Phosphorus Reductions in Runoff and Soils from Land-Applied Dairy Effluent Using Chemical Amendments: An Observation

A.M.S. McFarland
L.M. Hauck
Tarleton State University, Texas Institute for Applied Environmental Research, Mail Stop T0410, Stephenville, TX 76401
A.P. Kruzic
The University of Texas at Arlington, Department of Civil and Environmental Engineering, Box 19308, Arlington, Texas 76019-0308

ABSTRACT

Field application of dairy effluent at nitrogen (N) agronomic rates generally leads to an over-application of phosphorus (P). A build up of soil P then occurs that can increase the soluble P in rainfall-runoff. Increases in runoff soluble P can cause surface water quality problems, because P is generally the limiting nutrient to algal growth in freshwater systems. Chemical amendments may reduce P solubility from effluent application fields by binding P into less soluble forms. This demonstration was conducted to display the impacts of two amendments, alum and gypsum, to soils and runoff using simulated rainfall conditions on a field historically used for dairy effluent application. Large decreases in soluble P in runoff and soil extractable P were seen on the alum-amended plot compared to the control. On the gypsum-amended plot, changes in soluble P concentrations in runoff were not observed, although small but notable decreases in soil P were indicated. These results indicate that alum may be a suitable chemical amendment for reducing soluble P from dairy effluent application fields. Long-term, replicated studies under natural rainfall conditions are needed to evaluate the impact of alum not only on runoff and soil P concentrations but also on forage quality and yield.

KEYWORDS: soluble reactive phosphorous, alum, gypsum, waste management, water quality

Rainfall runoff from animal waste application fields is coming under ever increasing scrutiny as a nonpoint source of pollution, especially as a source of phosphorus. Animal wastes are generally applied at a nitrogen (N) uptake rate for crops, leading to an over-application of phosphorus (P) in relation to crop uptake. For example, the N to P ratio in dairy manure is about 3:1, while most plants uptake N and P at a ratio of about 10:1 (Gilliam 1995). This over application of P has been associated with high P concentrations in rainfall runoff (e.g., Reddy et al. 1979, Sharpley et al. 1993) and linked to increasing P concentrations in receiving stream waters (McFarland and Hauck 1999). The over application of P on land does not generally have a negative impact on the growth of crops, although excessive P in the soil has been noted to decrease the ability of

---

Corresponding author A.M.S. McFarland. This study was funded by the Texas State Soil and Water Conservation Board.

some plants to uptake micronutrients, particularly iron and zinc (Provin and Pitt 1999). In contrast, excessive P in surface waters can lead to negative impacts. Most freshwater systems are P limited with respect to algal growth (Gibson 1997). As additional P is added to lakes and streams via rainfall-runoff from waste application fields, the growth of algae and other aquatic plants may increase to undesirable levels impairing the use of water as fisheries, for recreation, and by industry and municipalities. The presence of excessive algae can physically cause filtration, aesthetic, and transportation problems, and also may cause chemical problems with regard to oxygen depletion (Boyd 1990) and the release of undesirable compounds generally associated with the decomposition of dead algae (Martin and Cook 1994, Codd 1995).

While most P that moves from agricultural fields to surface waters is sediment bound (NRC 1993), the application of manure to land, particularly when applied to the same field for many years, can increase the amount of soluble P moving in rainfall-runoff (Sharpley et al. 1993). Soluble P is largely readily available to algae for growth, while only a portion of sediment-bound P is readily available for algal uptake (Sharpley and Smith 1992). In controlling the runoff of P from fields, the reduction of soluble P losses may need to be considered separately from the reduction of sediment-bound P. Many erosion control practices, such as no-till, can greatly decrease the concentration of total P in field runoff, but may do little to control runoff of soluble P (e.g., Andraski et al. 1985, Baker and Laflen 1982).

One potential practice for controlling the runoff of soluble P from manure application fields involves the use of chemical amendments. Chemical amendments, such as gypsum and alum, have been used extensively in treating P in municipal wastewaters (Yeoman et al. 1988, Tchobanoglous and Burton 1991). Only recently have efforts focused on the transfer of this technology to animal wastes. Several laboratory studies have shown the potential promise of chemical amendments in reducing soluble P associated with animal manure (Anderson et al. 1995, Jones and Brown 2000, Moore and Miller 1994, Shreve et al. 1996), but only a few studies have evaluated the impact of chemical amendments on reducing P in runoff in the field (Edwards et al. 1999, Shreve et al. 1995). The purpose of this project was to demonstrate in the field using simulated rainfall the impacts of applying alum and gypsum as chemical amendments to a field historically used for dairy effluent.

