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Field Application of Processed Manure upon Water Quality and Crop Productivity

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Abstract: The purpose of this study was to conduct an applied field study investigating the feasibility of utilizing processed liquid swine manure in crop production. Four treatments were evaluated; unprocessed liquid swine manure, processed liquid effluent, inorganic nitrogen fertilizer and zero-rate control. For shallow subsurface water (as measured by lysimeters), the inorganic nitrogen fertilizer treatment had the greatest levels of nitrate-N. However, there were no significant differences for any measured chemical parameter for groundwater (as measured by sampling wells) among the four treatments. In general, the zero-rate control treatment was the lowest yielding treatment for corn (*Zea mays* L.), in contrast to the equivalent response of the other treatments. Nutrient accumulation was similar for the four treatments, with the exception of greater plant manganese content of the inorganic nitrogen fertilizer treatment. For soybean (*Glycine max* L.), all four treatments responded in a similar fashion. After 5 years of annual treatment application, the processed liquid effluent and unprocessed manure treatments were similar for most soil parameters. In addition, soil and plant tissue samples were evaluated for pathogenic organisms (total coliform and *Escherichia coli*) and non-detectable levels were found for all treatments. The results of this study indicate the processed liquid swine effluent produced in this study, inorganic nitrogen fertilizer and unprocessed manure had similar effects on crop characteristics and subsurface water quality.

Key words: Bacteria, groundwater, grain yield, soil quality

INTRODUCTION

The number of large-scale Concentrated Animal Feeding Operations (CAFOs) has grown rapidly in the last decade, raising a number of concerns about their effects on the environment, specifically air and water quality. In addition to their potential deleterious effects on the environment, CAFOs also produce large amounts of animal manure that may be applied to agricultural soils to improve soil quality. Manure has long been known to be more beneficial to the soil than synthetic fertilizers (Little, 1987; Cheeke, 1993), although both are potential sources of contaminants to shallow groundwater.

Solid-liquid separation has been generally used in the last few years as a physical treatment process for animal wastes, mainly for the improvement of manure handling properties by taking solids and fiber out of the slurry (Westerman and Bicudo, 2000). The main advantages related to mechanical separation of liquid swine manure include reduction of nutrient content, reduction of solid content and improvement in homogeneity in the liquid phase (MAFF, 1991; Burton and Turner, 2003). Chemical precipitation of animal and other wastes involves the addition of chemical flocculants to alter the physical state of dissolved and suspended solids and to facilitate their removal by sedimentation (Zhang and Westerman, 1997). In general, chemical treatment can remove up to 90% of the phosphorus (P) and 50% of the nitrogen (N) from liquid manure (Walker *et al*., 1999).

Potential contaminants to soil water and groundwater from manure applications include both chemicals and pathogens. Chemical contaminants identified beneath fields receiving manure applications include P, nitrate (NO_3-N), chloride (Cl^-), sodium (Na), potassium (K) and various heavy metals (Del Castilho *et al*., 1993; Chang and Entz, 1996; Eghball *et al*., 1996; Rasmussen, 1996; Nuñez-Delgado *et al*., 1997; Saviozzi *et al*., 1997; Periago *et al*., 2000; Novak *et al*., 2000; Karr *et al*., 2001; Pote *et al*., 2001). Rasmussen (1996) found significantly higher NO_3-N concentrations in groundwater down-gradient of fields receiving manure versus inorganic fertilizer. An important variable is irrigation or heavy rains,

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which can greatly increase leaching of N (Chang and Entz, 1996). Parameters that have been suggested as good environmental tracers of swine-manure contamination include Biological Oxygen Demand (BOD) (Quast *et al*., 1997), boron (B) (Komor, 1997) and N isotopes (Karr *et al*., 2001).

The potential transfer of pathogenic organisms like bacteria from manure through soil to groundwater, vegetative growth and/or seed production is not well understood. Pathogenic bacteria contained in manure applied to soils may migrate through the soils. The presence of manure and soluble N may increase leaching of pathogens (Gagliardi and Karns, 2000); the contamination of groundwater by livestock wastewater can increase the bacterial diversity in the groundwater (Cho and Kim, 2000). Opperman *et al*. (1989) found that the number of viable bacteria in soils amended with cattle slurry increased 10 to 100 times and coliform concentrations were elevated compared to untreated soil, although coliform concentrations dropped to below detection about 3 months after treatment.

This project was designed to evaluate the use of unprocessed manure and the liquid phase of separated swine slurry (processed effluent) as soil amendments and evaluate their effects on crop productivity and subsurface water quality. For the evaluation of the processed manure separation process, refer to Walker and Kelley (2003, 2005). In this study, the results of subsurface water quality, microorganism contamination and the subsequent effects of treatment application on crop and soil productivity will be presented.

