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Cycling of Geotube® Solids from Dairy Lagoons Through Turfgrass Sod

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Summary

Polymer – Abbreviation for polyacrylamide is used in water purification to flocculate suspended organic matter. Although polyacrylamide is designated as a non-toxic additive by USDA, its building block, acrylamide, is a potential nerve toxin in humans and causes birth defects and cancer in animals. A concentration limit of 500 ppm acrylamide in polyacrylamide preparations has been established for water treatment applications.

Geotube® solids – particulate matter collected from wastewater pumped from lagoon into semi-permeable fibrous sock.

Lysimeter – Container in which the volume of soil used to grow plants is isolated hydrologically from surrounding soil to control and measure water and nutrient inputs and losses.

Mineralization – Conversion of organic N to NH_4^+. Heterotrophic microorganisms use organic carbon compounds as an energy source for the conversion process.

Introduction

The Geotube® Dewatering System (Miratech Division of Ten Cate Nicolon Corporation; Commerce, Ga.) collects manure solids or sludge from wastewater in large, porous tubes or socks made of synthetic fibers. Alum (aluminum sulfate) and polymers are injected into wastewater during pumping from lagoons into the socks to facilitate particle flocculation as water drains out of the tube through pores in the fabric. Solids are trapped inside the sock (0440 ft^3), or Geotube®, while water drains from socks and is collected in a secondary lagoon. The injection of aluminum or other metal salts and/or polymers enhances separation of solids from lagoon wastewater and retention of particulate forms of nitrogen (N), phosphorus (P), and other nutrients within socks compared to wastewater filtering without chemical treatments (Worley et al. 2008). The use of chemical treatments also enhances water flow through porous Geotube® walls and improves system efficiency ultimately resulting in reduced total solids in wastewater by 93.5%, soluble P by 85%, and total P by 96% (Mukhtar et al. 2007).

Disposal of residual solids from the Geotube® poses another challenge. The injection of alum and polymers during effluent treatment raises questions about the sustainability of Geotube® solids application to agricultural or urban soils within or outside watersheds on which dairies are located (Sims et al. 2005). Sustainable systems for managing residual solids require maintenance of farm level and regional nutrient balances (Bergstrom et al. 2005).

Application and export of the nutrients in Geotube® solids through turfgrass sod or other high-value, non-food crops could enable repeated applications of the solids on land proximate to confined animal feeding operations (Vietor et al. 2002). However, the alum and polymers in treated solids could be detrimental to soil's physical, chemical and biological properties and turfgrass growth (Aggelides and Londra, 2000; Malecki-Brown et al. 2007; Wang et al. 1998). In addition, application of Geotube® solids to soil could contribute to leaching loss of soluble nutrient forms and in turn be detrimental to water quality (Maguire and Sims 2002).

The goal of this project was to evaluate the sustainability of systems for cycling Geotube® solids through turfgrass production for value-added export with sod. The first objective was to evaluate turfgrass establishment and physical, chemical, and biological properties of contrasting soil textures with and without incorporation of increasing rates of Geotube® solids. The second objective was to evaluate leaching losses of nutrients from contrasting soil textures with and without incorporation of Geotube® solids during turfgrass establishment.

Methods

Turfgrass growth, water and nutrient use

An experiment was designed to evaluate six treatment combinations made up of two soil types and three application rates of Geotube® solids. Each treatment combination was replicated four times. Geotube® solids were collected from a demonstration site on the XXX Dairy in Comanche County (Fig. 1). The solids were air-dried and sieved through a screen (0.25-inch mesh) before sampling, analysis, and incorporation in soil. The two contrasting soil types were a Windthorst fine sandy loam and Weswood sandy clay loam.

Figure 1. Geotube® solids were sampled one year after separation from wastewater pumped from the primary lagoon of XXX Dairy in Comanche County, Texas.

