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Vegetative Buffer and Fly Ash Pad Surface Material System Application for Reducing Runoff, Sediment and Nutrient Losses from Livestock Manure Windrow Composting Facilities

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Abstract

Applying livestock manures to agricultural cropland continues to contribute significant levels of sediment and nutrient pollutants to streams and other water bodies. Vegetative buffers have been extensively demonstrated to reduce surface runoff flow, sediment, and nutrient losses. The coal-fired combustion by-product fly ash also has been shown to exhibit significant water-absorption and phosphorus-sorbing properties. This study investigated a vegetative buffer and fly ash pad surface material system for reducing runoff flow and water quality effects from a livestock manure windrow composting facility. Surface runoff, runoff percent of rainfall, total solids, nitrate-nitrogen, ortho-phosphorus, and total phosphorus were researched during 2002-2004 at a central Iowa dairy cow manure windrow composting research facility. Three compost windrow: vegetative buffer area ratios comprised the surface runoff treatments that included 1:1, 1:0.5, and 1:0 (no buffer control) area ratios, respectively. The 1:1 and 1:0.5 area ratios represented a 6.0 m-wide x 23 m-long fly ash composting pad area compared to vegetative buffer areas of equal and one-half size, respectively, with three replications of each treatment for a total of nine runoff plots in a randomized complete block design. Results from this study showed significantly high levels of runoff flow, sediment, and nutrients from the 1:0 control plots compared to the 1:1 and 1:0.5 vegetative buffer plots. The 1:1 and 1:0.5 vegetative buffer treatments were not significantly different and average runoff loss reductions from the 1:1 and 1:0.5 vegetative buffer plots were 98% and 93%, respectively, when compared to the 1:0 control plots. These findings underscore the efficacy of vegetative buffers in reducing surface runoff flow, sediment, and nutrient losses from a livestock manure windrow composting operation. Mass balance analysis results also indicated 41% and 26% of ortho-phosphorus were lost from the compost windrows during the 2004 early season and late season composting periods, respectively. However, only 0.1% and 0.4% of ortho-phosphorus were lost to runoff from the 1:0 control plots during the respective 2004 early season and late season composting periods. These results indicate the significantly lower ortho-phosphorus losses in runoff are attributed to the inherent chemical and physical phosphorus-sorption characteristics of the fly ash composting pad surface material. This vegetative buffer and fly ash pad surface material system application can significantly reduce surface runoff flow, sediment, and nutrient losses from a livestock manure windrow composting facility.

Keywords

fly ash, livestock manure windrow composting, sediment/nutrient losses, surface runoff, vegetative filter strip (VFS) buffers, water quality

Disciplines

Agriculture | Bioresource and Agricultural Engineering | Water Resource Management

Comments

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Chapter

VEGETATIVE BUFFER AND FLY ASH PAD SURFACE MATERIAL SYSTEM APPLICATION FOR REDUCING RUNOFF, SEDIMENT AND NUTRIENT LOSSES FROM LIVESTOCK MANURE WINDROW COMPOSTING FACILITIES

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ABSTRACT

Applying livestock manures to agricultural cropland continues to contribute significant levels of sediment and nutrient pollutants to streams and other water bodies. Vegetative buffers have been extensively demonstrated to reduce surface runoff flow, sediment, and nutrient losses. The coal-fired combustion by-product fly ash also has been shown to exhibit significant water-absorption and phosphorus-sorbing properties. This study investigated a vegetative buffer and fly ash pad surface material system for reducing runoff flow and water quality effects from a livestock manure windrow composting facility. Surface runoff, runoff percent of rainfall, total solids, nitrate-nitrogen, ortho-phosphorus, and total phosphorus were researched during 2002-2004 at a central Iowa dairy cow manure windrow composting research facility. Three compost windrow: vegetative buffer area ratios comprised the surface runoff treatments that included 1:1, 1:0.5, and 1:0 (no buffer control) area ratios, respectively. The 1:1 and 1:0.5 area ratios represented a 6.0 m-wide x 23 m-long fly ash composting pad area compared to vegetative buffer areas of equal

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and one-half size, respectively, with three replications of each treatment for a total of nine runoff plots in a randomized complete block design. Results from this study showed significantly high levels of runoff flow, sediment, and nutrients from the 1:0 control plots compared to the 1:1 and 1:0.5 vegetative buffer plots. The 1:1 and 1:0.5 vegetative buffer treatments were not significantly different and average runoff loss reductions from the 1:1 and 1:0.5 vegetative buffer plots were 98% and 93%, respectively, when compared to the 1:0 control plots. These findings underscore the efficacy of vegetative buffers in reducing surface runoff flow, sediment, and nutrient losses from a livestock manure windrow composting operation. Mass balance analysis results also indicated 41% and 26% of ortho-phosphorus were lost from the compost windrows during the 2004 early season and late season composting periods, respectively. However, only 0.1% and 0.4% of ortho-phosphorus were lost to runoff from the 1:0 control plots during the respective 2004 early season and late season composting periods. These results indicate the significantly lower ortho-phosphorus losses in runoff are attributed to the inherent chemical and physical phosphorus-sorption characteristics of the fly ash composting pad surface material. This vegetative buffer and fly ash pad surface material system application can significantly reduce surface runoff flow, sediment, and nutrient losses from a livestock manure windrow composting facility.

Keywords: fly ash, livestock manure windrow composting, sediment/nutrient losses, surface runoff, vegetative filter strip (VFS) buffers, water quality

INTRODUCTION

Nonpoint-source (NPS) pollution from agricultural nutrients continues to be a significant contributor to poor water quality in many parts of the USA (USEPA 2009; USGS 2010). Two-thirds of the total beef cattle feeding in the USA is practiced in the central and southern Great Plains (Krause 1991). Consequently, managing manure produced in large feedlots and dairies has become a significant environmental issue for water, air, and land pollution (Ramos et al. 2006; Smith et al. 2007; Burkholder et al. 2007; James et al. 2007), and could potentially contribute to reported hypoxic conditions in the Gulf of Mexico (David et al. 2010; Jacobson et al. 2011). This waste management practice also can raise economic and logistical issues regarding manure transport distance to suitable target field sites for proper recycling (Bartelt and Bland 2007). Livestock manure can provide an excellent source of organic matter and plant nutrients, but even under proper management, conventional manure utilization can have negative impacts. Runoff concentrations of nutrients such as nitrogen (N), carbon (C), and phosphorus (P) can be elevated by land application of manure to agricultural fields (Westerman et al. 1987; Edwards and Daniel 1993; Heathwaite et al. 1998; Burton and Turner 2003). Parry (1998) also determined that surface runoff of nutrients from agricultural fields is a major source of water pollution in surface waters. Windrow composting is one strategy to minimize the adverse effects of livestock manure on the environment.