MATERIALS AND METHODS

Three 8-ft by 10-ft plots were located on a dairy waste application field in Erath county, Texas. Plots were oriented with the slope along the long axis. Plots were labeled A (alum amendment), G (gypsum amendment), and C (control). The slope was 5.4 percent for plot A, 6.4 percent for plot C, and 5.9 percent for plot G. Soil type was a Windthorst (subgroup *Udic Paleustalfs*) according to the Erath County Soil Survey (USDA-SCS 1973). The soil was classified as a sandy loam based on a soil texture analysis for a 0-6 inch sample with 60 percent sand, 30 percent silt, and 10 percent clay. The field was typically maintained in a sorghum (*Sorghum bicolor*)-wheat (*Triticum* spp.) rotation with dairy effluent historically applied using a center pivot irrigation system. Plots were installed after sorghum planting in mid-May 2001.

During the study, the dairy operator did not apply manure or effluent to the field-plot area. The dairy operator did apply nitrogen (N) fertilizer (33-0-0) in late-May at a rate of about 100 lb/ac N. No commercial N was to have been applied to the field-plot area, but a miscommunication occurred between researchers and the dairy operator

and his field personnel. The realization that commercial N had been applied to the field-plot area did not occur until after effluent was applied on the demonstration plots. This demonstration trial, thus, represents an over application of N above agronomic rates, which is not recommended. Although the focus of this demonstration is on P, the demonstration results also indicate the potential consequences of over applying N.

Effluent was applied on June 8, 2001 at the N agronomic rate assuming two cuttings of sorghum requiring 140 lb/ac N and 26 lb/ac P. Effluent application rates were calculated assuming 50 percent availability of total-N (TN) from the effluent. Forty gallons (21,200 gal/ac or 0.78 ac-inch) of effluent were applied to each plot based on results of an effluent sample collected on May 21, 2001 from the operator's secondary wastewater storage pond (1590 ppm TN and 363 ppm total P [TP]). At an application rate of 40 gallons per plot, 0.119 lb TP should have been applied via effluent to each plot. Samples taken of the effluent at the time of application (June 8) returned much lower nitrogen and phosphorus values than measured on May 21. The effluent applied measured 875 ppm TN, 86.9 ppm TP, 4.36 ppm orthophosphate-phosphorus (PO_4-P), 244 ppm ammonia-nitrogen (NH_3-N), and 4.1 ppm aluminum (Al) and had a pH of 7.9 standard units. Based on the laboratory analysis of the effluent applied, 0.028 lb TP and 0.0014 lb PO_4-P were applied to each plot. Assuming 50 percent nitrogen losses, only 0.146 lb TN were applied rather than 0.264 lb TN as calculated from the May 21 sample. The difference between the effluent sample taken on May 21 and the samples taken on June 8 indicate changes in nutrient concentrations within the secondary wastewater storage pond. No rainfall events occurred between May 21 and June 8, but the dairy operator was drawing down his primary wastewater storage pond into the secondary pond and irrigating from the secondary pond during this period. Because laboratory analyses generally take about two weeks to obtain, this indicates that dairy farmers may be in the position of applying more or less nutrients than expected if they do not frequently sample their wastewater storage ponds.

Chemical amendments of alum or gypsum were incorporated into the soil prior to effluent application. The stoichiometric equivalent of each amendment was calculated assuming all P in the May 21 effluent sample was in a soluble form available for binding with aluminum or calcium cations. The generalized reaction equations for calculating amendment dosage rates are provided below (Tchobanoglous and Burton, 1991):

$$Al_2(SO_4)_3{*}14H_2O + 2PO_4^{3-} \Leftrightarrow 2AlPO_4 + 3SO_4^{-2} + 14H_20$$

$$3HPO_4 + 5Ca^{+2} + 4OH^- \Leftrightarrow Ca_5(OH)(PO_4)_3 + 3H_2O$$

To bind all the P in the applied effluent (0.119 lb P based on the May 21 effluent sample), 1.15 lb alum were required and 1.27 lb gypsum assuming a 20.3 percent calcium equivalent in the gypsum. The stoichiometric rate was multiplied by 10 to allow for a binding reaction of amendments with P in the soil. Initial soil concentrations for extractable P averaged 417 ppm for a 0-6 inch sample using the TAMU extraction method (Hons et al. 1990). The dosage rate applied was 11.5 lb alum to plot A and 12.7 lb gypsum to plot G.

Three rainfall-simulation trials were conducted; one pretreatment and two posttreatment. The first simulation trial occurred on June 1, 2001 prior to the application of effluent or amendments. After the initial simulation trial, the surface of the plots was roughed up with a rake between the rows of sorghum to facilitate infiltration of the effluent and allow greater contact of the amendments with the soil. The second trial was conducted on June 11, three days after effluent and amendment application. The third trial was conducted on June 13. Plots were prewetted to saturation about 24 hrs prior to

each simulation trial. A rainfall simulator as described by Humphry et al. (2002) was used producing continuous flow at a rate of three inches per hour. Rainfall events were continued for 30-minutes once runoff was established. Time to runoff and volume of runoff at five-minute increments were recorded for each plot during each rainfall simulation trial as well as total volume of runoff from each plot.

