

Nutrient loads and sediment losses in sprinkler irrigation runoff affected by compost and manure

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Abstract: High water application rates beneath the outer spans of center pivot sprinkler systems can cause runoff, erosion, and nutrient losses, particularly from sloping fields. This field study determined runoff, sediment losses, and nutrient loads (dissolved organic carbon [C], nitrate-nitrogen [NO₃-N], ammonium-nitrogen [NH₄-N], total phosphorus [TP], ferric-oxide strip phosphorus [FeO P], dissolved reactive phosphorus [DRP], potassium [K], calcium [Ca], magnesium [Mg], and sodium [Na]) in sprinkler runoff for two years after a single application of either stockpiled or composted dairy manure. We studied five treatments, including a nonamended control, in each of six blocks, with each block situated under a different span of a low-pressure, moving-lateral sprinkler system. In October of 1999, we incorporated 29.1 Mg ha⁻¹ (13 tn ac⁻¹) or 71.7 Mg ha⁻¹ (32 tn ac⁻¹) of dry manure or 22.4 Mg ha⁻¹ (10 tn ac⁻¹) or 47 Mg ha⁻¹ (21 tn ac⁻¹) of dry compost into a calcareous silt loam soil on slopes from 0.8% to 4.4%. In the spring of 2000 and 2001, we collected surface soil (0 to 30 mm [0 to 1.2 in]) from furrows to determine soil test phosphorus (STP). We applied 21 to 46 mm (0.8 to 1.8 in) of water at an average application intensity of 28 mm h⁻¹ (1.1 in hr⁻¹; peak intensity of 40 mm h⁻¹ [1.6 in hr⁻¹]) to 6.4 × 36.6 m (21 × 120 ft) plots six times in 2000 and two times in 2001. Additional nonmonitored irrigations were made as needed to produce corn (*Zea mays* L.) silage each year. At 15 to 30 minute intervals after runoff began, we measured runoff rates and collected runoff samples to determine sediment and constituent losses for each monitored irrigation. None of the amendment treatments significantly affected runoff, sediment losses, or loads of dissolved organic C, NO₃-N, NH₄-N, TP, FeO P, or Mg when averaged across irrigations. Without exception, runoff, sediment losses, and loads of every measured constituent varied among irrigations after accounting for differences in water applied. Treatments influenced DRP, K, and Ca runoff loads. Loads of Ca decreased, but Na increased with increasing manure application rates. Relative to the control, manure DRP loads were five to six times greater, whereas compost DRP loads were similar.

Key words: center pivot—erosion—infiltration—nutrient losses—runoff—sprinkler irrigation

Sprinkler irrigation predominantly with center pivots is a common and rapidly expanding practice in the irrigated West.

In 2008, nearly three-fourths of the irrigated land in the Pacific Northwest was irrigated with sprinklers (NASS 2010). More than 97% of the potato (*Solanum tuberosum* L.) growers in Idaho use sprinklers to irrigate their crops (Pehrson et al. 2010). Irrigation with moving-lateral systems, including center pivots, is growing worldwide. Moving-lateral systems are commonly replacing surface irrigation systems in the irrigated western United States. In more humid areas of the United

States and the world, moving-lateral systems are being installed and used to supplement rainfall at critical crop growth stages or during times of drought (Frank 2001).

As sprinkler-irrigated land area increases, concern arises over the transport of nutrients in runoff—particularly from beneath pivot outer spans—to nearby water courses (Alva et al. 2005; Lentz and Lehrs 2010; Wilcock et al. 2011). Nitrogen (N) and P are important constituents of sediment and organic matter transported offsite in irrigation runoff (Heathwaite and Johnes 1996). As such, the N and P cause or accentuate eutrophication

of surface waters (Correll 1998). One must recognize, however, that from undulating surfaces common under moving-lateral irrigation systems nutrient-containing runoff from some areas may directly enter surface water bodies while runoff from other areas may not (Kleinman et al. 2011).

The P fractions in surface water are of greatest concern, at present. The dissolved reactive phosphorus (DRP) form is the P fraction soluble in water while ferric-oxide strip phosphorus (FeO P) can indicate the P fraction that is available to algae and has been referred to as bioavailable P (Sharpley 1993). Ultimately, both DRP and FeO P degrade surface water quality. Since total P loads and flow-weighted total phosphorus (TP) concentrations in runoff under both furrow and sprinkler irrigation are highly correlated with sediment in runoff (Aase et al. 2001; Westermann et al. 2001; Turner et al. 2004), erosion control is essential to minimize P loss (Kleinman et al. 2011). While sediment loss was the primary determinant of TP loss, runoff volume affected the loss of DRP and bioavailable P in the studies of Eghball and Gilley (2001) and Eghball et al. (2002). Tillage to incorporate P fertilizer deeper into soil profiles can decrease DRP losses but increase TP losses in the sediment transported offsite in runoff (Bundy et al. 2001; Kimmell et al. 2001).

Constituent concentrations, particularly P, differ markedly in the runoff from sprinklers compared to furrows. Studying the same soil as the current investigation, Turner et al. (2004) measured greater DRP concentrations in sprinkler runoff than Westermann et al. (2001) did in furrow runoff. Turner et al. (2004) attributed the differences to the limited interaction between surface soil and the water applied via furrows compared to the extensive mixing of surface soil with the higher kinetic energy water applied by sprinklers or simulated rainfall that likely lead, in turn, to increased DRP concentrations in sprinkler rather than furrow runoff.