MATERIALS AND METHODS

Field site: The field site was a 24.7 ha agricultural field located at the Illinois State University Farm in Normal, IL USA. This site had previously been in alfalfa (*Medicago sativa* L.) for 4 years without manure or fertilizer application. The soil and groundwater quality were monitored for approximately 3 years over five growing seasons (1998 to 2002). During years 1, 3 and 4, corn (*Zea mays* L.) was grown; soybean (*Glycine max* L.) was grown during years 2 and 5. The field site had uniform soil (Catlin silt loam; fine-silty, mixed, superactive, mesic Oxyaquic Argiudoll; United States Department of Agriculture), with 2 to 3% slope, good drainage, soil pH of 6.5, organic matter content of 4% and good fertility. Catlin soils are on relatively undissected till plains of Wisconsin an Age with 100 to 150 cm of loess or other silty material in the underlying loamy calcareous till (United States Department of Agriculture).

Each field plot consisted of twelve 76 cm crop rows by 410 m in length. A 3 m grass buffer strip separated each plot. Two replicates were placed adjacent to each other and separated from the other two replicates by 75 m grass buffer. The plots were laid out so that their long axis was roughly parallel to the groundwater flow direction (Fig. 1). However, just north of the experimental site was an area that had been treated annually with unprocessed manure for at least 37 years prior to this study. Groundwater flow and quality data collected during the study indicated that groundwater at the zero-rate control treatment was impacted by this area; water quality data from the zero-rate control treatment are thus not considered in this study.

Five shallow monitoring wells and four soil-water samplers (suction cup lysimeters) were installed at the site (Fig. 1). Two of the wells were installed hydraulically up-gradient of the treatments to the east (U-1 and U-2), in order to obtain background water-chemistry data. The other wells were installed just hydraulically down-gradient of the inorganic N fertilizer (F-1), processed effluent (E-1), and unprocessed manure (M-1) treatments. Wells were installed using a hollow-stem auger, drilled to a depth of 6.1 m, with the bottom 1.5 m screened and intersected the top portion of the saturated zone in the till. The holes were backfilled with sand to a depth of approximately 1 m above the top of the well screen and with bentonite chips to within approximately 1 m of the land surface. The remainder of the hole was filled with drill cuttings. Lysimeters were installed using a hand auger and the suction cups were set into a slurry made from native soil.

One of the lysimeters was installed in an up-gradient location (US-1) and one on each treatment (FS-2, ES-2, and MS-2). The lysimeters on the treatment plots were installed to a depth of 1.2 m and US-1 was installed to a depth of 1.5 m.

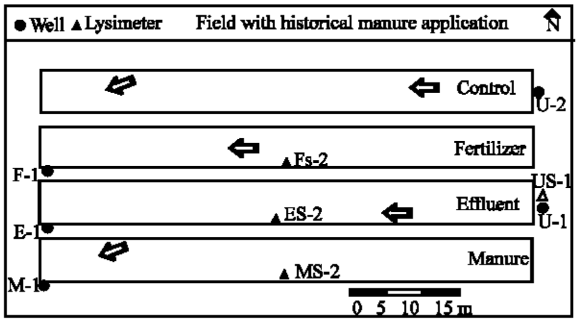

Fig. 1: Layout of experimental site at Illinois State University Farm, Normal, IL USA. First letter of well and lysimeter labels indicate treatment type. U: Up-gradient; M: Unprocessed manure; E: Processed liquid effluent; F: Inorganic N fertilizer. Large arrows indicate direction of groundwater flow

Treatments: Four treatments were evaluated: (1) unprocessed liquid swine slurry, i.e., raw manure, (2) processed effluent from separated swine slurry, i.e., processed effluent, (3) inorganic N fertilizer and (4) zero-rate control. The unprocessed manure, processed liquid effluent and inorganic N fertilizer were targeted to supply 200 kg N ha^{-1} to the crop. The zero-rate control provided background information during the study. Treatment applications occurred a few days before crop planting in the late spring (during the second half of May), except for the inorganic N fertilizer treatment, which was side dressed utilizing 28% Urea Ammonium Nitrate (UAN) at the third leaf crop stage.

During the first three growing seasons (years 1, 2 and 3), co-mingled gestation-finishing anaerobic swine slurry was pumped out of a 2.4 m deep pit across a static gravity screen-roll press combination separator with 1.59 mm diameter holes (Model 100, Key Dollar Cab Inc., Milton-Freewater, OR USA). The processed effluent was stored in a 1.8 m deep pit in which 21.97 mm^3 of air was continuously circulated. Following 90 day of aeration and 48 h prior to application, the blowers were shut off and the effluent was allowed to settle. During years 4 and 5 the swine slurry was treated with 0.075% (equivalent to 2.85 L of polymer per 3,800 L of swine slurry) polyacylamide cationic polymer (Cytec Superfloc C-1507®, Cytec Industries Inc., Kalamazoo, MI USA) and passed over a continuous gravity belt thickener (Model GSC-1®, Series III; Komline-Sanderson, Peapack, NJ USA).

Unprocessed manure and processed liquid effluent were pumped by vacuum into a PTO powered pull-type slurry tank and broadcast on appropriate plots. Each surface application was incorporated into the soil 0.8 to 1.6 cm deep by disking immediately following application.

Sampling: Samples of the unprocessed manure and processed effluent that were applied to the fields were collected prior to application each year. Samples for percent N were not filtered. Samples for percent P and total element analysis were passed through medium filter paper, retaining particles greater than 11 μm. In year 1 and 2, unprocessed manure and processed effluent samples were diluted 100 fold and filtered through a 0.45 μm high capacity filter to analyze for dissolved constituents.