Total runoff volume was collected in separate barrels for each plot. After each rainfall simulation, each barrel was thoroughly mixed and two one-liter samples were extracted. The laboratory analyses of these two samples were averaged as duplicates in the results. These samples were analyzed for PO_4-P, TP, total Kjeldahl nitrogen (TKN), nitrite-nitrogen plus nitrate-nitrogen (NO_2-N+NO_3-N), NH_3-N, total suspended solids (TSS), and Al (Table 1), except in the third simulation trial. In the third simulation trial, Al was analyzed only for plots A and C for comparison purposes. Changes in Al runoff concentration were not expected on plot G with the gypsum amendment. Measurements of pH and conductivity were made of the runoff water captured in each barrel using a multiprobe instrument. A water sample of the simulated rainfall was collected and analyzed to determine background concentrations of N and P. The rainfall simulation water was groundwater obtained from a well on the dairy where the demonstration project was conducted. Concentrations within the simulated rainwater were 0.03 ppm NH_3-N, 0.25 ppm NO_2-N+NO_3-N, 0.23 ppm TKN, 0.006 ppm PO_4-P, <0.065 ppm TP, < 4 ppm TSS, and < 1.0 ppm Al. The simulated rainwater had a pH of 7.5 and conductivity of 651 µmhos/cm.

Table 1. Analysis methods and laboratory method detection limits (MDLs) for water quality and soil constituents analyzed by TIAER's laboratory.

Constituent	Method	Source	MDL (mg/L)
----------Water Samples----------			
NH_3-N	EPA 350.1	EPA (1983)	0.015
NO_2-N+NO_3-N	EPA 353.2	EPA (1983)	0.015
TKN	EPA 351.1,2	EPA (1983)	0.12
PO_4-P	EPA 365.2	EPA (1983)	0.004
TP	EPA 365.4	EPA (1983)	0.065
TSS	EPA 160.2	EPA (1983)	4
Al	EPA 3050B, EPA 7020	EPA (1997)	1
----------Soil Samples----------			
TKN	EPA 351.2	EPA (1983)	not applicable
Water Extractable P	SSSA, p. 891	SSSA (1996)	not applicable
Total P	EPA 365.4	EPA (1983)	not applicable
Aluminum	EPA 3050B, EPA 7020	EPA (1997)	not applicable

Prior to each simulated rainfall event, soil samples were collected at depths of 0-2 inches and 0-6 inches using standard soil probes. The holes made by the probes were filled using soil from the area surrounding each plot prior to simulating rainfall. Soil samples were dried for 48 hours, roughly ground to break up large clods, and then split for separate analyses by TIAER's laboratory and by the Texas A&M Soil, Forage, and Water Testing Laboratory in College Station. All soil samples were analyzed for water extractable P (water ext-P), TP, and TKN by TIAER's laboratory (Table 1). Soil samples from all three plots from trials 1 and 2 were also analyzed for Al and from plot A for trial 3. Splits of each soil sample were sent to the Texas A&M laboratory to obtain an analysis of extractable P using the TAMU method based on Hons et al. (1990). As part of the

routine analysis at the Texas A&M laboratory, measurements of pH, NO_3-N, calcium (Ca), sulfur (S), and salinity are also presented.

RESULTS

The pretreatment results represent plot conditions prior to treatment with dairy effluent or any chemical amendments. Compared to pretreatment conditions, PO_4-P concentrations in runoff during the first posttreatment trial decreased over 90 percent with the alum amendment (Table 2). During the first posttreatment trial, an increase of 65 percent occurred on the control plot, while the gypsum amended plot indicated an increase of only 40 percent compared to pretreatment conditions. During the second posttreatment trial, runoff from the alum amended plot still showed a considerable decrease in PO_4-P concentrations compared to pretreatment levels, while the control and gypsum plots indicated PO_4-P runoff concentrations only slightly higher then pretreatment conditions.

Table 2. Runoff P and N constituent concentrations for pre- and posttreatment rainfall simulation events.