For many producers, composting is an attractive option for handling livestock manure. Composting of dairy manure kills

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weed seeds, reduces weight and volume, increases product uniformity, and facilitates field application (Sweeten 2000; Richard 2005). Composting of dairy manure decreases the manure's carbon (C) to N (C:N) ratio and concentrations of ammonium-nitrogen ($\text{NH}_4\text{-N}$) and total C while increasing the electrical conductivity (EC) and concentrations of nitrate-nitrogen ($\text{NO}_3\text{-N}$), FeO P (bio-available P), and TP, in general (Eghball et al. 1997; Larney et al. 2006). Composted dairy manure is often available for application to land used to produce high-value crops in irrigated areas (Sweeten 2000; Lehrs and Kincaid 2007).

A greater understanding of manure and compost effects on the quality of sprinkler irrigation runoff from treated areas is increasingly important because of the expanding moving-lateral-irrigated land area. Only a few studies have compared the runoff quality from soils treated with manure and composted manure (hereafter simply termed compost) (Eghball and Gilley 1999; Qu et al. 1999; Miller et al. 2006). Eghball and Gilley (1999) found no or little effects of compost or manure on concentrations of DRP or FeO P in runoff. Concentrations of TP and $\text{NO}_3\text{-N}$ in runoff tended to be higher, but $\text{NH}_4\text{-N}$ in runoff tended to be lower under compost than manure. Qu et al. (1999), who found in a soil-less study that soluble C and total N were greater in snowmelt runoff from manure than compost, concluded that of the two, compost posed a lesser threat to surface water quality. Protecting surface water quality is difficult where manure is applied to runoff-prone soils, even after the manure is tilled into the soil (Kleinman et al. 2009). The greatest nutrient losses in rainfall runoff from manure-amended fields commonly occur with the first runoff event (Pote et al. 2003). Miller et al. (2006) reported TP, DRP, and $\text{NH}_4\text{-N}$ losses in runoff from simulated rainfall applied in the spring to plots that received either fresh manure or composted beef manure the preceding fall. They found greater TP, DRP, and $\text{NH}_4\text{-N}$ concentrations and greater DRP loads in runoff from manure rather than compost plots after amendments were applied for two consecutive years. By delaying irrigation until the spring, one can greatly reduce sediment and nutrient losses in surface irrigation runoff from fields that received manure the preceding fall (Lentz and Westermann 2010).

Potassium (K) in runoff is of little environmental concern except when the K is associated with certain anions that increase the salt loading to receiving water bodies. From a grower's viewpoint, regardless of its source, K transported in runoff from cultivated soil decreases K use efficiency and is an economic loss (Lentz and Lehrs 2010). In some irrigated regions, though, increased K loads in runoff may benefit other growers who use upstream runoff as furrow irrigation inflow (Moore et al. 2011). Potassium supplied with irrigation water may help replace the estimated 50% of the native K lost from agricultural soils in the inland Pacific Northwest during the last half century (Westermann and Tindall 1997).

Despite the studies conducted thus far, research needs still exist. Published studies of runoff and sediment losses from large plots under moving-lateral irrigation systems are scarce in the literature (Undersander et al. 1985). Studies of nutrient losses (loads) in runoff from such systems, let alone from fields amended with compost or manure, have seldom been reported. Studies that document amendment effects on multiple, rather than lone, constituents in runoff are also needed (Maguire et al. 2011). Much research has focused upon manure application rate and method effects on N or P transport in simulated rainfall runoff (usually from $\leq 2 \text{ m}^2$ [$\leq 43 \text{ ft}^2$] plots) that occur within a few days or weeks after application. Little research, in contrast, has studied changes in nutrient losses through longer time periods. Measuring runoff volumes and nutrient losses repeatedly through one or more growing seasons is needed (1) to adequately characterize constituent losses from manure or compost applications to agricultural areas across multiple time scales (Eghball et al. 2002; Miller et al. 2006; Macrae et al. 2010); and (2) to document the effects of progressive seal and crust development in tilled soil (Neave and Rayburg 2007).

Corn (*Zea mays* L.) silage yields and N uptake from the current study have been reported earlier (Lehrs and Kincaid 2007). Yields in 2000 were similar among all rates of both amendments and the control. In 2001, yields increased with compost applications and increased then decreased with increasing manure applications. Corn took up 15% more N on average from amended plots than the control.

In view of the identified research needs, our hypothesis was that organic amendments would affect nutrient loads in runoff under moving-lateral irrigation. Our objective, then, was to determine runoff, sediment losses, and nutrient loads in runoff from a lateral-move irrigation system for two years as affected by one-time applications of compost or manure. We studied relatively large applications that might supply nutrients for multiple years. This study was designed to answer a number of questions: do one-time fall applications of compost or manure affect runoff, sediment losses, or the loads of chemical constituents in sprinkler irrigation runoff when measured repeatedly throughout two growing seasons? Do loads vary from one irrigation to another, after accounting for differences in water applied? Are constituent losses related to compost or manure application rates?

Materials and Methods

Site and Amendments. The experiment was conducted for two years on a poorly structured Portneuf silt loam, a coarse silty, mixed, superactive, mesic Durinodic Xeric Haplocalcid, located at 42°30'58" N, 114°22'40" W at an elevation of 1,186 m (3,891 ft), about 2.1 km (1.3 mi) southwest of Kimberly, Idaho. The Portneuf developed in loess, contained mostly illite in its clay fraction, and like many western soils, was unstable (Lehrs and Kincaid 2001). The soil's Ap horizon (0 to 0.3 m [0 to 1 ft]) contained 580 g silt kg^{-1} (58% silt), 230 g clay kg^{-1} (23% clay), and 9.4 g organic C kg^{-1} (0.94% organic C). Its pH (saturated paste) was 7.9, EC was 1.4 dS m^{-1} , and calcium carbonate (CaCO_3) equivalent 80 g kg^{-1} .