Soils were packed into polyvinyl chloride (PVC) cylinders (4-in. diameter x 12-in. depth) over a layer of glass fiber cloth, which separated soil from a 2-in. depth of washed gravel. The 4- to 12-in. depth comprised soil without Geotube® solids. The 0- to 4-in. depth of soil was amended with Geotube® solids at three rates: 0, 12.5, and 25% by volume. The soil with or without Geotube® solids was packed within 2-in. increments to achieve a consistent bulk density throughout the cylinder. All treatments were sprigged with Tifway bermudagrass (Cynodon dactylon L. Pers. X C. transvaalensis Burtt-Davey) after soil was firmly packed into cylinders (Fig. 2). The hydrostatic pressure of a water column was used to wet soil initially from the bottom to the surface within cylinders after sprigging. Excess water, which drained through fittings in caps sealed on the bottom of cylinders, was collected for analysis. Subsequent irrigation was applied on the soil surface. Given water and nutrient inputs and loss were monitored, the cylinders of soil functioned as lysimeters over the 90-d study.

Figure 2. Tifway bermudagrass grown in soil columns with varying soil and Geotube® material amendments

One pore volume of leachate was displaced through surface irrigation of soil in cylinders and was collected at each 45 and 90 days after sprigging. Leachate volumes were measured and sub-sampled for analysis. Leachate was filtered (pore size < 0.45 μm) for colorimetric analysis of dissolved reactive P (DRP) and ammonium (NH_4-N), for spectroscopic analysis of total dissolved P (TDP), and for automated analysis of nitrate (NO_3-N). Soil and Geotube® solids were sampled, dried, ground (< 0.1 in.), and digested prior to analysis of total and extractable nutrients, cations and organic carbon. Turfgrass was clipped to a 2-in. height when plant height exceeded 6 in. Clippings were dried, combined over cutting dates, weighed, ground, and digested for analysis of total N and P

Decomposition of solids

Decomposition of Geotube® solids was measured for the six treatment combinations comprising the two soil types mixed with three rates of solids. The six treatments were replicated four times. Soil was mixed with Geotube® solids as described above for the 0- to 4-in. depth of the cylinders of soil. After incorporating Geotube® solids, soil was incubated under laboratory conditions to evaluate release of CO_2 and inorganic N from organic carbon and N over time. Soil was enclosed within glass jars for 56 days at 77° F. Alkali traps (0.25 N NaOH) adsorbed CO_2 released from soil, which was titrated with acid (0.25 N HCl) at 1, 2, 3, 7, 14, 21, 28, 35, 42, 49, and 56 days after solids were mixed with soil. Inorganic N (NO_3-N + NH_4-N) in extracts of soil sampled before and after the incubation period were measured as described above to estimate rates of N release from soil.

Results

Turfgrass responses in cylinders of soil (lysimeters)

Under greenhouse conditions, mean productivity of Tifway bermudagrass over the 90-d experiment increased (P=0.05) as the volume-based rate of Geotube® solids increased from 0 to 25% (Fig. 3). In addition, turfgrass productivity without Geotube® solids was greater for the Windthorst fine sandy loam than for the Weswood sandy clay loam soil (P=0.05). The results indicated neither the alum nor polymers were injected during solids separation in the Geotube® were detrimental to turfgrass growth in soils amended with volume-based rates of the solids and irrigated with well water.

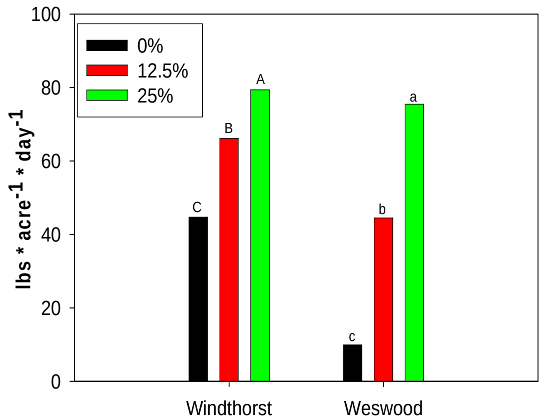

Figure 3. Mean productivity of Tifway bermudagrass in two soil types amended with 0%, 12.5% and 25% by volume of Geotube® solids during a 90-d period after sprigging under greenhouse conditions.