Treatment	Trial	PO_4-P (ppm)	TP (ppm)	NH_3-N (ppm)	NO_2-N +NO_3-N (ppm)	TKN (ppm)
Alum	Pre	0.66	13.3	0.33	0.65	55.1
	Post 1	0.04	12.9	1.96	0.68	45.7
	Post 2	0.07	14.3	0.40	1.88	56.5
Control	Pre	0.40	7.4	0.11	0.48	26.4
	Post 1	0.66	6.5	0.56	0.68	19.1
	Post 2	0.48	6.4	0.14	1.32	22.9
Gypsum	Pre	0.54	12.1	0.14	0.43	41.4
	Post 1	0.76	14.4	0.93	0.96	36.9
	Post 2	0.57	11.1	0.12	1.61	30.5

Posttreatment 0-2 inch soil samples also showed decreases in TAMU ext-P on the alum amended plot (Table 3). For a 0-6 inch soil sample, the alum amendment decreased soil TAMU ext-P concentrations by 11 percent compared to pretreatment levels. Notable decreases also occurred in posttreatment water ext-P concentrations for soils within the alum and gypsum amended plots compared to pretreatment conditions, particularly for the 0-2 inch soil samples. In contrast on the control plot, a slight increase in water ext-P occurred in the 0-2 inch soil layer. The alum amendment was by far the most effective in reducing water ext-P with over a 90 percent reduction in the 0-2 inch soil layer and about an 80 percent reduction in the 0-6 inch soil layer. The gypsum amendment reduced water ext-P by about 50 percent in the 0-2 inch layer and between 4 to 21 percent in the 0-6 inch layer in the two posttreatment trials.

Table 3. Soil P and N concentrations for pre- and postreatment rainfall simulation trials.

Treat-ment	Depth (in)	Trial	Water ext-P (ppm)	TAMU ext-P (ppm)	TP (ppm)	NO_3-N (ppm)	TKN (ppm)
Alum	0-2	Pre	40.5	215	372	44	1,880
		Post 1	2.9	161	464	125	1,570
		Post 2	2.2	155	460	139	1,700
Alum	0-6	Pre	42.7	209	398	62	2,030
		Post 1	10.7	187	439	106	1,650
		Post 2	7.2	185	438	109	1,550
Control	0-2	Pre	33.1	237	411	30	1,850
		Post 1	39.8	259	474	89	1,740
		Post 2	42.0	251	467	62	1,510
Control	0-6	Pre	32.5	210	422	41	1,930
		Post 1	37.8	250	445	75	1,360
		Post 2	35.2	262	395	67	1,300
Gypsum	0-2	Pre	45.2	335	523	25	1,980
		Post 1	21.4	334	529	80	1,520
		Post 2	22.4	340	539	59	1,520
Gypsum	0-6	Pre	35.8	270	431	38	1,810
		Post 1	28.2	296	563	75	1,490
		Post 2	34.5	325	518	51	1,400

In contrast to PO_4-P, TP concentrations in runoff showed relatively little difference between the three rainfall simulation trials on a given plot (Table 2). The percent change between posttreatment and pretreatment trials was less than 20 percent in all cases. Between plots notably higher TP concentrations were indicated for the alum and gypsum amended plots compared to the control plot. These higher runoff concentrations of TP from the alum and gypsum amended plots are partially associated with higher TSS concentrations measured in runoff (Tables 2 and 4), although this relationship does not appear to be linear (Figure 1). When TP concentrations in runoff were adjusted for TSS concentrations, the alum amended plot showed the lowest TP concentrations per unit of TSS in runoff, while the gypsum amended plot showed the highest TP concentrations per unit of TSS (Table 5). While differences in runoff TP concentrations between pretreatment and posttreatment trials were relatively small, a distinct change in soil TP concentrations occurred (Table 3). Soil TP concentrations increased from pretreatment to posttreatment on all three plots. As expected, the P applied with the effluent and already in the soil does not go away with treatment, but the alum amendment chemically binds much of the soluble P into a more insoluble form that is less likely to move without the movement of sediment.

Table 4. Runoff TSS, Al, conductivity, and pH values for pre- and posttreatment rainfall simulation events.

Treatment	Trial	TSS (ppm)	Al (ppm)	Conductivity (µmhos/ cm)	pH
Alum	Pre	11,200	220	672	8.0
	Post 1	12,700	266	974	7.0
	Post 2	15,200	314	1070	7.4
Control	Pre	4,090	106	662	8.1
	Post 1	3,640	100	675	8.2
	Post 2	3,520	79	677	8.4
Gypsum	Pre	5,640	117	670	8.1
	Post 1	7,340	139	1410	8.0
	Post 2	5,030	na	1320	8.1

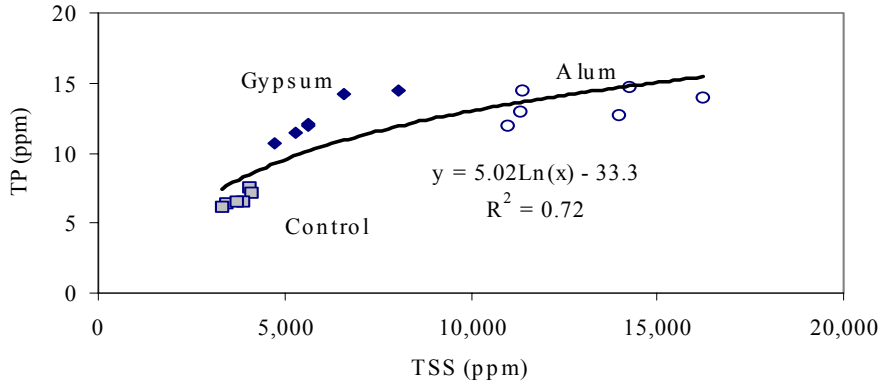

Figure 1. Relationship of TP to TSS in simulated runoff. Squares represent data from control plot, diamonds data from the gypsum-amended plot, and circles data from the alum-amended plot.