Rynk et al. (1992) described windrow composting as the placing of manure and other raw materials in long narrow piles or windrows that are agitated or turned on a regular basis. Research has shown that composted manure is less hazardous to the environment (Eghball and Power 1999; Vervoort et al. 1998) and much of the mineral N is converted to more stable organic forms (Rynk et al. 1992). The composting process also has been shown to significantly reduce nitrate-N (NO_3-N) leaching relative to conventional fertilizers (Maynard 1993).

Compost filter sock applications have been reported to reduce P in runoff from road construction sites (Jurries 2003) and dissolved agrochemicals from corn (*Zea mays* Linnaeus) fields (Shipitalo et al. 2010). However, a major disadvantage of windrow composting is nutrient loss during the composting process, which can occur through leaching, runoff, and volatilization (Christensen 1983, 1984; Richard and Chadsey 1994; Eghball et al. 1997; Tiquia et al. 2000; Michel et al. 2004; Parkinson et al. 2004; Peigne and Girardin 2004; Webber et al. 2009, 2010a, 2011). Windrow composting site runoff water quality also can be effected by compost maturity levels relative to rainfall event occurrence and duration (Larney et al. 2014a, 2014b). A mass balance analysis study of a windrow composting site indicated 20% to 60% losses of N, P, and potassium (K) during composting processes (Tiquia et al. 2002), of which the most significant losses were runoff and leachate (Garrison et al. 2001). Seymour and Bourdon (2003) found concentrations of NO_3-N, ortho-P (PO_4-P), and K were highest in leachate compared to runoff samples from compost windrows under natural rainfall conditions. Wilson et al. (2004) reported that approximately 68% of both natural and simulated rainfall on saturated compost windrows resulted in runoff.

Vegetative filter strip (VFS) buffers are bands of vegetation located downslope of cropland or other potential pollutant source areas. These VFS buffers can provide erosion control and filter nutrients, pesticides, sediment, and other pollutants from agricultural runoff by reducing the sediment carrier and via interception-adsorption, infiltration, and degradation of pollutants dissolved in water (Dillaha et al. 1989). The VFS buffers also are considered to be a best management practice (BMP) that has been shown to reduce sediment and nutrient losses in a range of agricultural settings, including crop fields and feedlots (Dillaha et al. 1985; Magette et al. 1989; Mickelson and Baker 1993; Patty et al. 1997; Lee et al. 2000; Wang et al. 2005; Hay et al. 2006). These researchers determined that VFS buffers have potential for significantly improving the water quality of runoff. Factors that contribute to VFS buffer efficacy include vegetation species, soil type, soil texture, type of contaminant, slope of the runoff area, activities on the runoff area (i.e., tillage), and field condition (Dillaha et al. 1989; Arora et al. 1996; Schmitt et al. 1999; Lee et al. 2000; Abu-Zreig et al. 2003; Goel et al. 2004; Petersen and Vondracek 2006; Webber et al. 2009, 2010a, 2010b). However, Lam et al. (2011) determined that a combination of BMPs was most effective in improving water quality from a study evaluating several BMPs including extensive land use management, grazing management practice, field buffer strips, and a nutrient management plan. Other recent studies have reported benefits and limitations of VFS and other vegetative buffer BMPs regarding highly-eutrophic streams, deep soils, and subsurface lateral flow (Weigelhofer et al. 2012; Heinen et al. 2012; Salazar et al. 2015, respectively),

A critical aspect of a windrow composting operation is proper site selection, which includes several key factors such as materials transport, road access, and neighborhood relations. From an environmental management perspective, important issues include soil type, slope, and the nature of the buffer between the site and surface or groundwater resources (Richard 1996). Since NO_3-N and other nutrients can move through the soil and into streams as subsurface flow or leach down to the groundwater (Tiquia et al. 2002; Garrison et al. 2001), soil permeability is an important factor that impacts windrow composting site design. Consequently, Richard (1996) determined that a working surface of gravel, compacted sand, oiled stone, or even asphalt or concrete may be appropriate for some windrow composting facilities.

Sikora and Francis (2000) reported that lime and fly ash materials produced a hardened, nearly impervious surface layer capable of supporting equipment normally used at a windrow composting facility. They also found that the construction of a 0.73 ha (1.80 ac) windrow composting pad from lime and fly ash materials was approximately 28% of the cost of a comparable-size 15 cm (6.0 in)-thick concrete pad. Another benefit of fly ash and lime composting pad materials is the P-sorption properties reported by many researchers (Dou et al. 2003; Boruvka and Rechcigal 2003; Lau et al. 2001; Brauer et al. 2005; DeLaune et al. 2006; Penn and Bryant 2006; Hedström and Rastas 2006; Korkusuz et al. 2007; Weber et al. 2007; Jensen 2008; Webber et al. 2009; Stone 2013; Penn 2014). Dou et al. (2003) found fly ash reduced soluble P by 60% from converting water soluble-P (H_2O-P) in dairy manure to sodium bicarbonate extractable-P ($NaHCO_3$-P), a fraction less vulnerable to runoff losses. Significant quantities of aluminum oxide (Al_2O_3) and calcium oxide (CaO) were found in fly ash samples (Pathan et al. 2003), and either compound can react with PO_4-P. For this study, approximately 390 m^3 (13,773 ft^3) of fly ash were provided by a central Iowa electric utility power generating station for the composting pad construction.

There are few studies in the scientific literature documenting the effects of VFS buffers and fly ash pad surface material on sediment and nutrient losses in surface runoff from a livestock manure windrow composting site. Although this report addressed those issues, windrow composting, VFS buffer, and fly ash pad surface material effects can vary with the complex soil-water environment. Moreover, potentially different field conditions can include species of VFS buffer vegetation, type of livestock manure and resulting compost, and the particular pad surface material used at the site. Consequently, important objectives of this investigation were to quantify effects of windrow composting practices, VFS buffers, and fly ash pad surface material on losses of runoff, runoff percent of rainfall, sediment (total solids), nitrate-nitrogen, ortho-phosphorus, and total-phosphorus during natural rainfall events. Critical consideration also was given to determining accurate compost nutrient mass balance analysis results in order to validate effects of the fly ash composting pad surface material on runoff quantity and water quality.