Dairy feedlots were the source of both our stockpiled and composted manure (table 1). The TP, K, calcium (Ca), magnesium (Mg), and sodium (Na) concentrations were determined by ashing the amendments followed by an acid digest (Wolf et al. 2003). Briefly, amendments were ashed at 500°C (932°F) for 4 hours, and the ash was dissolved in 10 mL of 1 Normal HNO_3 (0.34 oz of 1 Normal HNO_3), heated to 100°C (212°F) for 600 seconds, then diluted with deionized water to 50 mL (1.7 oz). The digest was filtered through a Whatman #50 filter before being analyzed via inductively coupled plasma optical emission spectroscopy (ICP-OES) using an Optima Model 4300 DV spectrometer (Perkin Elmer Instruments, Waltham, Massachusetts).

Table 1
Compost and manure properties and total element concentrations after Lehrsch and Kincaid (2007). All measurements are on a dry-weight basis.

Amendment property	Compost	Manure
Dry matter content (kg kg ⁻¹)	0.71	0.53
pH	9.3	8.6
Carbon (C, g kg ⁻¹)	111	289
Nitrogen (N, g kg ⁻¹)	11.7	21.2
Nitrate-nitrogen (NO ₃ -N, mg kg ⁻¹)	940	120
Ammonium-nitrogen (NH ₄ -N, mg kg ⁻¹)	85	326
Phosphorous (P, g kg ⁻¹)	6.1	7.7
Potassium (K, g kg ⁻¹)	18.8	24.1
Calcium (Ca, g kg ⁻¹)	21.3	22.0
Magnesium (Mg, g kg ⁻¹)	7.4	9.4
Sodium (Na, g kg ⁻¹)	5.8	6.7
Electrical conductivity (EC, dS m ⁻¹)	10.3	11.5
C:N ratio	9.5	13.6
C:P ratio	18.2	37.6
N:P ratio	1.9	2.8

Experimental Design and Treatments.

The experimental design was a randomized complete block with five treatments replicated in six blocks. Each of four amendment treatments and two controls was randomly assigned to one of six, 6.4 m (21 ft) wide by 36.6 m (120 ft) long plots in each block. Results from the two controls in each block were arithmetically averaged prior to statistical analyses. Plots in each block were arranged under one of six spans of a traveling lateral sprinkler system. Blocks were laid out in the field to account for known variation in slope. The long axis of each experimental plot was oriented perpendicular to the irrigation lateral and sloped to the south. In general, plot slopes gradually increased from 0.8% in span 1 of the irrigation lateral to 4.4% in span 5, then decreased to 2.7% in span 6.

Compost and manure were applied at low and high rates (table 2) representative of regional production practices (Brady and Weil 2002; Miller et al. 2006). A consequence of the rates chosen was that neither the low rates nor the high rates of compost and manure applied similar amounts of total P, total N, or available N (table 2). Thus, when treatment effects were significant, we compared each treatment at each rate to the control.

Field Operations. The compost and manure applications and subsequent crop production aspects of the overall investigation were described in Lehrsch and Kincaid (2007). In brief, we used a truck equipped as a manure spreader to apply air-dried compost and stockpiled manure once at the study's initiation. On October 14, 1999, compost was applied at a moisture-free rate of 22.4 or 47 Mg ha⁻¹ (10 or 21 tn ac⁻¹) and manure was

applied at a moisture-free rate of 29.1 or 71.7 Mg ha⁻¹ (13 or 32 tn ac⁻¹). The next day, we used our sprinkler system to apply 23 mm (0.9 in) of water to all plots. A few days later, the amendments were incorporated by disking the entire area three times to a depth of 0.15 m (6 in). From the day the amendments were applied in fall of 1999 until the day that runoff was first collected the following season, all plots at the site received a total of 225 mm (8.85 in) of water, 27% of which was irrigation and the remainder precipitation.

In the spring of each year, soil samples were collected to a depth of 0.3 m (1 ft) from control plots, then the site was tilled twice with an offset disk to a depth of 0.15 m (6 in). Based upon soil tests on the collected samples and a yield goal of 50 Mg corn silage ha⁻¹ (22.3 tn corn silage ac⁻¹) (Brown et al. 2010), on May 4, 2000, and April 25, 2001, all needed fertilizer was broadcast equally to all plots, then incorporated by roller-harrowing to 0.06 m (2.4 in). We applied 202 kg N ha⁻¹ (180 lb N ac⁻¹; as urea [CH₄N₂O], 0.46 kg N kg⁻¹ [46% N]), 39 kg P ha⁻¹ (35 lb P ac⁻¹; as triple superphosphate), and 139 kg K ha⁻¹ (124 lb K ac⁻¹; as potassium chloride [KCl]) in 2000, and 224 kg N ha⁻¹ (200 lb N ac⁻¹; as urea [CH₄N₂O]) and 98 kg P ha⁻¹ (88 lb P ac⁻¹; as triple superphosphate) in 2001. Pioneer 3751 corn was planted to a nominal plant population of 68,900 plants ha⁻¹ (27,880 plants ac⁻¹) on May 12, 2000, and May 9, 2001, into 0.76 m (30 in) rows oriented down the field slope and perpendicular to the irrigation system lateral. At planting, we formed 75 mm (2.9 in) deep, triangular-shaped furrows between all corn rows, leaving low, flat-topped beds on each plot. This furrowing operation and subsequent cultivation produced eight furrows, one every 0.76 m across each 6.4 m (21 ft) wide plot that directed runoff downslope. Corn was harvested for silage in late September. In both 2000 and 2001, we employed standard fertilization and cultural practices to produce silage and control insects and weeds (Brown et al. 2010).

