and fecal coliforms were analyzed using the membrane filter technique (Greenberg et al., 1992). Preliminary water samples from test runs taken 1 to 3 days before each test were analyzed to determine each dilution before bacteria were counted. Water samples were diluted in a series of 2 (1 ml sample water to 99 ml sterile deionized water) to 5 (1 ml sample water to 99,999 ml sterile deionized water). One hundred milliliters of final dilution of each sample was vacuum-filtered through a sterile 0.45 μm filter and placed on Em endo medium to determine total coliforms, fecal coliforms medium to determine fecal coliforms. Total coliforms were incubated at 39.5 ± 0.02° C for 24 hours fecal coliforms were incubated at 44.5 ± 0.02° C for 24 hours.

Statistical analyses. All dependent variables were tested for normal distribution. Total and fecal coliform bacteria numbers were transformed using logarithms to achieve normal distributions. Data were then analyzed using general linear model (GLM) procedures for a randomized complete block design with Statistical Analysis Systems (SAS Institute Inc., 1996). In all analysis, residuals were equally distributed with constant variances. Differences reported were significant at p≤0.05, as determined by the Least Squares Means test. Total and fecal coliforms are reported in untransformed numbers.

Results and Discussion

Surface flow. In the surface-flow study, statistical comparisons for total and fecal coliforms were made for waste application x PAM treatment x time during irrigation x PAM treatment x distance from inflow x sampling time because GLM models showed these interactions were not significant at p≤0.05; therefore, results are presented with regard to PAM treatment x days since dairy waste was applied (Snedecor and Cochran, 1980; Kirk, 1982). Total coliforms in surface flow did not differ when waste was applied to soil, regardless of PAM treatment or days since waste was applied (Table 1). Total coliforms in surface flow decreased by tenfold, seven days after waste, regardless of PAM treatment. Total coliforms did not decrease from 7 to 63 days after waste was applied. Fecal coliforms in surface flow was higher when waste was applied to soil regardless of PAM treatment. Fecal coliforms in surface flow decreased by tenfold seven days after waste application and one hundredfold 28 days after waste application, regardless of PAM treatment. Fecal coliforms did not decrease from 28 to 63 days after waste was applied.

Soil study. In the soil study, statistical comparisons for total and fecal coliforms were made for waste application x PAM

treatment x soil depth because GLM models showed comparisons of waste application x PAM treatment soil depth x distance from inflow x sampling time were not significant at $p \leq 0.05$; therefore, results are presented with regard to PAM treatment x days since dairy waste was applied (Snedecor and Cochran, 1980; Kirk, 1982). Total coliforms in soil did not differ the day waste was applied to soil, regardless of PAM treatment or soil depth (Table 2). When dairy waste was applied at 0 and 7 days, fecal coliforms were higher in the 15 to 30 cm (5.9 to 11.8 in) depth of soil compared with when PAM was not applied. Total coliforms in soil decreased by tenfold 7 days after waste was applied, one hundredfold 28 days after waste was applied, and one thousandfold 63 days after waste was applied, regardless of PAM treatment or soil depth. Total coliforms did not differ in soils receiving waste, regardless of soil depth or PAM treatment. Fecal coliforms in soil were greater in the 0 to 5 and 5 to 15 cm (0 to 2.0 and 2.0 to 5.9 in respectively) soil depths when waste was applied to soil, regardless of soil PAM treatment. Fecal coliforms in soil were greater in the 15 to 30 cm (5.9 to 11.8 in) soil depth when waste and PAM was applied in irrigation water or to soil as a patch treatment. Fecal coliforms in all three soil depths decreased from ten to one thousand-fold 28 and 63 days after waste and PAM treatments were applied.

Soil water. In the soil water study, statistical comparisons for total and fecal coliforms were made for waste application x PAM treatment x time since waste application because GLM models showed comparisons of waste application x PAM treatment x distance from inflow these interactions were not significant at $p \leq 0.05$; therefore, results are presented with regard to PAM treatment x days since dairy waste was applied (Snedecor and Cochran, 1980; Kirk, 1982). Except on day 29 in the NRCS-PAM treatment, total coliforms increased when waste was applied to soil, regardless of PAM treatment (Table 3). In all treatments, except the waste application x PAM patch treatment, total coliforms in soil water decreased at 29 and 64 days after waste was applied. We found no fecal coliforms in 1 m (3.28 ft) deep soil water throughout our sampling period.