MATERIALS AND METHODS

Site Description

The research procedures and findings from this study were originally published in the *Journal of Soil and Water Conservation* (Webber et al. 2009). The study site was located at the former Iowa State University Dairy Teaching Farm, Ames, central Iowa, USA (42° 0' 34" N, 93° 39' 16" W). The study site total area was 0.25 ha (0.62 ac) and comprised of nine plots, each 6.0 m-wide x 46 m-long (20.0 ft x 150 ft). The VFS buffer research plot area was selected on uneven terrain with an average slope of 5%. Dominant vegetation included 75% smooth brome (*Bromus inermis* Leyss.) and 25% switchgrass (*Panicum virgatum* L.), with a trace of mixed broadleaf species. Smooth brome occupied approximately 75% of each 1:1 VFS buffer plot, primarily in the upslopes, and approximately 100% of each 1:0.5 VFS buffer plot. Switchgrass in the downslope areas occupied approximately 25% of each 1:1 VFS buffer plot, but only a trace was observed in the 1:0.5 VFS buffer plots. The average tiller population for VFS buffers was estimated at 2.7M tillers/ha (6.7M tillers/ac). Tiller population was determined using a method from Arora et al. (2003). The tiller density value from this study contrasts with approximately 9.0M tillers/ha (22M tillers/ac) (Arora et al. 2003) and 50M tillers/ha (124M tillers/ac) (Brueland, et al. 2003) from two other central Iowa research sites that included similar vegetation types.

The major soil association at the research site is the Clarion-Webster-Nicollet association, with the minor soil association of Hayden-Lester-Storden in the area. All soils were formed in glacial till and local alluvium from till, with Clarion loam (a fine-loamy, mixed, mesic Typic Hapludolls) the dominant soil at the research site (Dewitt 1984). The upslope composting pad surface area of the site was comprised of fly ash, a by-product of combustion from coal-fired power plants provided by Alliant Energy, Inc., Marshalltown, Iowa, USA. The 0.13 ha (0.32 ac) composting pad area was constructed by machine grading to approximately a 2% average slope, and fly ash was hydro-compacted to a depth of 30.5 cm (12.0 in).

Experimental Design and Data Analysis

This study focused on the effects of a livestock manure windrow composting practice with VFS buffers and a fly ash pad surface on runoff flow, sediment, and nutrient transport under natural rainfall conditions. Runoff data were collected from six events from 2002 through 2004. The composting period was based on 60-day durations during a particular research season, occurring approximately during the June and July early season (ES) and August and September late season (LS) time periods. The 2002 project year included one LS composting period, 2003 included one ES composting period, and 2004 included both ES and LS composting periods.

Dairy cow manure (2002-LS and 2003-ES), horse manure (2004-ES), and a dairy cow/horse/sheep manure mixture (2004-LS) were composted in full-scale windrow systems, each trial containing nine windrows. These samples were collected three times during a composting period at 0, 30, and 60 days after compost windrow construction. A total of three, waist-height (1.0 m [3.3 ft]) "grab-sample" runs per windrow were conducted, with a collection of about a 3.0-L (0.8-gal) volume sample per run for nutrient analysis. Compost windrows were turned with tractor-assisted, elevating-face conveyor and rotary drum flail-type compost turning implements on a weekly basis for the first two weeks and bi-weekly for the remainder of the 60-day composting period. Compost sample analysis included evaluating compost characteristics (nutrients, moisture, and air-filled porosity) and conducting a compost nutrient mass balance analysis. Some of these data analysis results were then compared to surface runoff water quantity and quality.

Hydrologic and contaminant data collected and analyzed for this study included Runoff, runoff percent of rainfall (Runoff %), total-solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) losses from natural rainfall events. Runoff treatments were comprised of three compost windrow: VFS buffer area ratios that included 1:1, 1:0.5, and 1:0 (no buffer) control. The 1:1 and 1:0.5 area ratios represented a 6.0 m x 23 m (20 ft x 75 ft) fly ash compost pad plot area compared to an equal and one-half size VFS buffer plot area, respectively. All treatments had three replications for a total of nine runoff plots distributed in a randomized complete block design (Cochran and Cox 1957). Both compost windrow and VFS buffer plots used water-filled vinyl fire hoses and an 8.0-cm (3.0-in) high barrier that included 15-cm (6.0-in) sheet metal borders driven approximately 7.0 cm (2.8 in) into the ground, respectively, to minimize cross-contamination from adjacent plots. The fire hoses provided a heavy barrier that could be drained and moved quickly and were used in place of conventional sandbags to expedite the removal and replacement process for compost sampling and turning operations. The fire hoses also eliminated sand contamination of runoff samples from damaged sandbags.

A tipping-bucket flow meter system (Hansen and Goyal 2001) was used to measure and collect runoff from each plot after a rainfall event. A perforated 10-cm (4.0-in) diameter polyvinyl chloride (PVC) collector pipe was used at the downslope end of each 1:1 and 1:0.5 VFS buffer plot to direct runoff to the tipping-bucket system through 6.0 m to 30 m (20 ft to 98 ft)-long PVC flow pipes. Runoff also was collected at the downslope end of the composting pad plots for the 1:0 (no-buffer) control treatments. The runoff samples were collected in 19-L (5.0-gal) plastic gasoline tanks through a plastic tube connected to an orifice in the 90° elbow at the end of the flow pipe for each runoff unit to collect an integrated sample over the duration of the runoff event.

Onset Computer HOBO data loggers connected to magnetic switches were used to record runoff volume-calibrated "tips" for the tipping-bucket units, and HOBO Shuttle Data Transporters were used to collect tipping-bucket digital runoff volume data for laboratory analysis (Onset Computer, Inc. 2001). Runoff samples were collected after rainfall event depths of approximately 25 mm (1.0 in) or greater (events of less depth did not produce sufficient runoff for treatment comparisons). Samples were then refrigerated until analysis at the Department of Agricultural and Biosystems Engineering Water Quality Laboratory, National Swine Research and Information Center, Iowa State University, Ames, Iowa, USA.

Runoff volume (L) was determined from the tipping-bucket units and converted to equivalent depth (mm) across each windrow composting pad/VFS buffer runoff plot. Total-solids concentrations (g kg^{-1}) in runoff were measured using a gravimetric oven-drying method (American Water Works Association 1998). Nitrate-N concentrations (mg L^{-1}) were analyzed by the automated flow injection cadmium reduction method (American Water Works Association 1998) using a Lachat Quickchem 2000 Automated Ion Analyzer system (Hach Company, Colorado, USA). Ortho-P concentrations (mg L^{-1}) were analyzed by the automated flow injection ascorbic acid method (American Water Works Association 1998) using a Lachat Quickchem 2000 Automated Ion Analyzer system. Total-P concentrations (mg L^{-1}) were determined from unfiltered runoff samples using the ascorbic acid method (Hach Method 8190, Hach Company 2002). All TS and nutrient (NO_3-N, PO_4-P, and TP) concentrations were converted to total losses units of g and mg, respectively. The significance among treatments was determined using the General Linear Model (GLM) Procedure and Least Squares Mean (LSMEANS) Test (SAS Institute, 2004) to analyze differences among plot treatment means at the 95% probability level.