Table 5. TP, Al, and TKN as a percent of TSS in runoff.

Treatment	Trial	TP per unit TSS	Al per unit TSS	TKN per unit TSS
Alum	Pre	0.12%	1.96%	0.49%
	Post 1	0.10%	2.09%	0.36%
	Post 2	0.09%	2.06%	0.37%
Control	Pre	0.18%	2.59%	0.64%
	Post 1	0.18%	2.73%	0.52%
	Post 2	0.18%	2.25%	0.65%
Gypsum	Pre	0.21%	2.07%	0.73%
	Post 1	0.20%	1.89%	0.50%
	Post 2	0.22%	not measured	0.61%

Aluminum concentrations in runoff showed a very close linear relationship with TSS concentrations (Figure 2). An increase in Al runoff in the posttreatment trials on the alum-amended plot appeared to occur (Table 4), but when Al concentrations were adjusted for TSS, basically no change in Al concentrations was apparent between the alum or control plots (Table 5). Background soil aluminum concentrations across plots averaged 5,550±685 ppm for the 0-2 inch layer and 6,220±276 ppm for the 0-6 inch layer (Table 6). On the alum amended plot, a 25 percent increase in aluminum was indicated in the 0-2 inch layer after treatment. A similar increase was noted on the control plot. In the 0-6 inch soil layer, a slight increase in Al concentrations occurred on the alum amended plot, while decreases were noted on the control and gypsum amended plots.

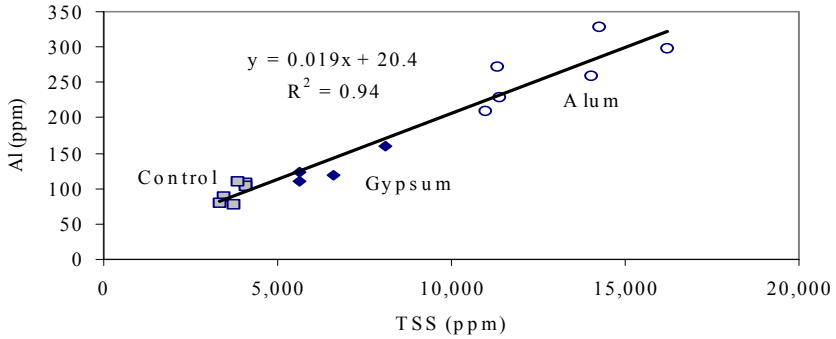

Figure 2. Relationship of Al to TSS in simulated runoff. Squares represent data from control plot, diamonds data from the gypsum-amended plot, and circles data from the alum-amended plot.

Table 6. Soil pH, Al, Ca, salt and S concentrations for pre- and postreatment rainfall simulation trials.

Treatment	Depth (in)	Trial	pH	Al (ppm)	Ca (ppm)	Salt (ppm)	S (ppm)
Alum	0-2	Pre	7.6	6,320	12,600	482	39
		Post 1	7.4	7,920	11,200	3,830	1,600
		Post 2	7.2	6,560	13,300	3,070	1,410
Alum	0-6	Pre	7.5	6,510	11,500	562	38
		Post 1	7.4	6,790	44,400	2,630	677
		Post 2	7.3	7,250	14,300	2,360	913
Control	0-2	Pre	7.6	5,000	12,900	408	53
		Post 1	8.2	6,090	11,600	963	67
		Post 2	8.1	na	11,700	582	69
Control	0-6	Pre	7.5	6,200	11,800	414	37
		Post 1	7.8	4,840	11,700	728	45
		Post 2	7.7	na	12,500	599	57
Gypsum	0-2	Pre	7.4	5,340	10,700	365	44
		Post 1	7.6	5,810	12,200	3,450	2,280
		Post 2	7.4	na	13,000	2,080	1,660
Gypsum	0-6	Pre	7.4	5,960	9,700	408	44
		Post 1	7.4	5,210	8,500	2,350	683
		Post 2	7.3	na	10,800	1,530	648

While the focus of this demonstration project was on phosphorus, nitrogen constituents also need to be considered in any evaluation of nutrient runoff. The amendments were expected to have little impact on nitrogen constituents, although it was thought that potential changes in soil pH brought about by the amendments might influence dynamics between N constituent forms. TKN comprised 95 percent or more of total-N in runoff from all rainfall simulations and showed some decreases in concentration with posttreatment simulation trials within plots (Table 2). Between plots, very notable differences in runoff TKN concentrations occurred. As with Al and to a lesser degree TP, TKN concentrations were strongly tied to TSS concentrations (Figure 3). Concentrations of TKN adjusted for TSS indicated a slight decrease in the first posttreatment trial compared to the pretreatment trial, but only minor differences between plots (Table 5). Clear decreases in soil TKN concentrations were indicated for both the 0-2 inch and 0-6 inch samples in comparing pretreatment with posttreament trials (Table 3).