Surface flow discussion. This study is one of the first to measure total and fecal coliforms survival in surface flow, soil water, and

soil in an irrigated management regime. This research revealed that total and fecal coliforms in surface water, soil at depths 0 to 5 cm, 5 to 15 cm, and 15 to 30 cm (0 to 2.0, 2.0 to 5.9, and 5.9 to 11.8 in) and total coliforms in soil water declined approximately ten to one hundredfold by day 63. Entry et al. (2000a) found that total and fecal coliforms in soil water and shallow soil water declined by approximately tenfold every 7 days for the first 14 days, regardless of vegetative treatment or season. Initial total and fecal coliforms die-off rates in water and soil seem to be 14 to 28 days slower than in nonirrigated systems. Irrigation keeps the soil moister during the growing season, and, therefore, total and fecal coliforms survive longer in soil and soil water. This study also found that total and fecal coliforms in irrigation water did not decline as the water moved down slope, regardless of PAM treatment, and there were few total coliforms and no fecal coliforms in soil water, regardless of waste application or PAM treatment, indicating that the top 1 m (3.28 ft) of soil filtered these bacteria, preventing soil water contamination. When dairy waste was applied in both PAM treatments, at 0 and 7 days fecal coliforms were higher in the 15 to 30 cm depth of soil compared with measurements when PAM was not applied. PAM addition to soils in these concentrations is known to increase water infiltration (Lentz and Sojka, 1994; Lentz et al., 1992, 1998). Bacteria may have been carried to the 15 to 30 cm (5.9 to 11.8 in) depth by the increased water flow to that depth.

Entry and Sojka (2000) found that PAM, $PAM+Al_2(SO_4)_3$, and PAM+CaO reduced total coliforms, fecal coliforms, and fecal streptococci in surface flow by ten to one hundredfold in water flowing 1 and 27 m (3.28 and 88.56 ft) downstream of the treatments compared with the control treatment. In this study, irrigating long furrows through dense grass stand and litter, PAM did not reduce total and fecal coliforms in surface flow. If as in studies conducted by Entry and Sojka (2000) and Entry et al. (2002), larger amounts of dairy waste were applied. If larger amounts of dairy waste were applied so that a increase in total and fecal coliforms were measured in the manure treatments, PAM should have reduced total and fecal coliforms in surface flow and soil compared with controls as reported in previous studies.

Environmental concerns. The water-soluble PAMs developed for use in erosion control are very large anionic molecules that have been shown to be safe for a variety of food, pharmaceutical, and sensitive environmental applications (Barvenik, 1994). They should not be confused with gel forming cross-linked PAM, or evaluated with other PAM formulations, especially cationic PAMs, which have known safety concerns related to their specific chemistries (Barvenik, 1994). Environmental regulation, safety and toxicity issues related to PAM use have been extensively reviewed (Seybold, 1994; Barvenik, 1994).

Although the precise mechanism is not fully understood, polyacrylamide compounds are used in many industrial processes to accelerate flocculation. Polyacrylamide has been used in irrigated agriculture for erosion control and increased infiltration (Aase et al., 1998; Lentz et al., 1992; Lentz and Sojka, 1994; Sojka et al., 1998a, 1998b). Lentz et al. (1998) and Lentz and Sojka (1994) reported that PAM treatment reduced sediment-loss rate over time with improvement of the runoff water-quality parameters dissolved reactive P, total-P, nitrate, and biological oxygen demand. Subsequent studies have further documented the capacity of PAM treatment to reduce sediments, nutrients, and pesticides in irrigation water (Agassi et al., 1995; Singh et al., 1996; Sojka et al., 1998a, 1998b). We hypothesized that PAM flocculates microorganisms attached to soil particles, as well as microorganisms suspended in water. The PAM, Superfloc® A836, used in this study is an extremely large, negatively charged molecule (Lentz et al., 2000; Barvenik, 1994). When PAM is combined with either $Al(SO_4)_3$ or CaO in soil, $Al(SO_4)_3$ or CaO should quickly disassociate, freeing Al^{+3} and Ca^{+2} to bind with anionic nutrients such as $H_2PO_4^-$ and NO_3^-. Free Al^{+3} and Ca^{+2} most likely bind with anionic sites on the PAM molecule, forming a bridge with anionic nutrients such as $H_2PO_4^-$ and NO_3^-. The anionic charges on PAM would not only flocculate microorganisms, but also positively charged nutrients in wastewater.