Effect of Geotube® solids on soil properties

Analysis of soil before incorporation of Geotube® solids indicated concentrations of total N and P and extractable P were similar between the Windthorst and Weswood soils (Table 1). In contrast, the concentration of extractable NO_3-N was greater for the Windthorst soil than the Weswood soil. The analysis of Geotube® solids indicated concentrations of total P and water-extractable P (WEP) were lower than concentrations of various dairy manure sources as reported by Leytem et al. (2004) (Table 1). In contrast, analyses of Geotube® solids indicated NO_3-N concentrations were very high compared to concentrations for composted dairy manure (Johnson et al. 2006). The volume-based rates of 12.5% and 25% by volume of Geotube® solids in soil resulted in large concentrations of total N, total P, and total organic C within the 0- to 4-in. depth of soil within PVC cylinders.

	pH	TOC %	TN %	TP ppm	M3P ppm	WEP ppm	NO_3 ppm
Windthorst	6.4	0.3	0.05	211	12.5	4.1	45.8
Weswood	8.3	1.2	0.04	285	16.9	4.6	1.9
Geotube Solids	5.7	22.1	2.1	1586	-	18.6	3277

Table 1. Chemical properties of soil and Geotube® solids before mixing and packing into PVC cylinders. Total Organic Carbon (TOC), Total Nitrogen (TN), Total Phosphorus (TP), Mehlich-3 P (M3P), Water Extractable P (WEP), and Nitrate (NO_3) were measured.

The increasing rates of Geotube® solids incorporated in the top 4 in. of soil increased TOC concentrations and decreased soil bulk density (Table 2). Incorporating solids at 25% by volume increased mean TOC concentration to 5.8 times greater (P= 0.001) than soil without solids. Similarly, 12.5% by volume of Geotube® solids increased TOC to triple (P= 0.001) that of concentrations in soil without added solids. Soil bulk density decreased (P= 0.05) 14.4% for soils amended with 25% by volume of Geotube® solids, compared to soil without solids. Similar reductions (19.7%) in soil bulk density have been reported for loamy soils after incorporation of volume based rates (160 yd^3 ac^{-1}) of compost (Aggelides and Londra 2000).

Geo residue rate %	pH	density lb ft^3	GWC lb lb^{-1}	TOC %	TN %	TP ppm
Windthorst 0	8.6	82	0.22	0.33	0.04	43
Windthorst 12.5%	8.3	78	0.21	1.15	0.12	239
Windthorst 25%	8.1	71	0.12	2.23	0.21	594
Weswood 0	8.7	81	0.31	0.43	0.05	272
Weswood 12.5%	8.6	74	0.28	1.15	0.12	432
Weswood 25%	8.3	69	0.26	2.13	0.19	683
std error of means	0.08	5.6	0.02	0.06	0.005	46.7

Table 2. Variation of soil physical and chemical properties (0- to 4-in. depth) as rates of incorporated Geotube® solids are increased in two soil types. Variation of mean gravimetric water content (GWC) and total organic carbon (TOC), total N (TN), total P (TP) was evaluated for soil sampled after a 90-d period of turfgrass establishment.

Previous studies demonstrated additions of organic residues increased soil water content (Aggelides and Londra 2000). In contrast, gravimetric soil water content was lower for soil amended with 25% by volume of Geotube® solids (P = 0.05) than soil with 12.5% by volume solids or no solids (Table 2). In the present study, variation of gravimetric soil water content sampled at 90 d was inversely related to variation of turfgrass productivity among treatments over the 90-d period (R^2=0.55). Greater turfgrass uptake and transpiration of water for soils amended with 25% by volume of Geotube® solids could have depleted soil water content compared to soil with less or no added solids. If large, volume-based rates of Geotube® solids increase turfgrass growth and water use, soil water content could be reduced if rainfall or irrigation is not sufficient to balance plant water uptake and loss.