Wells and lysimeters were sampled for water-quality analysis approximately quarterly for 3 years, beginning in June of year 1 and ending in May of year 2. During the last 2 years of the study, the summer sampling occurred following the first significant rain subsequent to soil amendment application. An additional sampling of several of the wells and lysimeters was done in June of the year subsequent to the last year of the study. Standard sampling procedures were used. Wells were purged and allowed to recover. Field parameters such as temperature, pH, oxidation-reduction potential, specific conductance and Dissolved Oxygen (DO) were measured in the field using a Hydrolab® minisonde, either directly in the well or in a flow-through cell. Once the field parameters had stabilized, water samples were collected and preserved as appropriate. To prevent cross-contamination between wells, sample tubing was dedicated to each well.

The lysimeters were evacuated 24 to 48 h prior to sampling under a vacuum of 4.22 kg cm^{-1}. Because the water was sitting in the lysimeters for more than a day prior to sampling, the only field parameter measured in soil-water samples was pH.

Unprocessed liquid swine manure, processed liquid swine effluent, soil and groundwater samples were collected aseptically for bacterial analysis using disinfected collection apparatuses and transferred to sterile plastic or glass containers for transport and storage. Samples were held on ice in coolers or refrigerated until bacterial analysis were completed within 72 h of collection. Liquid-swine-manure samples were collected prior to application each year. Soil samples were collected in May of year 1 prior to application of soil amendments, December of year 1, May of year 2 and October of year 4. Samples were collected from each treatment plot. All of the wells were sampled on two occasions, in July of year 1 and May of year 4. Grain samples (corn and soybean) were collected at harvest maturity using aseptic technique held in whirl-pac bags and analyzed for microorganism concentration within 24 h.

Initial soil parameters were measured prior to treatment application and yearly to determine the influence of annual treatment application on soil elements (P, K, Ca, Mg, S, Zn Mn and B), organic matter, pH and Cation Exchange Capacity (CEC). For corn, four plants were hand-harvested from each plot at physiological maturity (R6 corn growth stage), separated into grain and stover (leaves, stalk and husks), weighed and dried. A dried subsample was sieved through a 20 mesh screen and analyzed for nutrient concentration and content. Corn yield at crop maturity was also measured for the center four rows with a small plot combine. For soybean, seed yield at harvest was determined by harvesting the center six rows of each plot with a small plot combine.

Analytical methods: Unprocessed manure and processed effluent samples were analyzed for percent N as determined by the total N micro-Kjeldahl method and P concentration (Walker and Kelley, 2005). Total element concentrations were determined for Ca, Al, Cu, Fe, Mg, Zn, Co, Cr, Mn, Ni, K and Na using atomic absorption spectrophotometry. Groundwater, soil-water and filtered unprocessed manure and processed effluent samples were analyzed for a complete set of dissolved inorganic constituents, including anions, metals, alkalinity, ammonium-nitrogen (NH_4-N), Dissolved Organic Carbon (DOC) and 5 day BOD. Metals were determined by inductively-coupled plasma atomic emission spectrometry, anions were determined by ion chromatography and alkalinity (as $CaCO_3$) was determined by potentiometric titration. Bicarbonate (HCO_3^-) was calculated from alkalinity. Ammonium-N was determined by semi-automated colorimetry. DOC was determined by persulfate/ultraviolet oxidation and infrared detection.

Standard methods were used for microbiological analyses (Standard Methods, 2000). For liquid samples (unprocessed manure, processed effluent and groundwater), appropriate volumes (0.1 to 100 mL) were diluted and/or filtered. Bacteria on solid samples were resuspended in fluid following modifications reported by Kelley *et al.* (1994, 1995). Ten grams of solid samples (waste or soil) were transferred to sterile eight-ounce Ball® canning jars (Alltrista Corp., Muncie, IN USA). Twenty to 30 mL of sterile 1.0% buffered-peptone-water was added and jars were capped with sterile blender blade assembly caps. This mixture was blended for 30 sec at approximately 15,000 rpm to suspend bacteria in solution. The buffered-peptone-water solution acted both as a surfactant to remove bacteria from particle surfaces and to provide a nutritive medium prior to transfer to culture media. The sediment was allowed to settle for approximately 5 min.