Summary and Conclusion

Total coliforms in surface flow did not differ when waste was applied to soil, regardless of PAM treatment. Total coliforms in surface flow decreased by tenfold seven days after waste application, regardless of PAM treatment. Fecal coliforms in surface flow

Table 2. Total and fecal coliform bacteria numbers in the 0-5, 5-15, and 15-30 cm soil depths after dairy waste application and irrigation water flowed over polyacrylamide treatment and the dairy waste at 1, 8, 29, and 64 days after waste and polyacrylamide was applied.

Day	Waste application	Polyacrylamide treatment	Soil depth (cm)	Total coliform bacteria[a,b]	Fecal coliform bacteria[a,b]
				— bacteria / 100 ml water —	
1	None	None	0-5	3.74×10^5a	1.90×10^3a
	None	None	5-15	2.26×10^5a	0.99×10^3a
	None	None	15-30	3.21×10^5a	0e
	Waste	None	0-5	5.62×10^5a	2.9×10^3a
	Waste	None	5-15	1.00×10^6a	9.69×10^2b
	Waste	None	15-30	2.41×10^5a	0e
	Waste	Patch	0-5	2.51×10^5a	0e
	Waste	Patch	5-15	4.30×10^5a	1.96×10^2b
	Waste	Patch	15-30	5.12×10^5a	2.65×10^3a
	Waste	NRCS	0-5	1.99×10^5a	2.18×10^3a
	Waste	NRCS	5-15	4.18×10^5a	1.96×10^2b
	Waste	NRCS	15-30	5.70×10^5a	6.15×10^3a
8	None	None	0-5	3.94×10^3b	0e
	None	None	5-15	1.01×10^4b	0e
	None	None	15-30	4.45×10^4b	0e
	Waste	None	0-5	5.70×10^4b	9.58×10^2b
	Waste	None	5-15	8.30×10^4b	0e
	Waste	None	15-30	3.70×10^4b	0e
	Waste	Patch	0-5	6.59×10^4b	5.95×10^4
	Waste	Patch	5-15	1.52×10^4b	2.05×10^3a
	Waste	Patch	15-30	5.53×10^4b	0e
	Waste	NRCS	0-5	2.98×10^4b	0e
	Waste	NRCS	5-15	1.15×10^4b	3.24×104a
	Waste	NRCS	15-30	9.53×10^4b	0e
29	None	None	0-5	8.27×10^2c	10d
	None	None	5-15	1.30×10^3bc	4d
	None	None	15-30	9.74×10^2b	12d
	Waste	None	0-5	9.73×10^2b	12d
	Waste	None	5-15	4.71×10^2b	6d
	Waste	None	15-30	5.88×10^2b	12d
	Waste	Patch	0-5	7.78×10^2b	9d
	Waste	Patch	5-15	1.47×10^3b	14d
	Waste	Patch	15-30	6.07×10^2b	0e
	Waste	NRCS	0-5	7.46×10^2b	11d
	Waste	NRCS	5-15	6.09×10^2b	12d
	Waste	NRCS	15-30	3.94×10^2b	2de
64	None	None	0-5	5.8×10^1c	3.4×10^1c
	None	None	5-15	2.2×10^1c	2de
	None	None	15-30	4.30×10^1c	0e
	Waste	Waste	0-5	4.50×10^1c	9.2×10^1c
	Waste	Waste	5-15	7.30×10^1c	1.98×10^1c
	Waste	Waste	15-30	4.18×10^1c	6d
	Waste	Waste	0-5	1.37×10^2bc	3.17×10^1c
	Waste	Waste	5-15	6.57×10^1c	6d
	Waste	Waste	15-30	1.38×10^2bc	0e
	Waste	NRCS	0-5	5.61×10^1c	5.21×10^1c
	Waste	NRCS	5-15	1.19×10^2bc	0e
	Waste	NRCS	15-30	8.90×10^1c	2de

a) In the soil study, statistical comparisons for total and fecal coliforms were made for waste application x PAM treatment x soil depth because GLM models showed comparisons of waste application x PAM treatment soil depth x distance from inflow x sampling time were not significant at $p \leq 0.05$ (Snedecor and Cochran, 1980; Kirk, 1982).

b) In each column, values followed by the same letter are not significantly different as determined by the Least Square Means Test ($P \leq 0.05$; n = 8).