Incorporating increasing rates of Geotube® solids increased concentrations of total and extractable P and N in soil sampled from cylinders after 90 d of turfgrass establishment (Tables 2 and 3).

Geo residue rate % by Volume	**M3P ppm**	**WEP ppm**	**NO_3 ppm**	**NH_4 ppm**	**M3Al ppm**
Windthorst 0	16.1	1.9	79.4	13.9	53.2
Windthorst 12.5%	94.5	10.2	104.1	24.8	48.4
Windthorst 25%	173.2	15.3	114.8	41.6	48.0
Weswood 0	20.7	1.8	55.7	11.5	14.5
Weswood 12.5%	79.2	10.4	102.8	23.4	17.7
Weswood 25%	151.1	13.6	116.8	40.4	17.4
std error of means	4.6	1.2	20.51	7.0	1.5

Table 3. Variation of Mehlich-3 P (M3P), Water Extractable P (WEP), Mehlich-3 Al (M3Al), and inorganic N in soils 90 d after incorporation (0- to 4-in. depth) of increasing rates of Geotube® solids.

Incorporating 12.5% by volume of solids increased (P=0.001) soil total N 2.7-fold, total P 2.1-fold, and Mehlich-3 P 4.7 fold compared to soil without solids. In addition, incorporating the highest rate of solids (25% by volume) resulted in greater (P=0.001) soil total N, total P, and Mehlich-3 P than the lower rate of solids or un-amended soil. Moreover, as the rate of Geotube® solids increased, soil WEP concentration increased (P= 0.001) (Table 3).

Although soil was sampled after the second leaching event, increasing rates of Geotube® solids remained evident as greater mean concentrations of inorganic N (NO_3 and NH_4) in amended soils. At the relatively high soil pH observed after 90 d of irrigation with well water, increasing application rates of incorporated Geotube® solids did not increase soil Mehlich-3-extractable Al compared to soil without solids. Yet, Mehlich-3 Al was greater for the Windthorst (P= 0.001) than the Weswood soil.

Effect of Geotube® solids on leaching loss

Total dissolved P concentration in leachate collected following wetting of soil in cylinders at day 1 was less than 0.15 ppm and was similar among rates of Geotube® solids and between soil types. In contrast, incorporation of 12.5% and 25% by volume of Geotube® solids increased TDP concentration in leachate collected at 45 d (P= 0.001) and 90 d (P= 0.001) compared to control soils (Table 4). In addition, the mass loss of TDP in leachate was greater (P=0.01) for soils amended with Geotube® solids than un-amended controls at 45 d and 90 d (Table 4). Concentration of TDP in leachate collected at 90 d was linearly (R^2 = 0.67) related to concentration of WEP in soil. Although incorporation of Geotube® solids increased TDP concentration in leachate, concentrations in the present study were much lower than those reported for soil amended with livestock manure in previous studies (Chardon et al. 2007).

Dissolved reactive P (DRP) concentration in leachate, which is indicative to inorganic P forms, was below detection limits for even the highest rate of Geotube® solids (25% by volume) in leachate collected at 45 and 90 d for both soil types. Mean DRP concentration in leachate from both leaching events for the Weswood soil was 0.014 ppm without Geotube® solids and was 0.01 ppm for the intermediate rate of solids (12.5%). The low leachate concentrations of DRP are consistent with expected effects of alum and polymer additions on inorganic P forms in the lagoon wastewater during solids collection in the Geotube® sock.

Dissolved un-reactive P (DUP) was defined as DUP = TDP-DRP for leachate that was filtered through a 0.45 μm pore size to remove sediment. The DUP was attributed to organic P forms in the filtered leachate. A large fraction of TDP in filtered leachate was DUP for soil with and without Geotube® solids.

For leachate collected at 45 and 90 d, DUP was greater (P= 0.01) for soils receiving Geotube® solids than soils without the amendment (Table 4). The percentage of TDP quantified as DUP ranged from 60 to 90% for soils without incorporated solids and from 87 to 100% for soils amended with increasing rates of the Geotube® solids at 90 d. Chardon et al. observed that 90% of TP in leachate was DUP for soil columns amended with animal slurries or manure (1997, 2007). The large percentages of DUP in leachate supported the hypothesis that polymers and alum within the Geotube® solids adsorbed DRP in the soil solution; however, a portion of the DUP in soil was soluble and transported in leachate.