Full-strength aliquots and/or appropriate dilutions of replicates of each sample analyzed were plated in duplicate. A membrane filtration technique was used for isolation and enumeration of total coliform and *Escherichia coli* (Standard Methods, 2000). Appropriate aliquots were transferred to the surface of sterile 0.45 μm pore size, 47 mm diameter sterile polycarbonate gridded filters (Micron Separations Inc., Westborough, MA USA) in a Nalgene® filtration apparatus (Nalgene Co., Rochester, NY USA). Fluid samples were drawn through the filter by partial vacuum using a vacuum pump, the funnel rinsed with sterile 0.1% peptone-water to remove bacteria adhering to the funnel and filters transferred aseptically to the surface of appropriate sterile agar culture media (Difco Laboratories, Detroit, MI USA) in 50 mm Petri dishes. Culture media used for isolation and enumeration of fecal coliform and enterococci were M-FC and ME, respectively (Standard Methods, 2000). Culture media used for isolation and enumeration of total coliform and *E. coli* was mTMM. This mTMM media was a MUG-(4-methylumbelliferyl-D-glucaronide) based media with added tergitol and monensin for improved recovery of total coliform and enumeration of *E. coli* through conversion of MUG to a long-wave UV fluorescent metabolite (4-methylumbelliferone) so that *E. coli* colonies could be concurrently identified and enumerated (Freier and Hartman, 1987). Petri dishes were inverted and transferred to incubators at 35°C for 18 to 24 h prior to enumeration of bacterial colonies (Standard Methods, 2000). Bacterial concentrations were reported as colony-forming-units (cfu) per 100 mL for groundwater and liquid samples and on a cfu per gram dry weight basis for solid samples.

Statistical analysis: Chemical data were analyzed using multiple comparison tests, including one way ANOVA with Tukey test and Kruskal-Wallis one way ANOVA on ranks with Dunn's method. Data were grouped several ways, including by treatment, by well or lysimeter and by season. Bacterial data for the unprocessed manure, processed liquid effluent and inorganic fertilizer N were subjected to paired t-test analysis to compare component and processed effluent bacterial concentrations. Significance was determined at a probability $p<0.01$ level.

For the soil data, a Randomized Complete Block (RCB) ANOVA with four replicates was conducted at the end of the study to ascertain long-term changes in the soil (utilizing the data from the last soil sampling only). For the plant data, a combined year RCB ANOVA with four replicates within a year was conducted within each crop (corn and soybean), with treatments considered as fixed and years considered as random. Treatment means were compared by calculating Fisher's protected Least Significant Difference (FLSD) at $p = 0.05$ level.

RESULTS AND DISCUSSION

Manure and effluent composition: The chemical composition of the unprocessed swine manure and processed liquid effluent are reported in Table 1; there was considerable variability over the years of the study. Both the unprocessed manure and processed effluent had elevated levels of many constituents in one or more years, especially NH_4-N, HCO_3^-, phosphate (PO_4^{-3}), B, Cl^-, K, Na, DOC, BOD and several metals (Al, Cr, Cu, Fe and Zn). The processed effluent clearly had more desirable quality than the unprocessed manure with lower ($p<0.05$) levels of N, P and most metals. However, for Cr, the separation process appeared to increase its concentration.

Some of the constituents elevated in the unprocessed manure and processed effluent would not be expected to reach the groundwater in significant concentrations. The metals and phosphate are relatively immobile in most soils, although metals complexed with organic matter could be mobile (McBride *et al*., 1997). Ammonium would be expected to be adsorbed, taken up by crops, or nitrified. A substantial fraction of the cations K and Na probably would adsorb or exchange with other cations in the soil and clays and thus their transport would be retarded. The anion Cl^-, however, would be expected to migrate conservatively. Nitrate, also, can behave conservatively in some environments, although it may be influenced by various biochemical processes, including plant uptake and denitrification. Boron in the environment is usually present as the neutral ion $B(OH)_3$; it would not be expected to be extensively adsorbed in the subsurface, but it is essential to plant growth and may be taken up by crops .

Bacterial concentrations recovered from unprocessed manure samples were also high (Table 1). The separation and processing (subsequent aeration) of the swine manure decreased bacterial concentrations and in some years significantly for some potential harmful microorganisms (Table 1). Treating manure can destroy pathogens such as *E. coli*, but elevated temperatures are usually needed (Lung *et al*., 2001).

Shallow water quality: Median, maximum and minimum concentrations for major ions and other constituents of interest for the lysimeters are reported in Table 2. The lysimeter beneath the inorganic N fertilizer treatment (FS-2) had significantly greater concentrations of NO_3-N than the other treatments and US-1. There were no significant differences among the lysimeters for NH_4-N,B, or any other parameters, including all the metals. The median concentrations for most metals were near or below their detection limits. There were also no significant seasonal differences among the lysimeters for any parameter.

Elevated Cl^- concentrations were not observed in the lysimeters beneath the unprocessed manure and processed effluent treatments. Nitrate-N concentrations began to increase in FS-2 about 2 years after the experiment started, from between 7 and 14 mg L^{-1} to greater than 25 mg L^{-1}. This suggests leaching of the inorganic N fertilizer but also a time lag, perhaps due to a N deficit in the soil at the start of the experiment. Although there was temporal variability in the NO_3-N concentrations in some of the lysimeters, seasonal differences were not statistically significant in any of them. The lysimeters sampling the unprocessed manure and processed effluent treatments had NO_3-N concentrations that varied from below detection to almost 20 mg L^{-1} with no obvious temporal trends, with concentrations slightly greater in the processed effluent lysimeters. This suggests some leaching of N from these treatments, although concentrations were much less than for FS-2 and were not significantly different from US-1.