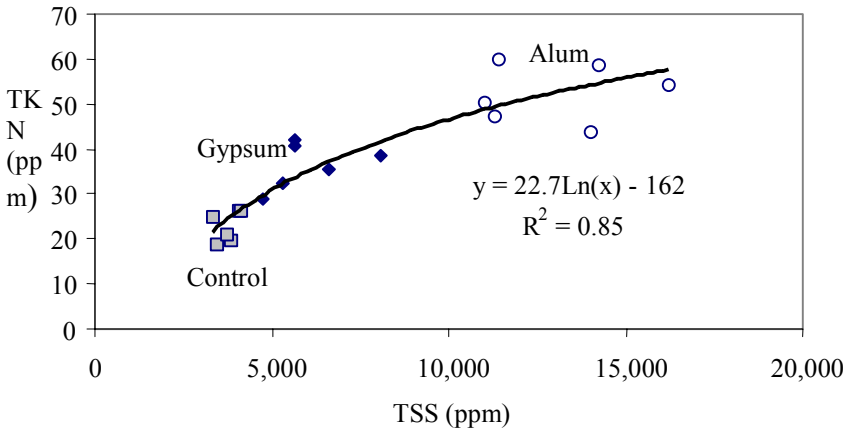

Figure 3. Relationship of TKN to TSS in simulated runoff. Squares represent data from control plot, diamonds data from the gypsum-amended plot, and circles data from the alum-amended plot.

For NH_3-N a fairly notably increase in runoff concentration occurred in the first posttreatment trial on the alum amended plot compared the control and gypsum amended plots (Table 2). In comparing NH_3-N with NO_2-N+NO_3-N concentrations between the first and second posttreatment trials, the nitrification of NH_3-N to NO_2-N+NO_3-N was quite apparent (Table 2). While NH_3-N and NO_2-N concentrations were not measured in the soil, soil NO_3-N concentrations increased with effluent application in the first posttreatment trial regardless of plot treatment (Table 3). On average across plots, soil NO_3-N in the first posttreatment trial increased 240 percent in the 0-2 inch layer and 84 percent in the 0-6 inch layer in comparison to pretreatment conditions. In the second posttreatment trial, decreases in soil NO_3-N concentrations were apparent in all but the alum-amended plot compared to the first posttreatment trial. This decrease in soil NO_3-N was likely in response to the ready movement of the nitrate ion in water and its transport through the soil column after the two simulated intense rainfall events.

A pretreatment pH value across plots averaged 8.07 $\pm$ 0.03 standard units. During the posttreatment trials, a notable decrease in runoff pH occurred on the alum-amended plot, while a slight increase was noted on the control plot (Table 4). Runoff from the gypsum-amended plot showed a fairly constant pH across all three trials. The pH decrease on the alum-amended plot was greatest for the first posttreatment simulation trial. This decrease in pH may explain the relatively high NH_3-N runoff concentrations associated with that trial on the alum-amended plot. Total ammonia nitrogen or NH_3-N as measured in the laboratory is comprised of NH_3 and NH_4^+ ions in equilibrium. The fraction of total ammonia nitrogen represented by NH_3 and NH_4^+ is a function of pH. The NH_4^+ form is more common at lower pH values and is not subject to volatilization loss, while the NH_3 form is more common at higher pH values and is subject to volatilization loss. Because more of the ammonia on the alum amended plot would be in the nonvolatile NH_4^+ form, more ammonia was available for movement in runoff in the first posttreatment trial and also for oxidation to NO_3-N. NO_3-N runoff and soil concentrations increased notably in the second posttreatment trial on the alum-amended plot. Changes in runoff pH, in general, appeared to follow noted changes in soil pH. For 0-2 inch and 0-6 inch samples, soil pH showed a slight decrease on the alum-amended plot, a notable increase on the control plot, and no change on the gypsum-amended plot (Table 6).

Conductivity in runoff increased notably from the alum and gypsum amended plots, while conductivity remained constant in runoff from the control plot (Table 4). Increases in conductivity were accompanied by large increases in soil salinity as noted by increased S concentrations, particularly in the 0-2 inch soil layer within the alum and gypsum amended plots (Table 6). The soils associated with this demonstration project were highly calcareous (Table 6). No notable increase in Ca was apparent on the gypsum-amended plot. Ca concentrations overall averaged 11,700 $\pm$ 1,350 ppm.