Table 3. Total and fecal coliforms in 1.0 m groundwater suction lysimeters after irrigation water flowed over polyacrylamide and then dairy waste at 1, 8, 29, and 64 days after treatment.

Day	Waste application	Polyacrylamide treatment	Total coliform bacteria[ab]	Fecal coliform bacteria[ab]
			—— bacteria / 100 ml water ——	
1	None	None	118bc	0a
	Waste	None	1,434a	0a
	Waste	Patch	472b	0a
	Waste	NRCS	747ab	0a
8	None	None	31c	0a
	Waste	None	63c	0a
	Waste	Patch	348b	0a
	Waste	NRCS	14c	0a
29	None	None	9d	0a
	Waste	None	96c	0a
	Waste	Patch	476b	0a
	Waste	NRCS	5d	0a
64	None	None	5d	0a
	Waste	None	36c	0a
	Waste	Patch	287b	0a
	Waste	NRCS	259b	0a

a) Statistical comparisons for total and fecal coliform bacteria were made for waste application x PAM treatment x time since waste application because GLM models showed that comparisons of waste application x PAM treatment x distance from inflow these interactions were not significant at p ≤ 0.05 (Snedecor and Cochran, 1980; Kirk, 1982).

b) In each column, values followed by the same latter are not significantly different as determined by the Least Square Means Test (P ≤ 0.05; n = 16).

decreased by tenfold seven days after waste application and 99%, 28 days after waste application, regardless of PAM treatment. Total coliforms in soil decreased by tenfold seven days after waste was applied, 99% 28 days after waste was applied, and 99.9% 63 days after waste was applied, regardless of PAM treatment or soil depth. Total coliforms did not differ in control soils and soils receiving waste soil depth or PAM treatment 28 and 63 days after dairy waste was applied. Fecal coliforms in soil were higher in the 0 to 5 and 5 to 15 cm soil depths when waste was applied to soil, regardless of soil PAM treatment. Fecal coliforms in all three soil depths decreased by up to 99.9% 28 and 63 days after waste and PAM treatments were applied. In all treatments except the waste application x PAM patch treatment, total coliforms in soil water decreased more than tenfold 28 and 63 days after waste was applied.

Animal producers need to be aware of the potential for the spread of disease causing microorganisms when land applying solid and or liquid dairy waste. Total and fecal coliforms grow well in moist-warm habitats, but during this study many species were also isolated in the drier autumn and summer months. Diseases associated with enteric bacteria range from bacteria that cause mild to life-threatening gastroenteritis, hepatitis, skin infections, wound infections, conjunctivitis, respiratory infections, and generalized infections (Moe, 1997). We also need to be aware of the potential for the spread of disease causing microorganisms to agricultural lands and to the length of time these organisms can survive in soil. Irrigation may increase survival of total and fecal coliforms in soils compared with nonirrigated fields.

References Cited

Aase, J.K., D.L. Bjorneberg, and R.E. Sojka. 1998. Sprinkler irrigation runoff and erosion control with polyacrylamide-laboratory tests. Soil Science Society of America Journal 62:1681-1687.

Abu-Ashour, J., D.M. Joy, H. Lee, H.R. Whiteley, and S. Zelin. 1998. Movement of bacteria in unsaturated soil columns with macropores. Transactions American Society of Agricultural Engineers 41:1043-1050.

Agassi, M., J. Letey, W.J. Farmer, and P. Clark. 1995. Soil erosion contribution to pesticide transport by furrow irrigation. Journal of Environmental Quality 24:892-895.

Barvenik, F.W. 1994. Polyacrylamide characteristics related to soil applications. Soil Science 158:235-243.

Buckhouse, J.C. and G..F. Gifford. 1976. Water quality implications of cattle grazing on a semiarid watershed in southeastern Utah. Journal of Range Management 29:109-113.

Coyne, M.S., R.A. Gilifillen, R.W. Rhodes, and R.L. Blevins. 1995. Soil and fecal coliforms trapping by grass filter strips during simulated rain. Journal of Soil and Water Conservation 50(4):405-408.