Groundwater quality: Median, maximum and minimum concentrations for major ions and other constituents of interest for the wells are reported in Table 3. There were no significant differences for any chemical parameter among the wells on the treatment plots (M-1, E-1, F-1). With the exception of Cl^-, elevated levels of the constituents contained in the unprocessed manure and processed effluent (e.g., N species, HCO_3^-, PO_4^{-3}, B, K, Na, DOC, BOD, Al, Zn) were not observed in water beneath the unprocessed manure or processed effluent plots.

Chloride concentrations were significantly greater in M-1 and E-1 (medians of 26 and 32 mg^{-1}, respectively) than in F-1, U-1 and U-2 (medians <13 mg^{-1}), possible evidence of the unprocessed manure and processed effluent being leached to the groundwater. However, as noted above, elevated Cl^- concentrations were not observed in the lysimeters on these plots. An important limitation of lysimeters is that they tend to collect relatively immobile water (e.g., water in micropores and thin films around soil aggregates), especially when soils are dry (Landon *et al*., 1999). This immobile water may have a substantially different solute composition than more mobile water (Jardine *et al*., 1990; Brandi-Dohrn *et al*., 1996). Chloride leaching from manure has been observed to migrate conservatively in soils (Nuñez-Delgado *et al*., 1997) and solutes can migrate rapidly if heavy rainfall occurs soon after application of fertilizers (Flury, 1996); thus chloride pulses may not have been detected by the lysimeters.

The lysimeters typically had significantly greater ($p<0.01$) concentrations of NO_3-N than the wells. Nitrate-N concentrations were generally low in M-1, E-1 and F-1, almost always less than 2 mg L^{-1}, while concentrations in the lysimeter on the inorganic N fertilizer treatment (FS-2) sometimes exceeded 50 mg L^{-1}. Thus there was a loss of NO_3-N during transport from the deep unsaturated zone to the shallow groundwater. This may be a result of denitrification in the saturated zone. The groundwater level seems to be an important variable influencing NO_3-N concentrations in the shallow groundwater, with the highest concentrations being measured when the water table was high (Fig. 2). However, none of the wells

Table 1: Chemical composition of unprocessed manure and processed liquid effluent for selected parameters at Normal, IL USA

	Year 1		Year 2		Year 3		Year 4	
Item	Manure	Effluent	Manure	Effluent	Manure	Effluent	Manure	Effluent
Total N (%)	0.64	0.45	0.67	0.45	0.46	0.22	0.79	0.74
P (%)	0.13	0.04	0.90	0.01	0.12	0.03	0.19	0.04
pH	7.2	7.0						
NH_4-N, d^{ac}	2,280	2,560	1,690	413				
NO_3-N, d^{ac}	23	31	23.2	9.5				
PO_4-P, d^{ac}	264	489	217	<20				
Al, t^{ab}	50	60	1,460	<0.045	43	<0.045	17	<0.045
B, d^{a}	16	15	9	6				
Ca, t^{ab}	440	1,050	2,350	360	427	957	117	151
Co, t^{ab}	60	<0.009	140	30	5	<0.009	5	<0.009
Cr, t^{ab}	380	270	<0.003	190	56	631	5	412
Cu, t^{ab}	410	50	670	10	2	6	2	<0.002
Fe, t^{ab}	890	490	1,030	100	150	137	40	35
K, t^{ab}	1,298	1,062	635	770	1,595	2,632	2,567	1,534
Mg, t^{ab}	1,430	1,380	930	160	297	1,211	106	439
Mn, t^{ab}	50	60	50	<0.002	21	73	4	4
Na, t^{ab}	1,060	339	480	235	587	575	680	492
Ni, t^{ab}	<0.006	<0.006	470	<0.006	46	1	5	9
Si, d^{a}	23.7	24.3	14.3	<5				
Zn, t^{ab}	200	220	70	20	103	1,000	23	23
TDS^{a}	12,700	11,600	6,650	2,550				
Alkalinity^{a}	8,000	9,200	7,508	3,090				
HCO_3^-, d^{ac}	8,880	9,670	8,420	3,770				
Cl^-, d^{ac}	1,660	1,590	709	327				
SO_4^{2-}, d^{ac}	<50	224	217	232				
F^-, d^{ac}	52.2	48.8	<2	<2				
DOC^{a}	>1,000	>1,000						
BOD^{a}	31,400	19,600	9,510	<100				
Total coliform^{d}	1.25e^{+6}	1.10e^{+2f}	6.85e^{+6}	4.00e^{+5f}	2.03e^{+3}	1.85e^{+2}	1.01e^{+3}	2.85e^{+2}
Fecal coliform^{d}	4.60e^{+6}	3.60e^{+3f}	5.00e^{+5}	3.25e^{+4}				
E. coli^{d}	1.43e^{+7}	1.21e^{+3f}	9.50e^{+5}	5.85e^{+4}	BDL^{e}	BDL	BDL	BDL
Staphylococci^{d}	1.50e^{+8}	1.51e^{+7}						
Heterotrophs^{d}	5.29e^{+9}	3.68e^{+3f}						

[a]Units reported as mg L^{-1}; [b]t: Total elemental concentration; [c]d: Dissolved concentration; [d]Bacterial concentrations reported as cfu per 100 mL; [e]BDL: Below detection limit of 1.00e^{+1}; [f] Averages within species and year significantly differed by $p<0.05$