RESULTS

Runoff Analysis and VFS Buffer Performance

Runoff event data included event dates, event numbers (E1 through E6), and rainfall depths for composting periods 2002-LS (8-5-02E1/35 mm [1.4 in]); 2003-ES (6-25-03E2/81 mm [3.2 in], 7-5-03E3/61 mm [2.4 in]); 2004-ES (7-3-04E4/46 mm [1.8 in]); 2004-LS (8-26-04E5/33 mm [1.3 in], 9-6-04E6/46 mm [1.8 in]). Average concentration and total losses data values were discussed in this paper regarding individual events for each ES and LS composting period during the three project years: 2002-LS (total event rainfall = 35 mm [1.4 in]), 2003-ES (total event rainfall = 142 mm [5.6

in]), and 2004-ES (total event rainfall = 46 mm [1.8 in]), 2004-LS (total event rainfall = 79 mm [3.1 in]).

Table 1. 1:1 drainage area: vegetative filter strip (VFS) buffer area ratio (6.0 m-wide x 23 m-long [20 ft x 75 ft] VFS buffer area) average concentration and total runoff loss analysis results of total-solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) for the windrow composting/VFS buffer research site early season (ES) and late season (LS) composting periods from 2002 through 2004. No significant differences ($p \leq 0.05$) were found within and among composting periods

1:1 Area Ratio		**2002-LS**	**2003-ES**	**2004-ES**	**2004-LS**
Concentrations	TS (g kg^{-1})	1.2	1.6	0.4	0.6
	NO_3-N (mg L^{-1})	0.0	12.9	0.3	20.3
	PO_4-P (mg L^{-1})	1.5	5.2	4.0	8.1
	TP (mg L^{-1})	2.0	4.6	4.6	10.5
Total Losses	TS (g)	196.9	419.8	0.6	5.9
	NO_3-N (mg)	19.8	2680.9	0.5	198.0
	PO_4-P (mg)	446.8	541.2	5.7	70.7
	TP (mg)	641.3	736.4	6.4	97.6

Table 2. 1:0.5 drainage area: vegetative filter strip (VFS) buffer area ratio (6.0 m-wide x 12 m-long [20.0 ft x 37.5 ft] VFS buffer area) average concentration and total runoff loss analysis results of total-solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) for the windrow composting/VFS buffer research site early season (ES) and late season (LS) composting periods from 2002 through 2004. No significant differences ($p \leq 0.05$) were found within and among composting periods

1:0.5 Area Ratio		**2002-LS**	**2003-ES**	**2004-ES**	**2004-LS**
Concentrations	TS (g kg^{-1})	0.9	1.6	1.4	0.8
	NO_3-N (mg L^{-1})	0.1	18.0	0.2	18.7
	PO_4-P (mg L^{-1})	2.7	2.8	9.7	10.6
	TP (mg L^{-1})	4.2	3.5	7.1	13.5
Total Losses	TS (g)	545.2	1346.3	0.6	3.7
	NO_3-N (mg)	37.4	16078.8	0.2	157.1
	PO_4-P (mg)	1155.9	1783.7	13.2	68.6
	TP (mg)	2337.4	2283.9	8.8	87.6

Runoff analysis results in Tables 1 through 3 and in Figures 1 through 6 show significantly higher losses ($p \leq 0.05$) of Runoff, Runoff%, TS, NO_3-N, PO_4-P, and TP, respectively, from the 1:0 (no buffer) control treatments compared to 1:1 and 1:0.5 treatments for all composting periods. The 1:1 VFS buffers reduced levels of Runoff, Runoff%, TS, NO_3-N, PO_4-P, and TP by 98%, 98%, 98%, 98%, 97%, and 96%, respectively. The 1:0.5 VFS buffers reduced levels by 93%, 93%, 94%, 94%, 93%, and 90%, respectively. The overall average surface runoff loss reductions were 98% and 93% for the 1:1 and 1:0.5 VFS buffers, respectively, compared to the 1:0 control plots. Figures 1 through 6 also show the 1:1 and 1:0.5 VFS buffer treatments were not significantly different ($p \leq 0.05$). The 1:1 and 1:0.5 VFS buffer plots were 23 m and 12 m (75.0 ft and 37.5 ft) in length, respectively. These VFS buffer performance results are similar to findings from other researchers. Edwards et al.

(1997) and Lim et al. (1998) found concentrations of several surface runoff contaminants were significantly reduced in approximately 6.0 m (20 ft)-long VFS buffers, which ranged in lengths from 0.0 to 12 m (0.0 to 39 ft) and 0.0 to 18.3 m (0.0 to 60 ft), respectively. Arora et al. (2003) also determined a 30:1 plot drainage area: buffer area ratio VFS buffer could perform as efficiently as a larger 15:1 VFS buffer area in significantly reducing agricultural herbicides in runoff, requiring less land removed from production to achieve desired results.

Table 3. 1:0 drainage area: vegetative filter strip (VFS) buffer area ratio (no buffer control) average concentration and total runoff loss analysis results of total-solids (TS), nitrate-nitrogen (NO_3-N), ortho-phosphorus (PO_4-P), and total-phosphorus (TP) for the windrow composting/VFS buffer research site early season (ES) and late season (LS) composting periods from 2002 through 2004. Significant differences ($p \leq 0.05$) within and among composting periods are indicated by different letters b and c, respectively

1:0 Area Ratio		**2002-LS**	**2003-ES**	**2004-ES**	**2004-LS**
Concentrations	TS (g kg^{-1})	2.7a	3.3a	2.6a	2.4a
	NO_3-N (mg L^{-1})	0.3a	29.8a	8.4a	41.7a
	PO_4-P (mg L^{-1})	4.5a	4.5a	1.5a	3.0b
	TP (mg L^{-1})	4.2a	5.4a	2.6a	4.4b
Total Losses	TS (g)	6373.2b	11707.1b	686.1bc	1375.0bc
	NO_3-N (mg)	588.0b	104677.9bc	3439.0b	25444.9b
	PO_4-P (mg)	10514.7b	15563.8b	397.0bc	1836.8bc
	TP (mg)	10379.9b	19311.6b	669.4bc	2650.2bc

Figures 1, 2, and 3 show average Runoff, Runoff %, and TS losses, respectively, in surface runoff from the windrow composting/VFS buffer site. These results indicate the 2002-LS and 2003-ES 1:0 control treatments are significantly higher ($p \leq 0.05$) than the 2002-LS and 2003-ES 1:1 and 1:0.5 VFS buffer treatments. Figures 1 through 3 also indicate the 2002-LS and 2003-ES 1:0 control treatments are significantly higher ($p \leq 0.05$) than all VFS buffer treatments in the 2004-ES and 2004-LS composting periods. Since antecedent moisture conditions were minimal for the 2002-LS composting period (< 12 mm [0.5 in] rainfall 25 days before the 35 mm [1.4 in] rainfall event 8-5-02E1), the higher volume of Runoff compared to the 2004 composting periods may be attributed to the more impervious surface condition of the fly ash material shortly after composting pad construction in 2002. Although composting pad infiltration in 2003 also may have been structurally minimized compared to 2004, the higher total rainfall and antecedent moisture conditions for 2003 (142 mm [5.6 in] combined rainfall total with > 50 mm [2 in] within seven days of rainfall event 7-5-03E3) probably contributed to the elevated 1:0 control plot Runoff levels. For the 2004 ES and LS composting periods, the significantly reduced Runoff levels in the 1:1, 1:0.5, and 1:0 treatments may have been due to freeze/thaw action that resulted in an increase of observed preferential flow cracks in the fly ash composting pad and VFS buffer soil materials.