All plots were irrigated using a 247 m (810 ft), six-span moving lateral sprinkler system equipped with low-pressure spray heads that had rotating, six-groove deflector plates and 138 kPa pressure regulators. The sprinklers were mounted 2.4 m (8 ft) above the soil surface and 3.05 m (10 ft) apart. Spray pattern width was about 16 m (52.5 ft) resulting in an average application rate of about 28 mm

Table 2
Treatment descriptions and amendment application rates along with the total phosphorus (P), total nitrogen (N), and available N added by each in the first year.

Treatment identification	Amendment	Application rate (dry material) (Mg ha ⁻¹)	Nutrients added (kg ha ⁻¹)		
			Total P	Total N	Available N
Control	None	0	0	0	0
Compost 1	Compost	22.4	137	262	-11
Compost 2	Compost	47.0	287	550	-24
Manure 1	Manure	29.1	224	617	107
Manure 2	Manure	71.7	552	1,520	264

Notes: The available N was an estimate calculated assuming first-year mineralization of -43 g N (kg total N)⁻¹ from compost (i.e., inorganic N was immobilized) and 174 g N (kg total N)⁻¹ from manure (Lentz et al. 2011).

Table 3

Water applied (in gross) to each span at each monitored irrigation. Irrigation dates are followed by day of year in parentheses.

Span	Water applied (mm)							
	June 22, 2000 (174)	June 29, 2000 (181)	July 12, 2000 (194)	July 18, 2000 (200)	August 22, 2000 (235)	August 30 to 31, 2000 (243 to 244)	July 19 to 20, 2001 (200 to 201)	August 22, 2001 (234)
1	30	—	—	—	—	32	32	32
2	31	—	—	—	—	32	32	32
3	31	40	45	41	31	29	29	32
4	29	41	46	42	32	29	29	29
5	30	39	40	35	30	21	21	30
6	30	40	39	35	30	21	21	30

h^{-1} (1.1 in hr^{-1}) (Kincaid 2005). The system's peak rate, defined as the average rate where sprinkler patterns overlapped along the lateral, was 40 mm h^{-1} (1.57 in hr^{-1}). Automatic valves controlled the flow to each span. The lateral's discharge rate was $7.45 \text{ L (min m)}^{-1}$ ($0.6 \text{ gal [min ft]}^{-1}$), which was representative of middle spans of a typical center pivot lateral in southern Idaho. Corn was irrigated to replace calculated evapotranspiration on average, two to three times per week, with all spans receiving the same gross water application, except on test days when runoff was measured. In total, we applied about 480 mm (18.9 in) of water in 2000 and 530 mm (20.8 in) in 2001. The irrigation water, withdrawn from the Snake River, commonly has a pH of 7.6, an EC of 0.5 dS m^{-1} , and an Na adsorption ratio of 0.65. For most irrigations each year, the lateral traveled uphill applying less gross water, in general, than on test days; we did not measure runoff.

Field and Laboratory Measurements. We measured STP within six days of the first monitored irrigation each year. On June 21, 2000, and July 25, 2001, we collected composite surface soil samples to a depth of 30 mm (1.1 in) from furrows in each plot. Samples were air-dried and then ground. Soil test P was measured using the procedure of Olsen et al. (1954).

Runoff was measured from six monitored irrigations in 2000 and two in 2001 (table 3). We measured runoff from all 36 plots for the first and last irrigation each year. For all other monitored irrigations, we did not measure runoff from plots under spans 1 and 2, which had the least slopes. On most test days, only two or three spans were irrigated simultaneously. Prior to each run, the target gross application (as a function of lateral travel speed) was chosen sufficient to produce runoff from most plots. Since the plots under spans 5 and 6 tended to produce the most

runoff, we often applied less water to those plots on test days (table 3). In general, no constituents other than sediment were measured in runoff from July 12 or August 30 to 31, 2000, irrigations. Soil water contents to 0.15 m (6 in) were measured one to three days before each monitored irrigation using neutron thermalization in 2000 (Hignett and Evett 2002) and gravimetric sampling in 2001. In 2000, water contents sensed at the 150 mm (6 in) depth were assumed to be representative of the soil water content in the 0 to 150 mm depth increment.

Runoff from each plot's center four furrows (two wheel track and two nonwheel track) was routed through a single, small trapezoidal flume (Trout 1992). Flow rate was manually recorded beginning 5 minutes after each plot's runoff began, and at about 15 to 30-minute intervals thereafter. We collected three runoff samples: two 55 mL (1.9 oz) samples for chemical analyses and one 1,000 mL (0.3 gal) sample for determining the runoff's sediment concentration in the field using the Imhoff cone technique (Sojka et al. 1992) from each flume's outflow whenever flow rates were recorded. All runoff samples contained both suspended and bedload sediment being transported in overland flow. One 55 mL sample was unfiltered. The remaining 55 mL sample was filtered through a $0.45 \mu\text{m}$ cellulose-nitrate ($\text{C}_6\text{H}_9[\text{NO}_2]\text{O}_5$) membrane (Millipore Corp., Billerica, Massachusetts) in the field within 15 minutes of collection, then stabilized with 0.5 mL (0.02 oz) of a saturated boric acid (H_3BO_3) solution, and stored at 4°C (39.2°F) until analyzed. Filtration in the field shortly after collection was necessary because DRP (i.e., orthophosphate-P) desorbs quickly and continually from any suspended sediment in the sample (Jarvie et al. 2002).