Table 2: Median (Med.), maximum (Max.) and minimum (Min.) concentrations of chemical constituents for shallow water (lysimeter) sampling at Normal, IL USA

		Concentration (mg L^{-1})									
Item	Statistic	Ca	Mg	Na	Cl^-	SO_4^{2-}	HCO_3^-	NO_3-N	NH_4-N	B	Mn
Manure	Med	88	36.6	7.0	24.5	52	315	2.50	0.04	<0.014	0.006
	Max	104	40.0	11.1	35.1	107	506	8.60	0.25	0.106	1.460
	Min	61	27.0	5.0	10.4	32	255	<0.11	<0.07	<0.014	<0.002
Effluent	Med	86	37.0	7.1	27.9	48	339	5.50	0.06	<0.014	<0.002
	Max	104	46.1	9.2	62.0	73	371	19.20	0.18	0.141	1.380
	Min	70	29.0	4.7	3.5	36	226	0.30	<0.07	<0.014	<0.002
Fertilizer	Med	104	46.7	7.5	46.1	59	292	14.20	<0.07	<0.014	<0.002
	Max	127	53.9	15.7	87.3	84	389	56.40	0.25	0.124	0.025
	Min	77	31.8	5.4	6.6	28	236	10.40	<0.07	<0.014	<0.002
US-1	Med	113	49.4	18.6	28.1	127	367	1.40	<0.07	<0.014	<0.002
	Max	122	50.5	46.0	37.5	242	492	10.20	0.12	0.158	0.015
	Min	101	38.9	5.3	25.1	68	332	<0.11	<0.07	<0.014	<0.002

US: Up-gradient of experimental treatments

appeared to have correlations between groundwater level and Cl^- concentrations. The high water table occurs when there is abundant precipitation and recharge, when leaching potential would be greatest. Nitrate recharged to the groundwater can then undergo denitrification. Chloride, which is not reactive, does not show this relationship.

Bacterial contamination: The levels of total coliform, *E. coli* and heterotrophs are reported in Table 4. Coliform numbers decreased with time in soil (Opperman *et al*., 1989). Total coliform and *E. coli* were detected in all wells at both sampling events (Table 5). Highest concentrations of total coliform were found in C-1 and E-1 at both sample dates and U-3 and U-4 at one sample date. M-1 had very

Table 3: Median (Med.), maximum (Max.) and minimum (Min.) concentrations of chemical constituents for groundwater (well) sampling at Normal, IL USA

		Concentration (mg L^{-1})									
Item	Statistic	Ca	Mg	Na	Cl^-	SO_4^{2-}	HCO_3^-	NO_3-N	NH_4-N	B	Mn
Manure	Med	99	43.5	20.5	26.2	88	423	1.50	0.05	0.063	0.130
	Max	115	52.8	34.7	32.8	100	439	7.90	1.91	0.257	0.720
	Min	83	34.3	11.0	21.2	69	355	0.10	<0.016	<0.014	0.054
Effluent	Med	112	48.3	7.6	32.0	107	414	0.80	0.03	0.033	0.184
	Max	121	55.6	25.7	38.2	138	444	3.20	0.17	0.149	0.593
	Min	64	22.9	6.9	23.2	62	242	0.10	<0.016	<0.014	0.091
Fertilizer	Med	94	49.3	14.9	11.1	103	428	0.20	0.13	0.087	0.249
	Max	106	54.1	18.4	39.8	151	485	0.90	0.35	0.190	0.447
	Min	89	47.0	14.0	8.3	77	399	<0.11	0.02	<0.014	0.137
U-1, U-2	Med	150	82.7	27.8	9.9	272	604	0.10	0.11	0.177	0.286
	Max	185	99.2	58.3	15.2	389	684	8.30	0.38	0.336	1.560
	Min	93	35.2	18.7	3.4	152	277	<0.11	0.02	<0.014	0.069

U: Up-gradient of experimental treatments

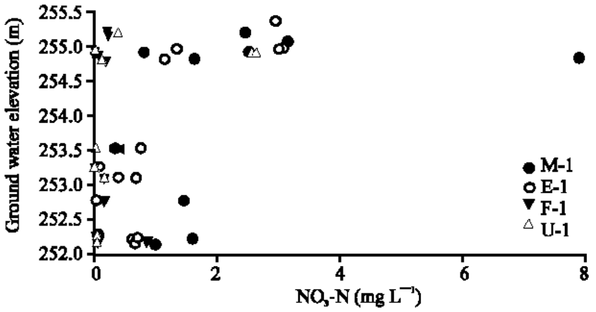

Fig. 2: Nitrate-N concentrations for wells as a function of groundwater elevations at Normal, IL USA. Elevation is reported in m above mean sea level (U: Up-gradient; M: Unprocessed manure; E: Processed liquid effluent; F: Inorganic N fertilizer)

low concentrations. Entry and Farmer (2001) found total coliform concentrations in groundwater generally less than 1000 cfu per 100 mL and fecal coliform was usually not detected. It appears that pathogens in the unprocessed manure and processed effluent, including the manure historically applied to the field to the north, do not thrive in the groundwater environment. In a similar study, Randall *et al.* (2000) detected fecal indicators in all samples but *E. coli* in less than 20% of samples in tile drainage water in a field treated with manure. Other researchers have also observed significant die-off of pathogens in the soil and groundwater environments (Reddy *et al.*, 1981; Stoddard *et al.*, 1998).