Crane, S.R. and J.A. Moore. 1986. Modeling enteric bacterial die-off: a review. Water, Air and Soil Pollution 27:411-439.

Darling, L.A. and G.B. Coltharp, 1973. Effects of livestock on water quality of mountain streams. Pp.. 1-8. In: Proceedings of the Symposium on Water-Animal Relations at Southern Idaho College in Twin Falls, Idaho.

Entry, J.A. and R.E. Sojka. 2000. The efficacy of polyacrylamide related compounds to remove microorganisms and nutrients from animal wastewater. Journal of Environmental Quality 29:1905-1914.

Entry, J.A., R.K. Hubbard, J.E. Thies, and J.J. Furhmann. 2000a. The influence of vegetation in riparian filter-strips on coliform bacteria I. movement and survival in surface flow and groundwater. Journal of Environmental Quality 29:1206-1214.

Entry, J.A., R.K. Hubbard, J.E. Thies, and J.J. Furhmann, 2000b. Influence of vegetation in riparian filterstrips on coliform bacteria II. Survival in soil. Journal of Environmental Quality 29:1215-1224.

Entry, J.A., I. Phillips, H. Stratton, and R.E. Sojka. 2002. Efficacy of polyacrylamide+Al(SO4)3 and polyacrylamide+CaO to filter microorganisms and nutrients from animal wastewater. Environmental Pollution 121:463-472.

Fajardo, J.J., J.W. Bauder, and S.D. Cash. 2002. Managing nitrate and bacteria from livestock confinement areas with vegetative filter strips. Journal of Soil and Water Conservation 56(3):185-191.

Fraser, R.H., P.K. Barten, and D.A. Pinney. 1998. Predicting stream pathogen loading from livestock using a geographical information system-based delivery model. Journal of Environmental Quality 27:935-945.

Greenberg, A.F., L.S. Clescerl, and A.D. Eaton. 1992. Standard methods for the examination of water and wastewater. Eighteenth edition. American Public Health Association, Washington, D.C.

Howell, J.M., M.S. Coyne, and P. L. Cornelius. 1996. Effect of particle size and temperature on fecal bacteria mortality rates and the fecal coliforms/fecal streptococci ratio. Journal of Environmental Quality 25:1216-1220.

Hubbard, R.K., G.L. Newton, J.G. Davis, R. Lowrance, G. Vellidis, and C.R. Dove. 1998. Nitrogen assimilation by riparian buffer systems receiving swine lagoon wastewater. Transactions American Society of Agricultural Engineers 41:1295-1304.

Huysman, F. and W. Verstraete. 1993. Water facilitated transport of bacteria in unsaturated soil columns: influence of cell surface hydrophobicity and soil properties. Soil Biology and Biochemistry 25:83-90.

Jordan, T.E., D.T. Correll, and D.E. Weller. 1993. Nutrient interception by a riparian forest receiving inputs from adjacent cropland. Journal of Environmental Quality 14:467-472.

Khaeel, R., K.R. Reddy, and M.R. Overcash. 1980. Transport of potential pollutants in runoff water from land areas receiving animal wastes: a review. Water Research 14:421-436.

Kay-Shoemake, J.L.,M.E. Watwood, R.D. Lentz, and R.E. Sojka. 1998a. Polyacrylamide as an organic nitrogen source for soil microorganisms with potential impact on inorganic soil nitrogen in agricultural soil. Soil Biology and Biochemistry 30:1045-1052.

Kay-Shoemake, J.L., M.E. Watwood, R.E. Sojka, and R.D. Lentz. 1998b. Polyacrylamide as a substrate for microbial amidase. Soil Biology and Biochemistry 30:1647-1654.

Kirk, R.E. 1982. Experimental design: Procedures for the behavioral sciences, second edition. Brooks Cole Publishing Company, Belmont, California.

Lentz, R.D., I. Shainberg, R.E. Sojka, and D.L. Carter. 1992. Preventing irrigation furrow erosion with small applications of polymers. Soil Science Society of America Journal 56:1926-1932.

Lentz, R.D. and R.E. Sojka. 1994. Field results using polyacrylamide to manage furrow erosion and infiltration. Soil Science 158:274-282.

Lentz, R.D., R.E. Sojka, and C.W. Robbins. 1998. Reducing phosphorus losses from surface-irrigated fields: emerging polyacrylamide technology. Journal of Environmental Quality 27:305-312.