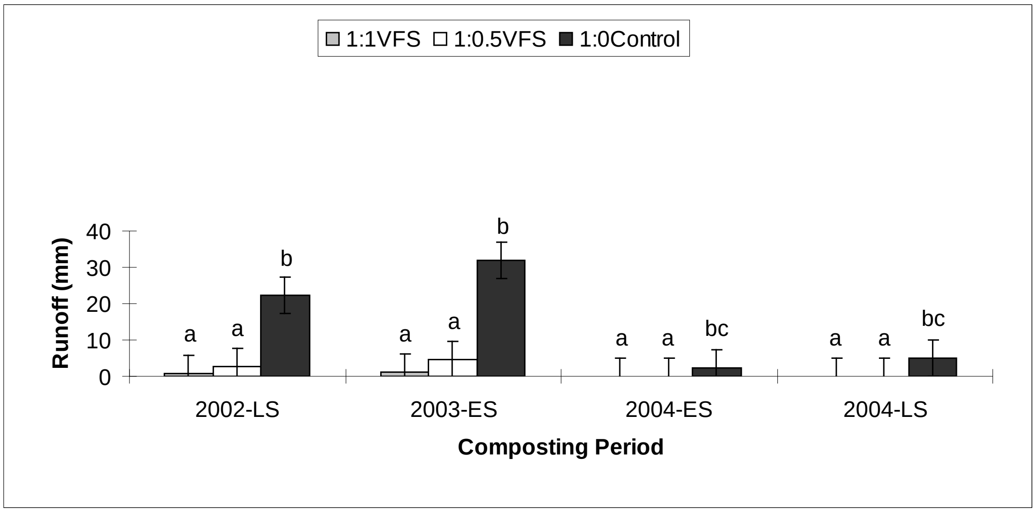

Figure 1. Effects of windrow composting practice and vegetative filter strip (VFS) buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting area: VFS buffer area ratios) on average Runoff depth (mm) for 2002 through 2004 early season (ES) and late season (LS) composting period rainfall events. Significant treatment differences ($p \leq 0.05$) within and among composting periods are indicated by different letters b and c, respectively. Error bars represent one standard deviation.

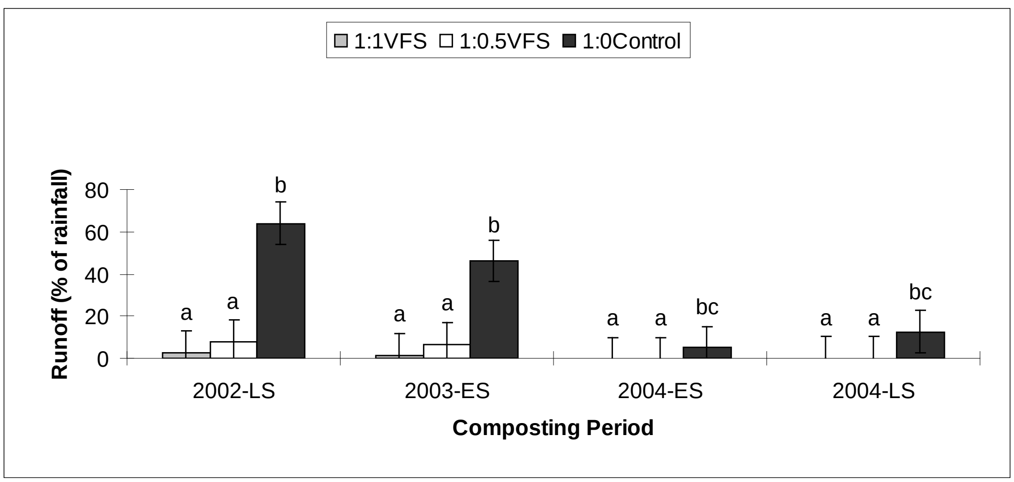

Figure 2. Effects of windrow composting practice and vegetative filter strip (VFS) buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting area: VFS buffer area ratios) on average runoff percent of rainfall (Runoff %) for 2002 through 2004 early season (ES) and late season (LS) composting period rainfall. Significant treatment differences ($p \leq 0.05$) within and among composting periods are indicated by different letters b and c, respectively. Error bars represent one standard deviation.

Other action that may have affected the fly ash composting pad surface during 2002 through 2004 came from various mechanized implements used for manure and compost transporting, turning, and sampling operations. This grinding and scraping action resulted in pad surface compaction and deformation, possibly accelerating the observed accumulation of fly ash granules at the downslope end of the compost pad plots throughout the three-year project period. Although composting pad surface compaction during composting periods may have caused a reduction in runoff infiltration, the accumulation of fly ash granules downslope in the composting pads and upper margins of the 1:1 and 1:0.5 VFS buffers could have contributed to increased runoff absorption (Webber et al. 2010b). Punjab Agriculture University researchers also reported the application of fly ash as a soil amendment was found to increase the available water content of loamy sand soil by 120% and of sandy soil by 67% (PAU 1993).