None of the bacterial pathogens selected for analysis were detected in either corn or soybean seed grown on any of the treatments (data not shown), similar to earlier study of Kelley *et al.* (1999). These data suggest that indicator pathogens (total coliform and *E. coli*) detected in unprocessed manure that is land-applied is not transferred to seed. Therefore, concern regarding pathogen transfer to feed grains may be negligible for land-applied manure or effluent-processed liquid swine manure.

Soil and crop productivity: After 5 years of annual treatment application, the unprocessed manure and processed liquid swine effluent acted in an analogous manner, approximately doubling the soil P and K levels compared to the zero-rate control and inorganic N fertilizer treatments (Table 6). It was hoped that removing the solids from unprocessed manure (the processed liquid swine effluent) would reduce the buildup of soil P and K often observed with land application of unprocessed manure, but this was not the case. A complicating factor was the variable content of the processed liquid effluent for P and K content across the years of the study (Table 1). These results are similar to the findings of Smiciklas *et al.* (2008) for the unprocessed manure and compost application to row-crop fields. For the other measured soil nutrients, no significant increase was observed over the 5 year period (Table 6). Thus, unprocessed manure and processed liquid effluent acted in a similar fashion for soil nutrient composition during the time frame of the study.

For corn, grain yield of plants supplied with unprocessed manure, processed liquid effluent, or inorganic N fertilizer were similar (Table 7). The lowest yielding treatment was the zero-rate control (Table 7). This observation was expected, since the corn plants must rely on soil N and cannot obtain N from the atmosphere like soybean. Corn plants grown in the zero-rate control also tended to be the lowest dry weight with the fewest number of kernels per ear (Table 7), similar to study of Jokela and Randall (1989). Thus, grain yield and productivity was not influenced by the type of N supplied in this study, keeping in mind that all three treatments were designed to supply the same amount of soil N (200 kg N ha^{-1}). In terms of plant nutrient content, the four treatments acted in an identical fashion, with the exception of plant Mn (Table 8). The inorganic N fertilizer treatment contained the greatest levels of plant Mn. Sarhadi-Sardoui *et al.* (2003) also found that plant Mn response to manure treatments on a sandy soil was

Table 4: Concentrations of bacteria in soil samples for at Normal, IL USA

		Concentration (cfu g^{-1})		
Year	Treatment	Total coliform	*E. coli*[a]	Heterotrophs
0[b]	Fertilizer	$3.22e^{+2}\pm2.20e^{+1}$	BDL	$1.29e^{+7}\pm2.17e^{+5}$
	Manure	$2.85e^{+2}\pm3.67e^{+1}$	BDL	$1.18e^{+7}\pm6.18e^{+4}$
	Effluent	$6.09e^{+2}\pm4.67e^{+1}$	BDL	$5.42e^{+7}\pm2.21e^{+5}$
1	Fertilizer	$3.72e^{+5}\pm5.38e^{+4}$	$1.93e^{+5}\pm4.80e^{+4}$	$3.57e^{+10}\pm6.85e^{+9}$
	Manure	$3.26e^{+5}\pm6.23e^{+4}$	$4.40e^{+5}\pm2.30e^{+4}$	$4.83e^{+10}\pm5.40e^{+8}$
	Effluent	$1.62e^{+6}\pm2.30e^{+6}$	$5.80e^{+6}\pm5.55e^{+6}$	$3.74e^{+10}\pm4.40e^{+9}$
2	Fertilizer	$4.01e^{+5}\pm2.63e^{+4}$	$4.85e^{+4}\pm5.13e^{+4}$	$6.42e^{+5}\pm4.80e^{+4}$
	Manure	$1.29e^{+4}\pm5.48e^{+4}$	$1.32e^{+5}\pm1.75e^{+4}$	$6.42e^{+5}\pm4.80e^{+4}$
	Effluent	$6.42e^{+5}\pm4.80e^{+4}$	$8.73e^{+4}\pm8.75e^{+6}$	$6.42e^{+5}\pm4.80e^{+4}$
3	Fertilizer	$1.78e^{+2}\pm4.45e^{+1}$	BDL	$1.30e^{+7}\pm1.44e^{+5}$
	Manure	$1.80e^{+2}\pm6.50e^{+1}$	BDL	$1.24e^{+7}\pm2.67e^{+5}$
	Effluent	$8.40e^{+1}\pm2.80e^{+1}$	BDL	$1.45e^{+7}\pm3.43e^{+5}$
4	Fertilizer	$3.70e^{+2}\pm2.24e^{+1}$	BDL	
	Manure	$4.11e^{+2}\pm3.57e^{+1}$	BDL	
	Effluent	$6.05e^{+2}\pm2.75e^{+1}$	BDL	