Lentz, R.D., R.E. Sojka, and C.W. Ross. 2000. Polymer charge and molecular weight effects on treated irrigation furrow processes. International Journal of Sediment Research 1:17-30.

Lentz, R.D., R.E. Sojka, and B.E. Mackey. 2002. Fate and efficacy of polyacrylamide applied in furrow irrigation: full-advance and continuous treatments. Journal of Environmental Quality 31:661-670.

Mallin, M.A., J. M. Burkholder, M.R. McIver, G.C. Shank, H.B. Glascow Jr., B.W. Touchette, and J. Springer. 1997. Comparative effects of poultry and swine waste lagoon spills on the quality of receiving waters. Journal of Environmental Quality 26:1622-1631.

Mawdsley, J.L., R.D. Bardgett, R.D. Merry, B.F. Pain, and M.K. Theodorou. 1995. Pathogens in livestock waste, their potential for movement through soil and environmental pollution. Applied Soil Ecology 2:1-15.

Moe, C.L. 1997. Waterborne transmission of infectious agents. Pp. 136-152. *In:* P C.J. Hurst, G.R. Knudsen, M.J. McInerney, L.D. Stetzenbach, and M.V. Walter (eds.). Manual of Environmental Microbiology. American Society of Microbiology, Washington, D.C.

SAS Institute Inc. 1996. SAS Users' Guide: Statistics-Version 6.03 edition. 584 pp. Statistical Analysis System Institute Inc., Cary, North Carolina.

Seybold, C.A. 1994. Polyacrylamide review: Soil conditioning and environmental fate. Communications in Soil Science and Plant Analysis 25:2171-2185.

Singh, G., J. Letey, P. Hanson, P. Osterli, and W.F. Spencer. 1996. Soil erosion and pesticide transport from an irrigated field. Journal of Environmental Science and Health B31:25-41.

Snedecor, W.G., and W.G. Cochran. 1980 Statistical methods, seventh edition. Iowa State University Press, Ames, Iowa. 354 pp.

Snyder, N.J., S. Mostaghimi, D.F. Berry, R.B. Reneau, S. Hong, P.W McClellan, and E.P. Smith. 1998. Impact of riparian buffers on agricultural nonpoint source pollution. Journal of American Water Resource Association 34:385-395.

Sjogren, R.E. 1994. Prolonged survival of an environmental *Escherichia coli* in laboratory soil microcosms. Water, Air and Soil Pollution 75:389-403.

Sorber, C.A. and B.E. Moore. 1987. Survival and transport of pathogens in sludge-amended soil: a critical literature review. Environmental Protection Agency Report, EPA 600 S2-87 028. Water Engineering Research Laboratory, Cincinnati, Ohio.

Sojka, R.E., R.D. Lentz, T.J. Trout, C.W. Ross, D.L. Bjorneberg, and J.K. Aase. 1998a. Polyacrylamide effects on infiltration in irrigated agriculture. Journal of Soil and Water Conservation 53(4):325-331.

Sojka, R.E., R.D. Lentz, and D.T. Westermann. 1998b. Water and erosion management with multiple applications of polyacrylamide in furrow irrigation. Soil Science Society of America Journal 62:1672-1680.

Sojka, R.E. and J.A. Entry. 2000. Influence of polyacrylamide application to soil on movement of microorganisms in runoff water. Environmental. Pollution 108:405-412.

U.S. Environmental Protection Agency (USEPA) 1998. Office of Water, Standards and Applied Sciences Division. Environmental Impacts of Animal Feeding Operations. Preliminary Data Summary. Feedlots Point Source Category Study. USEPA/Office of Water, Washington, D.C.

Walker, S.E., S. Mostaghimi, T.A. Dillaha, and F. F. Woests, 1990. Modeling animal waste management practices: Impacts on bacteria levels in runoff from agricultural land. Transactions American Society of Agricultural Engineers 33:807-817.

West, A.W., D.J. Ross, and J.C. Cowling. 1986. Changes in microbial C, N, P, and ATP contents, numbers and respiration on storage of soil. Soil Biology and Biochemistry 18:141-148.

Young, R.A., T. Hundtrods, and W. Anderson. 1980. Effectiveness of vegetated buffer strips in controlling pollution from feedlot runoff. Journal of Environmental Quality 9: 483-487.