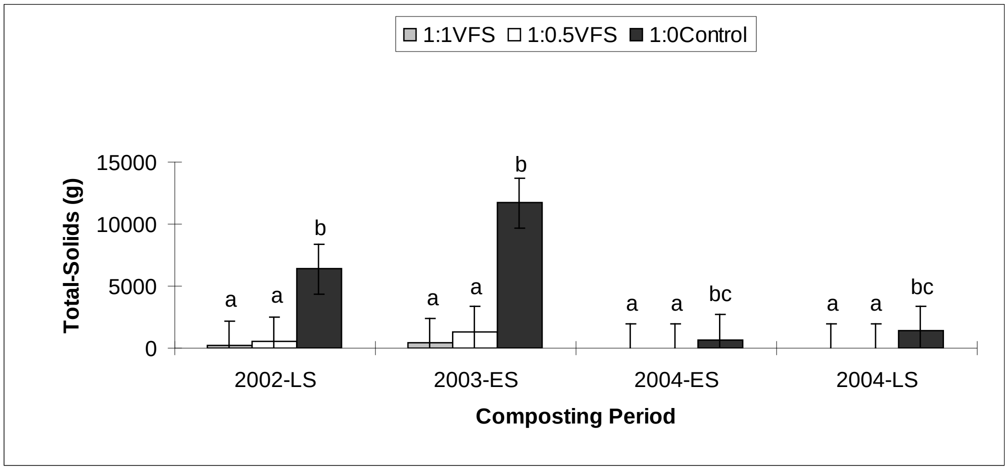

Figure 3. Effects of windrow composting practice and vegetative filter strip (VFS) buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting area: VFS buffer area ratios) on average Total-Solids (TS) surface runoff losses (g) for 2002 through 2004 early season (ES) and late season (LS) composting period rainfall events. Significant treatment differences ($p \leq 0.05$) within and among composting periods are indicated by different letters b and c, respectively. Error bars represent one standard deviation.

Figure 4 shows average NO_3-N total losses in runoff for 1:1, 1:0.5 VFS buffer, and 1:0 (no buffer) control treatments. The 2003-ES 1:0 control plot NO_3-N losses were significantly higher ($p \leq 0.05$) than all other treatments and composting periods. These NO_3-N losses roughly correspond to the event rainfall totals for each composting period, but also may be attributed to the variable nature of NO_3-N in runoff reported by other researchers. Seymour and Bourdon (2003) found NO_3-N concentrations varied by one order of magnitude in dairy manure windrow compost leachate, with lesser NO_3-N concentrations and variability in the runoff fraction. They suggested the variability to be a function of compost material age, compost process maturity, type of compost manure, and rainfall intensity and duration. Since this study used dairy cow manure and a mixture of dairy cow, horse, and sheep manure in the composting process periods, this may have contributed to the variable NO_3-N concentrations.

Figures 5 and 6 represent PO_4-P and TP runoff losses, respectively, for the 1:1, 1:0.5 VFS buffer, and 1:0 (no buffer) control treatments. These results show significantly higher losses ($p \leq 0.05$) for the 1:0 control plots compared to the 1:1 and 1:0.5 VFS buffer treatments. These results also indicate significantly lower ($p \leq 0.05$) losses in the 1:0 control plots for 2004 ES and LS composting periods compared to 2002 and 2003. Figures 7 and 8 show PO_4-P and TP runoff concentrations, respectively, for the 1:1, 1:0.5 VFS buffer, and 1:0 (no buffer) control treatments. These results are relatively lower than some other research findings. Seymour and Bourdon (2003) reported that P concentrations varied less than N species, but P tended to have higher concentrations in leachate compared to runoff. They found average PO_4-P concentrations for leachate and runoff were 21 and 15 mg L^{-1}, respectively. Average PO_4-P runoff concentrations from this study for all composting periods for the 1:1, 1:0.5 VFS buffers, and 1:0 (no buffer) control (Figure 7) were 5.0, 6.0, and 3.0 mg L^{-1}, respectively.

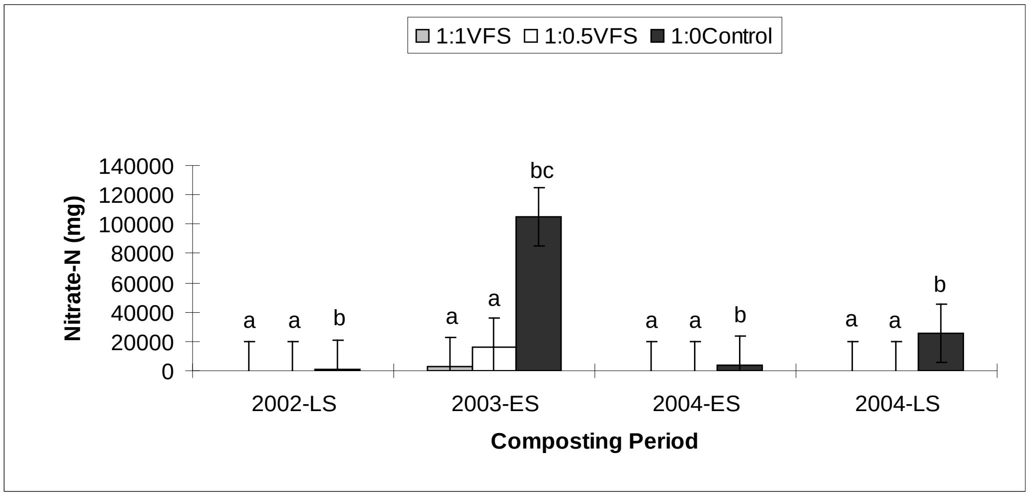

Figure 4. Effects of windrow composting practice and vegetative filter strip (VFS) buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting area: VFS buffer area ratios) on average Nitrate-Nitrogen (NO_3-N) surface runoff losses (mg) for 2002 through 2004 early season (ES) and late season (LS) composting period rainfall events. Significant treatment differences ($p \leq 0.05$) within and among composting periods are indicated by different letters b and c, respectively. Error bars represent one standard deviation.

Figure 7 also shows the 2004-LS composting period PO_4-P average concentration for the 1:0 control plots was significantly lower ($p \leq 0.05$) than the 1:1 and 1:0.5 VFS buffer average concentrations. Given the potential fly ash P-reduction effect remains equal for all runoff plot treatments, this may suggest the VFS buffer vegetation could be contributing PO_4-P to runoff. Haan et al. (2007) reported that cattle grazing (i.e., vegetation removal) stimulates new shoot and root growth, and non-grazed pastures (similar to VFS buffers) can gradually lose their capacity to sequester sediment and nutrients. Steinke et al. (2007) found TP losses were similar for both prairie and turfgrass VFS buffer species in a study assessing runoff quality and quantity. They also suggested the natural nutrient biogeochemical cycling can result in nutrient loss to surface waters regardless of vegetation type or size in VFS buffers. Although runoff dilution from rainfall and different compost manure and raw materials could affect PO_4-P concentrations and total mass losses, current research findings suggest the fly ash composting pad material can affect P levels in runoff. Consequently, a mass balance analysis was used in determining the difference in mass total losses of NO_3-N, PO_4-P, and TP in the compost windrows for comparison to nutrient losses in surface runoff.