In the laboratory in each unfiltered 55 mL (1.9 oz) sample, we determined TP

in a persulfate digest (Method 4500-P B) (Greenberg et al. 1992) and FeO-P using a FeO-impregnated filter paper strip (Sharpley 1993) to provide a measure of biologically available P. In the filtered sample, we measured DRP. All P concentrations were determined using the ascorbic acid method described by Watanabe and Olsen (1965). Also in the filtered sample, we measured dissolved organic C (DOC) using a Shimadzu TOC-5050A total organic C analyzer (Shimadzu Scientific Instruments, Columbia, Maryland) and colorimetrically with an automated flow injection analyzer, $\text{NO}_3\text{-N}$ after cadmium reduction of a KCl extract (Method 12-107-04-1-B, Lachat Instruments, Loveland, Colorado), and $\text{NH}_4\text{-N}$ using a salicylate-hypochlorite method (Method 12-107-06-2-A). Soluble K, Ca, Mg, and Na in the filtered sample were quantified with ICP-OES.

Calculations and Statistical Analysis. The flume outflow data were integrated with time to calculate runoff volume for each irrigation, subsequently expressed as percent of gross water applied. Sediment and nutrient concentrations in runoff were adjusted for constituent concentrations in the irrigation water inflow. Thus, runoff constituent concentrations reflect only changes resulting from the treatments themselves. All runoff constituent concentrations and corresponding flume flow rates were integrated with time using the computer program WASHOUT (Lentz and Sojka 1995; Lentz and Westermann 2010) to report loads as constituent mass per unit area per unit gross water applied, thus normalizing the measured nutrient loads by the irrigation water applied.

We first examined each response variable's error variance by treatment using the relationship between the variable's treatment means and corresponding treatment standard deviations (Box et al. 1978; Lehrsch and Sojka 2011). Where necessary we used an appropriate transformation, often log-

arithmetic though at times reciprocal square root, to stabilize the variable's error variance prior to performing an analysis of variance (ANOVA). We used the PROC Mixed procedure in SAS (SAS Institute Inc. 2009) to perform a repeated-measures ANOVA using mixed-model procedures and a significance probability (p) of 5%, unless otherwise noted. The repeated measures factor was irrigation, modeled using an autoregressive approach with lag of one. The repeated measures factor properly accounted for a response variable's time dependency (if any) from one irrigation to another. In the ANOVA model, random factors were block and treatment by block. As needed, ANOVA grouping options were used to account for heterogeneous variances among treatments in the response variables. For fixed effects found significant, least-squares means were separated from the control using Dunnett's test at $p = 0.05$. As needed, means were back-transformed into original units for presentation. In addition, contrast statements were used in each nutrient's ANOVA to test for compost or manure rate effects on loads. When significant, we used regression to quantify the linear or quadratic responses averaged across irrigations. We also determined the correlation between selected constituent loads in runoff by calculating Kendall's correlation coefficient, r_k , where $-1 \leq r_k \leq +1$ (SAS Institute Inc. 2009). To do so, the raw (untransformed) data were used since r_k is a nonparametric measure of association.

Results and Discussion

The compost and manure we studied (table 1) generally represented that common in the area (Lehrsch and Kincaid 2007). Relative to total N, plant-available N (or mineral N = $\text{NO}_3\text{-N} + \text{NH}_4\text{-N}$) was 8.8% in the compost and 2.1% in the manure. As is typical, the compost contained more $\text{NO}_3\text{-N}$ and less $\text{NH}_4\text{-N}$ than the manure. Relative to compost, manure contained nearly twice as much organic N per unit weight. Manure also contained more total N, P, K, and organic C than compost on a dry-weight basis. The manure's dry matter content (0.53 kg kg^{-1} [53% w w⁻¹]) was indicative of that of stockpiled, rather than freshly scraped manure.

Compared to the control, soil test P concentrations for each of two consecutive years were greater where amendments were applied, as expected (table 4). Unexpected, however, was the finding that STP concentrations were similar in magnitude among

all amendment-supplied total P rates ranging from 137 to 287 kg P ha⁻¹ (33 to 256 lb P ac⁻¹) (table 2). Every treatment's STP concentration decreased from 2000 to 2001, indicating (1) likely precipitation of P as some relatively insoluble, low molecular-weight calcium phosphate compound (Turner et al. 2004), and (2) uptake by the corn silage grown in 2000 and in 2001. The STP concentrations, even of the controls, were relatively high (ISDA 2012), suggesting that P in runoff might impact surface water quality if no precautions were taken.

Treatments influenced neither sprinkler runoff nor its associated sediment loads (table 5). The ANOVA did reveal, however, treatment effects on runoff loads of DRP, K, and Ca; irrigation effects on each of the runoff constituents; and a treatment by irrigation interaction effect on runoff K loads. Analysis also revealed significant trends (linear, quadratic, or both) in the responses of DRP, K, Ca, and Na to increasing rates of manure or, less frequently, compost.

Antecedent water contents (not shown) were statistically similar among treatments for each irrigation and for all irrigations. While the water contents varied statistically among irrigations, the variation practically was slight. Averaged across treatments, the mean water content for all irrigations was $0.2 \text{ m}^3 \text{ m}^{-3}$ (20% v v⁻¹) with a standard deviation of $0.02 \text{ m}^3 \text{ m}^{-3}$ (2% v v⁻¹). This variation likely accounted for a portion of the significant irrigation effects detected for all constituents (table 5).