Geo residue rate	**45 days**			**90 days**		
	TDP	**DUP**	**TDP**	**TDP**	**DUP**	**TDP**
m^3 m^{-3}	**ppm**	**ppm**	**lb ac^{-1}**	**ppm**	**ppm**	**lb ac^{-1}**
Windthorst 0	0.09	0.09	0.032	0.11	0.10	0.056
Windthorst 0.125	0.15	0.15	0.051	0.23	0.21	0.086
Windthorst 0.25	0.14	0.14	0.044	0.27	0.27	0.082
Weswood 0	0.06	0.05	0.022	0.05	0.03	0.047
Weswood 0.125	0.13	0.12	0.041	0.11	0.09	0.056
Weswood 0.25	0.19	0.18	0.056	0.19	0.18	0.059
std error of means	0.01	0.01	0.005	0.02	0.01	0.006

Table 4. Concentration and mass loss of total dissolved P (TDP) and dissolved un-reactive P (DUP) in leachate collected at 45 and 90 days.

In contrast to the low concentrations of soluble P forms, NO_3-N concentrations in leachate volumes were high and differed (P=0.05) among rates of Geotube® solids for one or both soils at 45 and 90 d after sprigging (Table 5). At 45 d, leachate concentration of NO_3-N was greater for soil with Geotube® solids (P=0.05) than soil without Geotube® solids. Increasing the rate of Geotube® solids incorporated in the Windthorst soil increased NO_3-N concentration in leachate 187% and 270% for the respective rates at 45 days (Table 5). In addition, both leachate concentrations and mass loss were greater (P= 0.05) for Windthorst than Weswood soil with or without incorporated solids at 45 and 90 d after sprigging. Although greater for the Windthorst soil, concentrations of NO_3-N in leachate declined for all rates of solids at 90 d compared to 45 d. The leachate concentration of NO_3-N for Windthorst soil amended with 25% Geotube solids decreased 72% from 45 to 90 d. Mass loss of NO_3-N and turfgrass uptake of N may have contributed to reductions in leachate NO_3-N concentrations from 45 to 90 d.

Geotube residue rate m^3 m^{-3}	**45 d NO_3-N ppm**	**90 d NO_3-N ppm**
Windthorst 0	85.7	0.3
Windthorst 0.125	160.6	1.2
Windthorst 0.25	231.6	64.5
Weswood 0	0.02	0.1
Weswood 0.125	77.5	0.1
Weswood 0.25	72.8	1.0
std error of mean	39.1	11.0

Table 5. Concentration of NO_3-N in leachate at 45 and 90 days

Incorporation of Geotube® solids in soil increased NO_3-N concentrations in leachate well above the health advisory level for drinking water set by the USEPA. Similar high concentrations of NO_3-N have been reported after incorporation of composted manures at 3800 lb ac^{-1} (Evanylo et al. 2008). Applications of Geotube® solids at the volume-based rates could exceed potential turfgrass N uptake during establishment and pose a threat to water quality. Yet, the NO_3-N applied with the Geotube® solids and subsequent release of inorganic N from degrading organic N contributed to increased productivity of turfgrass compared to soils without incorporated solids (Fig. 2) (Evanylo et al. 2008).