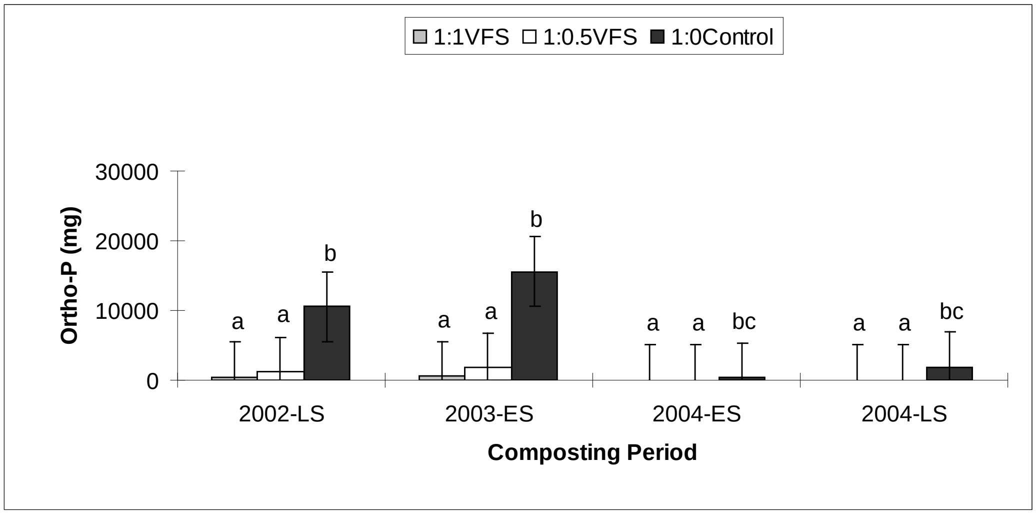

Figure 5. Effects of windrow composting practice and vegetative filter strip (VFS) buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting area: VFS buffer area ratios) on average Ortho-Phosphorus (PO_4-P) surface runoff losses (mg) for 2002 through 2004 early season (ES) and late season (LS) composting period rainfall events. Significant treatment differences ($p \leq 0.05$) within and among composting periods are indicated by different letters b and c, respectively. Error bars represent one standard deviation.

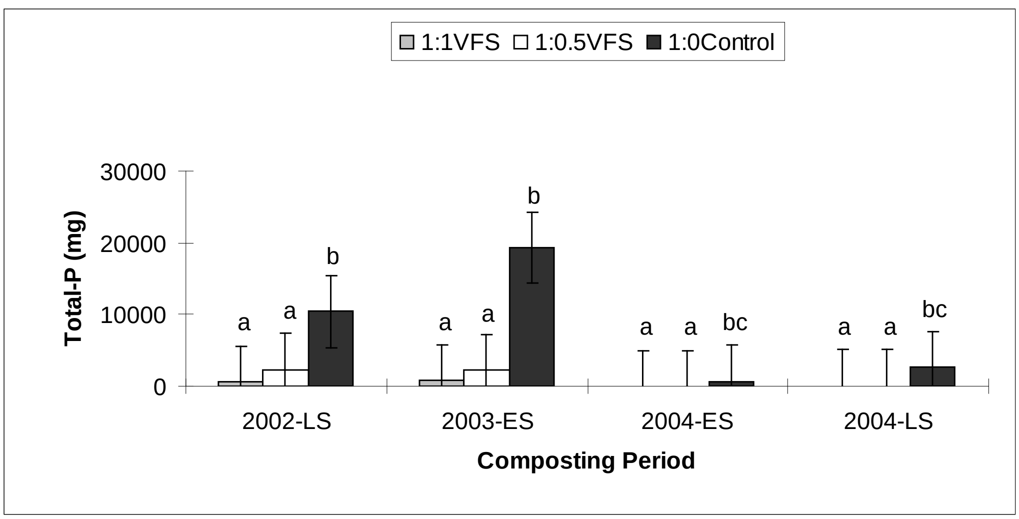

Figure 6. Effects of windrow composting practice and vegetative filter strip (VFS) buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting pad area: VFS buffer area ratios) on average Total-Phosphorus (TP) surface runoff losses (mg) for 2002 through 2004 early season (ES) and late season (LS) composting period rainfall events. Significant treatment differences ($p \leq 0.05$) within and among composting periods are indicated by different letters b and c, respectively. Error bars represent one standard deviation.

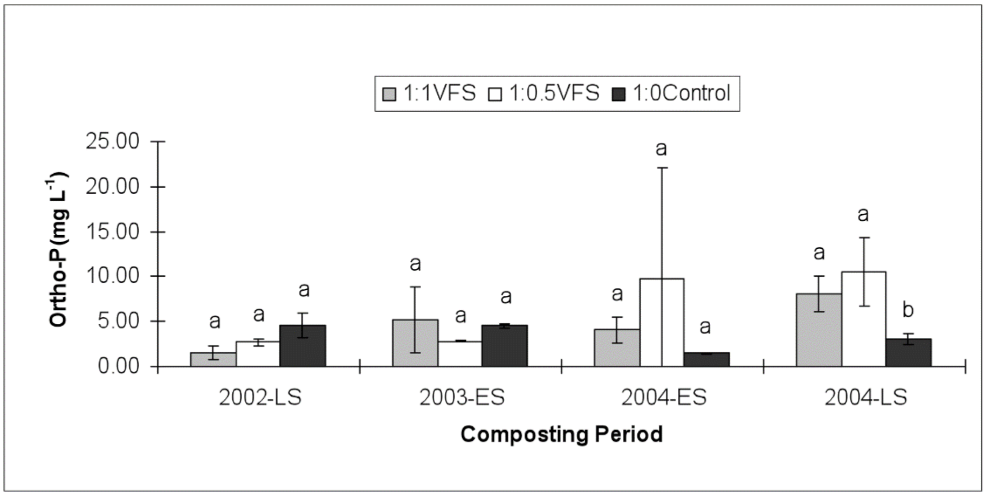

Figure 7. Effects of windrow composting practice and vegetative filter strip (VFS) buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting pad area: VFS buffer area ratios) on average Ortho-Phosphorus (PO_4-P) surface runoff concentrations (mg L^{-1}) for 2002 through 2004 early season (ES) and late season (LS) composting period rainfall events. Significant treatment differences ($p \leq 0.05$) within composting periods are indicated by a different letter b. Error bars represent one standard deviation.