The irrigation-to-irrigation variation in constituent loads is an important characteristic of these systems. Variation among irrigations in sediment losses, for example, underscores the need for multiple measurements throughout an irrigation season to adequately characterize season-long erosion responses to irrigation (Garcia et al. 2008; Verbree et al. 2010). At a larger scale, Macrae et al. (2010) also found that the export of DRP and $\text{NO}_3\text{-N}$ from an agricultural watershed varied greatly throughout a two-year study.

Some of our findings in table 5 are similar to those reported by others who studied simulated rainfall and, in one case, much smaller experimental plots—those with areas $\leq 2 \text{ m}^2$ ($\leq 43 \text{ ft}^2$). Gilley and Eghball (1998) reported that neither compost nor manure affected runoff or sediment losses when measured immediately after incorporating amendments by hand. Little et al. (2005) found that

Table 4

Treatment effects on soil test phosphorus (STP) measured for the first irrigation in 2000 and in 2001.

Treatment identification	STP (mg kg ⁻¹)	
	2000	2001
Control	36b	29b
Compost 1	97a	65a
Compost 2	105a	77a
Manure 1	109a	82a
Manure 2	200a	164a

Note: Within a column, a mean followed by the same letter as the control does not differ from the control at $p < 0.05$.

runoff measured within seven days of manure application and incorporation did not differ between manured and control plots. Thayer et al. (2012) reported that manure rates affected DRP loads.

Runoff and Sediment Loss. Runoff did not vary among treatments (table 6). King and Bjorneberg (2011) also studied runoff from the Portneuf silt loam, though at a 5% slope. In their study runoff averaged across irrigations ranged from ca. 8% to 24% of that applied for application depths from 15 to 25 mm (0.6 to 1 in) and from 3% to 8% for depths of 12.5 mm (0.5 in). The runoff we measured (3.6% to 6.2%) (table 6) for greater application depths (table 3) was less, likely because our field slopes were less (never exceeding 4.4%) and our plot lengths were greater. In addition, the peak application rates (where adjacent sprinkler's wetted areas overlapped) studied by King and Bjorneberg (2011) ranged from 57 to 207 mm h⁻¹ (2.24 to 8.15 in hr⁻¹), while our peak rate was only 40 mm h⁻¹ (1.57 in hr⁻¹). King and Bjorneberg (2011) also found—like we did—(table 5), much variability in runoff among irrigations. They found that runoff from the Portneuf silt loam often increased with successive irrigations, likely due to decreasing infiltration as a consequence of a continually developing surface seal on this poorly structured soil (Lehrsch and Kincaid 2001, 2006). That runoff did not vary with manure rates was also reported by Volf et al. (2007).

The equivalence in runoff among treatments was at least partially responsible for the observed lack of treatment effect on sediment loads (table 6). Treatments also had no influence on the stability of surface soil structure in 2000 or 2001 (data not shown). Thus, the compost or manure we applied only once in the fall did not help the Portneuf soil resist erosion caused by sprinkler drop-

Table 5
Treatment, irrigation, and contrast effects on runoff, sediment losses, and constituent loads in sprinkler irrigation runoff.

Source of variation	ANOVA P > F											
	Runoff	Sediment loss	Constituent loads in runoff									
			Dissolved organic carbon	Nitrate-nitrogen	Ammonium-nitrogen	Total phosphorous	Ferric oxide phosphorous	Dissolved reactive phosphorous	Potassium	Calcium	Magnesium	Sodium
Treatment	0.64	0.32	0.49	0.06	0.47	0.54	0.20	***	**	***	0.26	0.14
Irrigation	***	***	***	***	***	**	**	**	***	***	***	***
Treatment × irrigation	0.99	0.97	0.84	0.66	0.86	0.61	0.62	0.35	**	0.46	0.42	0.65
Contrasts												
Compost linear	0.78	0.79	0.34	0.12	0.16	0.31	0.71	0.23	*	***	0.16	0.92
Compost quad	0.51	0.78	0.68	0.53	0.81	0.91	0.61	0.09	*	0.86	0.18	0.47
Manure linear	0.24	0.20	0.11	0.17	0.46	0.80	0.12	***	***	***	0.18	*
Manure quad	0.37	0.08	0.99	0.87	0.47	0.27	0.19	*	0.05	0.95	0.54	0.32

Notes: Contrasts tested rate effects averaged across irrigations. Linear = linear trend in rates. Quad = quadratic trend in rates.
*p = 0.05 **p = 0.01 ***p = 0.001

Table 6
Treatment effects on runoff, sediment losses, and constituent loads in sprinkler irrigation runoff. All runoff and sediment loss means were averaged across eight irrigations and all remaining constituents were averaged across six irrigations. Interactions between treatments and irrigations were not significant at p > 0.35.