Values reported are the Mean±SD; [a]Minimum detection limit: 20 cfu g^{-1} dry weight; BDL: Below detection limit of $1.00e^{+1}$ [b]; Samples collected during early spring preceding year one of the study

Table 5: Concentrations of total coliform and *E. coli* in groundwater samples at Normal, IL USA

	Total coliform[a] (cfu/100 mL)		*E. coli*[a]	
Well	Year 2	Year 4	Year 2	Year 4
U-1	2,300±1,200	2,300±2500	200±100	150±50
U-2	2,900±400	5,200±1,100	200±100	500±100
M-1	1,700±300	250±50	300±100	40±10
E-1	22,500±3,500	49,000±3,000	1,500±500	3,000±150
F-1	4,100±200	2,000±1,000	2,200±500	1,800±250

Values reported are the Mean±SD; [a]Values less than 1,000 cfu/100 mL are estimated. U: Up-gradient; M: Unprocessed manure; E: Processed liquid effluent; F: Inorganic N fertilizer

Table 6: Measurements of soil element composition after five years of aunual treatment application at Normal, IL USA

	P	K	Ca	Mg	S	Zn	Mn	B
Treatment	(kg ha^{-1})				(mg kg^{-1})			
Control	86	259	7,378	903	1.6	1.9	20.1	0.45
Effluent	156	416	7,187	861	1.7	2.6	22.4	0.52
Manure	147	374	7,022	846	1.7	3.1	20.1	0.48
Fertilizer	64	256	6,847	857	1.6	1.6	19.7	0.43
LSD (0.05)	42	47	ns[a]	ns	ns	0.5	ns	ns

ns[a]: Not significant at 5% probability level

Table 7: Measurements of corn plant productivity at Normal, IL USA

Treatment	Grain yield (Mg ha^{-1})	Dry plant weight (g)	Grain test weight (kg hL^{-1})	Kernel number (per ear)	Kernel weight (mg kernel^{-1})	Harvest index (%)
Control	10.2	268	70.7	402	327	46.2
Effluent	11.5	290	70.9	447	329	48.8
Manure	11.4	288	70.9	438	335	48.3
Fertilizer	11.1	295	70.5	440	335	48.0
LSD(0.05)	0.7	ns[a]	ns	ns	ns	ns

ns[a]: Not significant at 5% probability level

Table 8: Measurements of corn plant nutrient composition at Normal, IL USA

	N	P	K	Ca	Mg	S	Cu	Mn	Fe	Zn
Treatment	(g plant^{-1})						(mg plant^{-1})			
Control	2.83	0.66	1.62	0.60	0.66	0.30	8.0	30.4	273	73.2
Effluent	3.06	0.70	2.18	0.61	0.63	0.31	9.3	32.5	259	80.9
Manure	3.11	0.73	2.05	0.62	0.66	0.32	8.8	32.6	257	76.8
Fertilizer	3.56	0.70	1.84	0.69	0.71	0.39	10.3	34.1	229	75.8
LSD(0.05)	ns[a]	ns	ns	ns	ns	ns	ns	2.0	ns	ns

ns[a]: Not significant at 5% probability level

not consistent during the course of the study. A possible explanation is the source of inorganic N fertilizer used in this study may have contained some Mn which accumulated in the plant but did not increase grain yield.

For the 2 years that soybean was grown in the study, seed yield was similar for the four treatments (data not shown). Since, soybean can acquire N from the atmosphere and the fertility of all plots was similar at the start of the experiment, this result was expected. Since the focus of this study was corn productivity, no soybean plant measurements besides seed yield were taken.

CONCLUSIONS

In this study, the shallow water quality was influenced by the treatment on the overlying plot; NO_3-N concentrations were significantly elevated in the soil water beneath the inorganic N fertilizer treatment and while numerically elevated beneath the processed effluent and unprocessed manure treatments. It also appears that Cl^- concentrations were elevated in groundwater beneath the processed effluent and unprocessed manure treatments. Other constituents that were elevated in the unprocessed manure and processed effluent (NH_4-N, HCO_3^-, PO_4-P, B, F^-, K, Na, Al, Cr, Cu, Fe, Zn, DOC and BOD) were not found in anomalous concentrations in the subsurface water beneath these treatments. The elevated Cl^- concentrations suggest some contamination of the groundwater by the unprocessed manure and processed effluent treatments, but other parameters that have been suggested as indicators of manure contamination, such as B, BOD and F^-, were not indicative in this study. Metals also, did not appreciably migrate through the soil and were thus not good indicators of manure contamination of groundwater at this site.

After 5 years of treatment application, the soil responded to unprocessed manure and processed liquid swine effluent in a similar fashion, with the greatest levels of soil nutrients. The inorganic N fertilizer treatment and the zero-rate control were similar for most parameters with the exception of soil N. Corn growth and productivity were similar for the unprocessed manure, processed liquid swine effluent and the inorganic N fertilizer treatments. The zero-rate control had the lowest overall productivity. For soybean, all four treatments responded in the same fashion. Thus, one can use processed liquid swine effluent in a similar fashion to unprocessed manure for crop production in fertile soils.

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