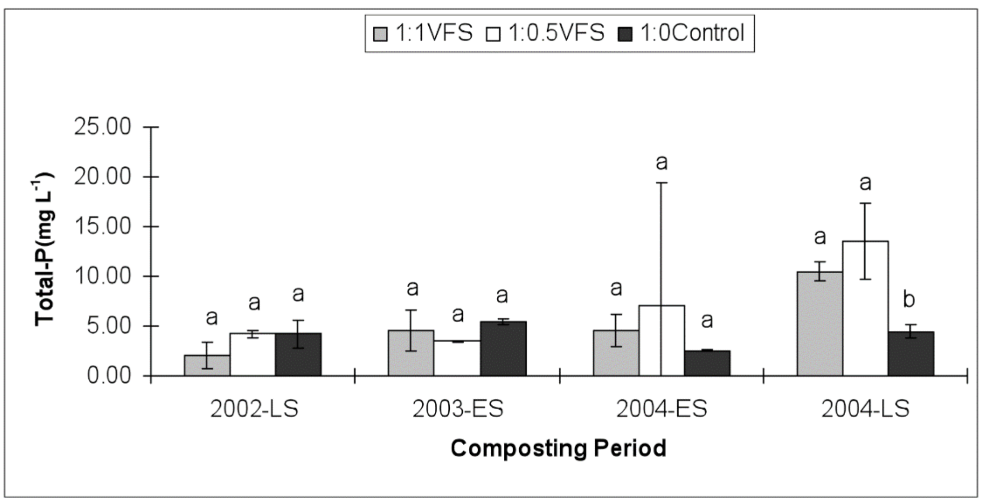

Figure 8. Effects of windrow composting practice and vegetative filter strip (VFS) buffer treatments (1:1, 1:0.5, and 1:0 [no buffer] control composting pad area: VFS buffer area ratios) on average Total-Phosphorus (TP) surface runoff concentrations (mg L^{-1}) for 2002 through 2004 early season (ES) and late season (LS) composting period rainfall events. Significant treatment differences ($p \leq 0.05$) within composting periods are indicated by a different letter b. Error bars represent one standard deviation.

Comparison of Compost and Runoff Nutrient Losses

Nutrient (NO_3-N, PO_4-P, and TP) mass balance calculations were conducted using windrow compost (Ahn et al. Unpublished manuscript) and were compared to surface runoff nutrient losses from the three 1:0 (no buffer) control plots at the Iowa State University windrow composting/VFS buffer research site used in this study. The 1:0 control plots were used exclusively in this analysis to limit the effects of rainfall infiltration and runoff to the compost windrows and fly ash composting pad plot areas. Differences of NO_3-N, PO_4-P, and TP content based on compost nutrient mass balance and runoff analysis calculations are shown in Table 4.

Table 4. Differences of nutrient content based on compost and runoff mass balance calculations for the windrow composting/vegetative filter strip (VFS) buffer site 1:0 drainage area: VFS buffer area ratio (no buffer control) plots for early season (ES) and late season (LS) composting periods from 2002 through 2004

1:0 Area Ratio		2002-LS	2003-ES	2004-ES	2004-LS
Compost	Dry matter (kg)	407	445	291	220
	TP (kg)	1.5	12.5	1.7	-
	NO_3-N (kg)	-	-	-0.19	-0.29
	PO_4-P (kg)	-	-	0.45 (41%)	0.44 (26%)
Runoff	Dry matter (kg)	6.4	11.7	0.7	1.4
	TP (g)	10.4	19.3	0.7	2.7
	NO_3-N (g)	0.6	104.7	2.3	254.4
	PO_4-P (g)	10.5	15.6	0.4 (0.1%)*	1.8 (0.4%)*

* Runoff fraction of total PO_4-P loss.

The pathway of N losses from the composting piles was probably through emissions of ammonia (NH_3) and, to a lesser degree, through nitrous oxide species (NOx) emissions. Generally, NH_3 production increases during the early stage of the composting period, and then is biologically transformed into NO_3-N/NO_2-N via nitrification. Due to this biochemical conversion, a NO_3-N concentration increase was observed in this study. This variability of NO_3-N concentrations also parallels the findings of Seymour and Bourdon (2003).

Levels of TP did not significantly change ($p \leq 0.05$) during the composting process since it is a non-volatile nutrient and is not lost to the atmosphere. Generally, TP can leach out of the compost windrows with runoff, and the composting process does not significantly affect TP levels. A compost PO_4-P reduction of 41% and 26% occurred during the 2004 ES and LS composting periods, respectively. These results compare to the runoff fraction PO_4-P losses of 0.1% and 0.4% during the respective 2004 ES and LS composting periods (Table 2). These mass balance and runoff nutrient analysis results indicate PO_4-P was removed from the runoff stream in a higher proportion than some similar studies (Seymour and Bourdon 2003). Results from this study indicate the PO_4-P in runoff from the compost windrows was absorbed or converted to more stable P compounds by the fly ash composting pad material.

CONCLUSION

Studies have shown that windrow composting can reduce potentially hazardous environmental effects of livestock manure that has been used as a land-applied fertilizer supplement. This is partially accomplished through the conversion of mineral-N to more stable organic-N species during the composting process. However, other research efforts have reported significant nutrient losses during composting, resulting in leaching, runoff, and volatilization. To minimize surface runoff sediment and nutrient losses, several researchers have suggested the use of VFS buffers and P-sorbent pad surface materials that can be applied to a range of agricultural settings that include livestock feedlots and windrow composting sites.

Results from this study indicate significantly higher levels ($p \leq 0.05$) of Runoff, Runoff%, TS, NO_3-N, PO_4-P, and TP from the 1:0 (no buffer) control plots occurred compared to the 1:1 and 1:0.5 VFS buffer plots. Results also show the 1:1 and 1:0.5 VFS buffer treatments were not significantly different ($p \leq 0.05$) and average runoff loss reductions from the 1:1 and 1:0.5 plots were 98% and 93%, respectively, compared to the 1:0 control plots. While these results reflect an overall effectiveness of VFS buffers for reducing runoff and contaminant losses from a windrow composting site, the statistical insignificance of the 1:1 and 1:0.5 VFS buffer treatment runoff data also indicates equal VFS buffer treatment efficiency. The smaller 1:0.5 VFS buffer area may provide some flexibility for producers with greater limitations on land area removal from production or other land use requirements.

Compost nutrient mass balance analysis results indicate 41% and 26% of PO_4-P were lost from the compost windrows during the 2004 ES and LS composting periods, respectively. However, only 0.1% and 0.4% of PO_4-P were lost to runoff from the 1:0 control plots during the respective 2004 ES and LS composting periods. These results and other recent findings indicate the relatively lower PO_4-P losses in runoff are attributed to the chemical and physical absorption and conversion effects of the fly ash composting pad surface material.

The development and implementation of more environmentally responsible strategies that reclaim or recycle certain waste materials for natural resource protection are high-priority political and social interests. Several studies to date have evaluated the runoff water quality-improving benefits of VFS buffers and the P-reduction effects of fly ash and other P-sorbent materials. Consequently, future research efforts should include comparisons of VFS buffers and fly ash to other potential P-sorbent composting pad surface materials to more thoroughly evaluate the efficacy of this pad surface material systems approach to applying VFS buffer areas and an industrial by-product for reducing offsite runoff and contaminant transport from windrow composting facilities.

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