CONCLUSIONS AND RECOMMENDATIONS

Alum as a soil amendment demonstrated very large decreases in soluble P in runoff (as represented by PO_4-P) and soil extractable-P using a water extraction method. A smaller, but notable decrease, was indicated for soil extractable P using the TAMU method. The smaller percent change in soil extractable P noted with the TAMU method versus the water method occurs, because the TAMU extraction method involves acids that break some P bonds with other particles, thus, representing a mixture of soluble and particulate P from the soil. The TAMU extraction method for P was developed to estimate the quantity of plant-available P in the soil for making fertilizer recommendations. The water extraction method represents only the soluble P pool from the soil and is thought to be a better indicator of soluble P available for movement during rainfall-runoff events (Pote et al. 1996).

The results using gypsum were not as clear. Changes in the percent PO_4-P in runoff from the gypsum plot were fairly similar to the control plot, although increases in TAMU ext-P from the soil were not as high on the gypsum plot as on the control plot. The gypsum-amended plot also indicated notable decreases in water ext-P from the 0-2 inch and 0-6 inch soil layers, while the control plot showed notable increases in both cases. It appears that alum may be a more useful soil amendment for controlling soluble P runoff from dairy effluent application fields than gypsum for the calcareous soil used in this demonstration project.

Because this was only a short-term demonstration, long-term, replicated field studies are necessary to more fully assess the value of gypsum or alum as amendments. Further studies are also warranted to evaluate the impact of alum and gypsum amendments on crop establishment and growth before these amendments can be recommended for controlling soluble P in runoff, particularly with regard to soil salinity. Erosion control measures should also be implemented in conjunction with any amendment application for the control of TP, Al, TKN, and TSS in field runoff.

These results also must be considered within the context of the rainfall simulation methods used and the conditions of the individual plots at the time of the simulation trials. The three inches per hour simulated rainfall is a rate recommended for standardization of studies being conducted under the Natural Resource Conservation Commission's National Soil P Project relating soil test P to runoff P in benchmark soils of the United States (D.R. Edwards, personal communication 1998). However, this rainfall rate represents a relatively high rate for the study area (Erath County) and has a return frequency in Erath County of over 10 years for a 1-hr rainfall (3-inch rain) and about 2 years for a 30-minute rainfall (1.5-inch rain). A more typical lower intensity rainfall rate would be expected to produce less runoff and have less energy for transport of sediment-bound nutrients.

Potential costs to producers for chemical amendments will vary with the phosphorus level in their effluent and soils and the degree of phosphorus control desired. In this demonstration project, alum was applied at a rate of 8.6 tons/ac and gypsum at a rate of 7.7 tons/ac. According to a representative from General Chemical Corporation (a major alum manufacturer), the cost for dry alum ranges from about $200 to $250 per ton depending on the supplier. Liquid alum can be purchased for about $180 per ton of active ingredient but may cost more in shipping, because liquid alum is more difficult to transport than dry alum. Gypsum, containing about 20 percent calcium, costs about $60 per ton. Given the rates used on the demonstration plots and prices listed above, using these amendments would cost about $1,900/ac for dry alum and $460/ac for gypsum, not including the cost of application. As with most chemicals, discount prices should be available for bulk purchases, but will depend on the amount needed and negotiations with specific suppliers. These costs must be considered highly preliminary. The long-term effectiveness of chemical amendments must be determined before reliable cost estimates can be made.

REFERENCES

Anderson, D.L., O.H. Tuovinen, A. Faber, and I Ostrokowski. 1995. Use of soil amendments to reduce soluble phosphorus in dairy soils. Ecological Engineering 5:229-246.

Andraski, B.J., D.H. Muller, and T.C. Daniel. 1985. Phosphorus losses in runoff as affected by tillage. Soil Science Society of American Journal 49:1523-1527.

Baker, J.L. and J.M. Laflen. 1982. Effect of crop residue and fertilizer management on soluble nutrient runoff losses. Transactions of the American Society of Agricultural Engineers 25:344-348.

Boyd, C.E. 1990. Water Quality in Ponds for Aquaculture. Birmingham Publishing Co., Birmingham, AL.

Codd, G.A. 1995. Cyanobacterial toxins: Occurrence, properties and biological significance. Water Science & Technology 32:149-156.

Edwards, D.R., P.A. Moore, Jr., S.R. Workman, and E.L. Bushee. 1999. Runoff of metals from alum-treated horse manure and municipal sludge. Journal of the American Water Resources Association 35:155-165.

EPA, Environmental Protection Agency. 1997. Test Methods for Evaluating Solid Waste, Physical/Chemical Methods. Office of Solid Waste, Washington, D.C. EPA SW-846.