Treatment identification	Runoff (%)	Sediment loss (kg [ha mm] ⁻¹)	Constituent loads in runoff (g [ha mm] ⁻¹)								
			Dissolved organic carbon	Nitrate-nitrogen	Ammonium-nitrogen	Total phosphorous	Ferric oxide phosphorous	Dissolved reactive phosphorous	Calcium	Magnesium	Sodium
Control	5.7	1.08	16.77	0.055	0.011	0.875	0.171	0.015b	0.110a	0.074	0.097
Compost 1	4.3	0.92	14.74	0.041	0.006	0.679	0.190	0.036b	0.013a	0.016	0.144
Compost 2	5.2	0.96	9.92	0.015	0.005	0.476	0.142	0.025b	0.002b	0.023	0.103
Manure 1	6.2	1.59	12.63	0.099	0.012	1.327	0.388	0.077a	0.011a	0.066	0.319
Manure 2	3.6	0.61	9.76	0.147	0.007	0.775	0.333	0.100a	0.001b	0.024	0.387

Notes: Within a column, a mean followed by the same letter as the control does not differ from the control at p < 0.05. Letters are not shown if the treatment effect in the analysis of variance test (ANOVA) was not significant.

let impact. Moreover, the lack of treatment effects on sediment loads may be related to two other factors. First, we applied relatively small amounts of amendments to our soil. At most, we applied then incorporated 71.7 Mg ha⁻¹ (32 tn ac⁻¹) of material (table 2) into 1,800 Mg ha⁻¹ (803 tn ac⁻¹) of soil in the profile's uppermost 0.15 m (6 in), assuming a bulk density of 1.2 Mg m⁻³ (1.2 g cm⁻³). Second, the nonsignificant treatment effects may be related to the timing of the manure and compost applications, which occurred eight months prior to the first irrigation. In a furrow irrigation study, Lentz and Lehrs (2010) showed that a spring-applied manure application reduced runoff soil loss in that season's irrigations, whereas manure applied in the previous fall, did not. Others have reported that more immediate manure applications (e.g., spring applications) decreased both runoff (Gilley and Risse 2000) and dispersion (Borda et al. 2011) and increased

aggregate stability, particularly of the >2 mm (0.08 in) diameter aggregates (Wortmann and Shapiro 2008). Sediment losses mirrored runoff for the five treatments we studied (table 6), with the correlation coefficient, r_k, between SL and RO being +0.71 (significant at p < 0.001). Sediment loss is frequently highly correlated with runoff because the latter's carrying capacity largely determines the quantity of detached soil that is transported across soil surfaces (King and Bjorneberg 2011). The sediment losses in sprinkler runoff reported in table 6 lay within the ranges of losses in furrow runoff reported by King et al. (2009). King and Bjorneberg (2011) reported sediment loss per unit water applied from the Portneuf silt loam that was often one, and in one case, more than two orders of magnitude greater than that we measured (table 6). In addition to the factors discussed earlier that may have accounted for runoff differences

between the studies, sediment transport and deposition may also have played a role. From the steep (5%) and short (2 m [6.5 ft]) plots studied by King and Bjorneberg (2011), the runoff's transport capacity was great and there was likely little sediment deposition occurring within the plots. Also, their entire plot surfaces received simulated irrigation for much of the one to two minutes required for the irrigation lateral to cross over the plots. King and Bjorneberg (2011), who found increased runoff and sediment loss from sprinklers that evenly distributed droplets across a wetted area, attributed the finding to increased turbulence from droplets impacting overland flow that kept sediment in suspension for longer periods. On the less sloping and 18 times longer plots we studied, detached soil could easily have been redeposited on plot surfaces before exiting the plot boundary through our flumes, especially when the lateral moved uphill, as was often the case.

Moreover as the lateral moved across the plots, only a portion of the plot's area at a given time was irrigated subjecting only that portion to droplet kinetic energy and the overland flow thereon to increased turbulence.

Nitrogen Loads. There were no differences in $\text{NO}_3\text{-N}$ or $\text{NH}_4\text{-N}$ loads between the control and any of the amendment treatments (table 6). This finding suggests that under the conditions we studied, compost and manure applied as we did would result in no more $\text{NO}_3\text{-N}$ loss or $\text{NH}_4\text{-N}$ loss in sprinkler runoff than from unamended fields. In contrast to our findings, Eghball and Gilley (1999) reported generally greater $\text{NO}_3\text{-N}$ loads in runoff from plots treated with compost rather than manure, and Little et al. (2005) reported greater $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ loads from manured plots than controls. In both those contrasting studies, loads in simulated rainfall runoff were measured within 7 days of amendment incorporation but in our study 252 days after incorporation. Delays between amendment incorporation and runoff measurement likely affected nutrient loads (Lentz and Lehrs 2010). In the current study, $\text{NH}_4\text{-N}$ loads in sprinkler runoff did not differ among treatments, as was also found by Eghball and Gilley (1999) and Miller et al. (2006).

Phosphorus Loads. As expected, TP loads in runoff (table 6) were highly correlated with sediment losses ($r_k = +0.86$; $p < 0.001$) since the bulk of the P lost in runoff was particulate P on the sediment. Phosphorus associated with runoff sediment accounted for 87% to 95% of the total P lost from the amended treatments and 98% of the total P lost from the control (table 6). Total P loads in runoff from each year's first irrigation were not correlated ($r_k = +0.04$; $p < 0.646$) with STP concentrations measured in soil collected from the furrows (table 4). Total P loads exceeding 5 g (ha mm)⁻¹ (0.113 lb [ac in]⁻¹) were seldom measured from plots where STP concentrations exceeded 100 mg kg⁻¹ (100 ppm) (data not shown). Indeed, on an individual plot basis total P loads in sprinkler runoff were commonly less than 5 g (ha mm)⁻¹ (0.113 lb [ac in]⁻¹) for STP concentrations ranging from 14 to 317 mg kg⁻¹ (14 to 317 ppm).

In contrast to TP loads, DRP loads in each year's first irrigation were strongly correlated ($r_k = +0.43$, $p < 0.001$) with STP measured before the irrigation (table 4). This positive correlation was to be expected since STP was a measure of the plant-available P

fraction, which included the P in slightly soluble compounds that could dissociate to supply orthophosphate ions to the runoff. The DRP load, though critically important for receiving water bodies, was nonetheless only a small proportion of the TP load. The loads of DRP, as a proportion of TP, from the amended treatments ranged from 5.3% for compost 1 to 12.9% for manure 2. The DRP proportion of TP for the control, however, was only 1.7% (table 6).