Decomposition of incorporated solids in soil

Decomposition rates for organic carbon, which are indicative of inorganic N release rates or mineralization from organic N, decreased over time for soils with and without Geotube® solids. Increasing the rate of incorporated solids in both soil types increased (P= 0.005) decomposition rate for organic carbon. Incorporating 12.5% by volume of Geotube® solids increased decomposition rate of organic carbon 230% compared to un-amended control soil. Similarly, the volume-based rate of 25% incorporated solids increased decomposition rate 337% compared to soil without solids. Decomposition rates of organic carbon comparable to the present study were reported for soils receiving 42 tons per acre of compost (Bernal et al. 1998). Similar to organic carbon observations, increasing the rate of Geotube® solids significantly increased (P= 0.05) mineralization rate of organic N (Fig. 4). Large quantities of inorganic N were released from the organic N forms in Geotube® solids,

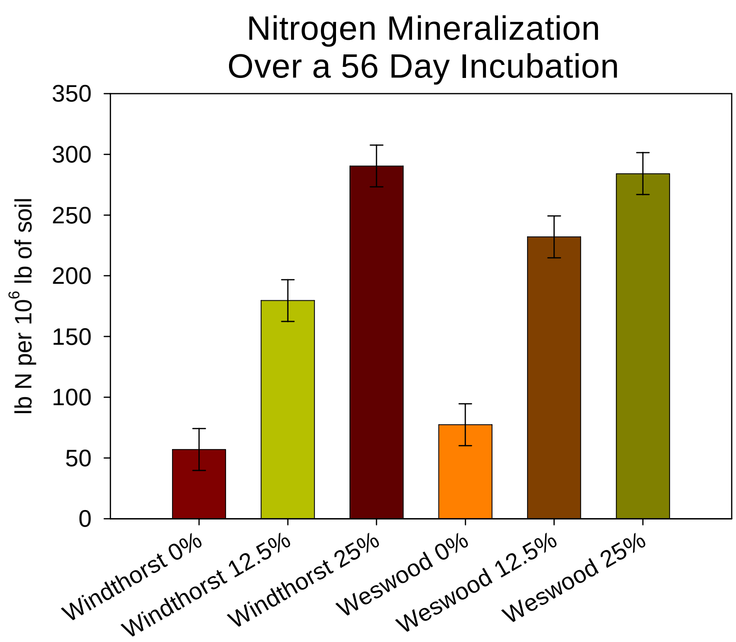

Fig. 4. Rate of inorganic N release from organic N in soils with and without Geotube® solids over a 56 day incubation. The two rates incorporated in soil were 12.5% and 25% by volume of Geotube® solids.

but no significant difference was observed between soil types. Incorporating 12.5% of solids increased the amount of N mineralized from organic N 2-fold and incorporating 25% by volume increased N mineralization 2.8-fold compared to soil without Geotube® solids. Similar organic N mineralization rates were reported by Flavel and Murphey for soils amended with compost (2006). High NO_3-N concentrations in the Geotube® solids sampled one year after collection, combined with continued mineralization of organic N, will necessitate analysis before application. The amount of inorganic N and other nutrients available from Geotube® solids must be managed in combination with fertilizer N sources to provide turfgrass requirements during establishment and maintenance and protect environmental quality.

Conclusion

Observed improvements in turfgrass productivity and soil properties combined with low leaching losses of SRP at high soil pH were indicative of the potential benefits of Geotube® solids. Increases in Tifway bermudagrass clipping yields during establishment and maintenance provided evidence that incorporated, volume-based rates of Geotube® solids were an excellent source of inorganic and organic sources of P and N. In addition, the organic carbon incorporated through volume-based rates of solids reduced soil bulk density. Despite benefits to turfgrass and soil properties, the rates of Geotube® solids need to be managed to prevent detrimental effects on groundwater quality. High NO_3-N concentrations in the volume-based rates applied in the present study exceeded Tifway bermudagrass requirements during establishment, which contributed to high NO_3-N concentrations in soil and leachate. In contrast, leaching loss of DRP from soil amended with the Geotube® solids was low even though volume-based rates increased total, soil-test, and water-extractable P to concentrations above plant requirements. Under the high soil pH conditions in the present study, the alum and/or polymers added during solids separation in the Geotube® could have limited solubility of reactive inorganic P forms even after the solids were incorporated in soil. Although leaching loss of SRP from volume-based rates of Geotube® solids was not problematic, observed leaching losses of inorganic N and organic P forms indicated rates less than 12.5% by volume may be necessary during turfgrass establishment.

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