EPA, Environmental Protection Agency. 1983. Methods for Chemical Analysis of Water and Wastes. Environmental Monitoring and Support Laboratory, Office of Research and Development, USEPA, Cincinnati, Ohio. EPA-600/4-79-020, Revised March 1983.

Gibson, C.E. 1997. The Dynamics of Phosphorus in Freshwater and Marine Environments, pp. 119-136. In: Phosphorus Loss from Soil to Water, H. Tunney, O.T. Carton, P.C. Brookes, and A.E. Johnston (eds.). Centre for Agriculture and Bioscience International, New York, NY.

Gilliam, J.W. 1995. Phosphorus control strategies. Ecological Engineering 5:405-414.

Hons, F.M., L.A. Larson-Vollmer, and M.A. Locke. 1990. NH4Oac-EDTA-extractable phosphorus as a soil test procedure. Soil Science 149:249-256.

Humphry, J.B., T.C. Daniel, D.R. Edwards, and A.N. Sharpley. 2002. A portable rainfall simulator for plot-scale runoff studies. Applied Engineering in Agriculture 18:199-204.

Jones, R.M. and S.P. Brown. 2000. Chemical and settling treatment of dairy wastewater for solids separation and phosphorus removal, pp. 132-141. In: Animal, Agriculture and Food Processing Wastes, Proceedings of the Eighth International Symposium, October 9-11, 2000, Des Moines, Iowa, J.A. Moore (ed.). American Society of Agricultural Engineers, St. Josesph, MI.

Martin, A. and G.D. Cooke. 1994. Health risks in eutorphic water supplies. LakeLine 14:24-26.

McFarland, A.M.S. and L.M.Hauck. 1999. Relating agricultural land uses to in-stream stormwater quality. Journal of Environmental Quality 28:836-844.

Moore, P.A., Jr. and D.M. Miller. 1994. Decreasing phosphorus solubility in poultry litter with aluminum, calcium, and iron amendments. Journal of Environmental Quality 23:325-330.

NRC, National Research Council. 1993. Phosphorus in the Soil-Crop System, pp. 283-312. In: Soil and Water Quality: An Agenda for Agriculture. National Academy Press, Washington, D.C.

Pote, D.H., T.C. Daniel, A.N. Sharpley, P.A. Moore, Jr., D.R. Edwards, and D.J. Nichols. 1996. Relating extractable soil phosphorus to phosphorus losses in runoff. Soil Science Society of America Journal 60:855-859.

Provin, T.L. and J.L. Pitt. 1999. Phosphorus — Too Much and Plants May Suffer. Texas Agricultural Extension Service, College Station, TX, L-5249 (February 1999).

Reddy, K.R., R. Khaleel, M.R. Overcash, and P.W. Westerman. 1979. Phosphorus — A potential nonpoint source pollution problem in land areas receiving long-term application of wastes, pp. 193-212. In: Best Management Practices for Agriculture and Silviculture, R.C. Loehr, D.A. Haith, M.F. Walter, and C.S. Martin (eds.). Ann Arobor Science, Ann Arbor, MI.

Sharpley, A.N., T.C. Daniel, and D.R. Edwards. 1993. Phosphorus movement in the landscape. Journal of Production Agriculture 6:492-500.

Sharpley, A.N. and S.J. Smith. 1992. Prediction of bioavailable phosphorus loss in agricultural runoff. Journal of Environmental Quality 21:32-37.

Shreve, B.R., P.A. Moore, Jr., D.M. Miller, T.C. Daniel, and D.R. Edwards. 1996. Long-term phosphorus solubility in soils receiving poultry litter treated with aluminum, calcium, and iron amendments. Communications in Soil Science and Plant Analysis 27:2493-2510.

Shreve, B.R., P.A. Moore, Jr., T.C. Daniel, D.R. Edwards, and D.M. Miller. 1995. Reduction of phosphorus in runoff from field-applied poultry litter using chemical amendments. Journal of Environmental Quality 24:106-111.

SSSA, Soil Science Society of America. 1996. Methods of Soil Analysis, Part 3: Chemical Methods. Soil Science Society of America, Madison, WI.

Tchobanoglous, G. and F.L. Burton. 1991. Metcalf & Eddy: Wastewater Engineering Treatment, Disposal, and Reuse, 3rd Ed. McGraw-Hill, Inc., New York, NY.

USDA-SCS. 1973. Soil Survey of Erath County, Texas. U.S. Department of Agriculture-Soil Conservation Service, Cartographic Division, Soil Conservation Service, USDA, Washington, D.C.

Yeoman, S., T. Stephenson, J.N. Lester, and R. Perry. 1988. The removal of phosphorus during wastewater treatment: A review. Environmental Pollution 49:183-233.