Applications of manure, but not compost, increased DRP loads relative to the control (table 6). This was due to the manure treatments applying on average, 1.83-fold more total P than the compost treatments (table 2). On average, DRP loads were nearly 3-fold greater from plots that received manure than compost (table 6). Manure treatments, which added the most total P per unit mass (table 1) lost the most inorganic P in runoff (table 6). Miller et al. (2006) also found that DRP loads were greater from plots that received manure rather than compost. In the latter study, organic amendments were applied annually before rainfall simulation. In our study, however, amendments were applied only once—in the fall before beginning our runoff sampling the following year. Volf et al. (2007) also reported P losses in runoff to be proportional to P additions from manure.

The DRP loads averaged across irrigations responded curvilinearly to increasing manure application rates (table 5 and figure 1). The relationship in figure 1 indicates that producers should apply less than 57 Mg dry manure ha⁻¹ (25.4 tn dry manure ac⁻¹) as a one-time, fall application to minimize DRP loads in subsequent seasons' sprinkler irrigation runoff.

Manure applications are thought to increase the potential for nutrient losses in surface irrigation runoff (Lentz and Westermann 2010). Our findings, however, revealed that the losses of $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, TP, and FeO P in sprinkler irrigation runoff did not differ for two years between unamended soils and soils into which manure had been applied, then incorporated (table 6). We also found that losses of DRP but not TP were greater in our manure treatments relative to the control (table 6). In contrast, Little et al. (2005) reported losses of total P that were greater in manured than control plots, though in simulated rainfall runoff shortly after manure application. In their study, DRP loads were similar among manured and control plots when averaged across the three-year

study. In the study of Little et al. (2005), yearly averages of both TP and DRP differed, but no trend was evident.

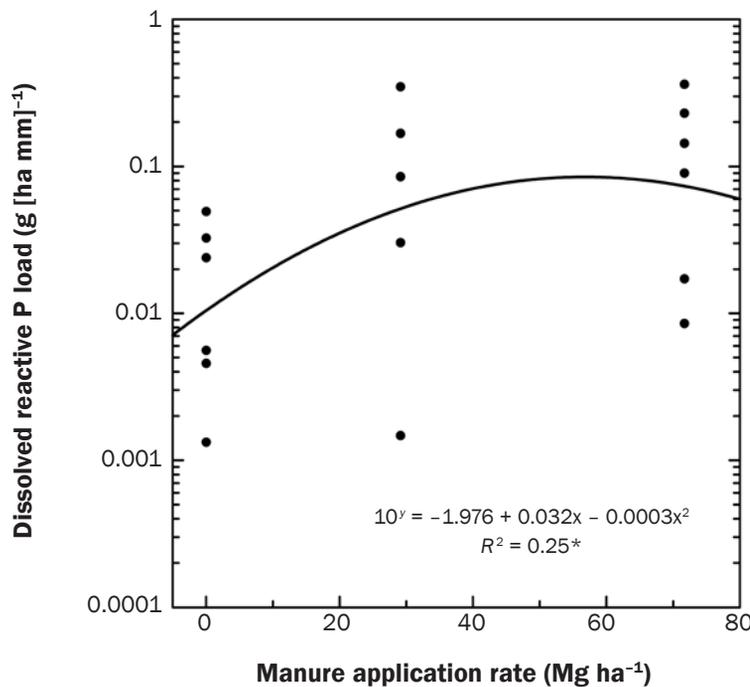
Loads of Potassium, Calcium, and Sodium. Treatments affected runoff K loads (data not shown in tabular form) only for irrigation 1 (day 174 in 2000; table 3) and irrigation 7 (days 200-201 in 2001). For irrigation 1, the load, all in units of g (ha mm)⁻¹, for the control (0.07) did not differ from that of compost 1 (0.82) but was less than that of compost 2 (1.58), manure 1 (1.49), and manure 2 (2.99). For irrigation 7, the load for the control (2.46) was less than that of compost 1 (6.82), compost 2 (9.14), manure 1 (7.01), and manure 2 (16.23). For all remaining monitored irrigations, treatment K loads ranged from 0.42 to 7.36 g (ha mm)⁻¹ (0.0095 to 0.167 lb [ac in]⁻¹). For irrigation 1, the first monitored after amendment application, K loads for amended treatments were 12- to 45-fold greater than the control, likely reflecting the recently added salts present in the amendments (table 1). Overall for both years, K loads in runoff increased with increasing sediment loads suggesting that K was introduced into the runoff via a simple soluble extraction as irrigation water interacted with eroded soil. Hence, organic amendments increased runoff K loads because the amendments increased the soil's K content.

Amendment applications at higher, but not lower, rates decreased Ca loads relative to the control (table 6). Indeed, the Ca loads at the higher amendment rates were in general two orders of magnitude less than those of the control. Moreover, the ANOVA revealed highly significant linear trends in the Ca load response to increasing rates of compost and manure (table 5). The Ca loads averaged across irrigations decreased as the organic amendment application rates increased (figure 2). These decreases are notable since greater application rates applied more, not less, Ca.

There may well be an inverse relationship between loads of Ca and DRP in sprinkler runoff, at least for manure (table 6). This association between Ca loads and DRP loads could well have been due to soluble Ca being removed from solution, as it was precipitated in some form with orthophosphate. With less Ca in the runoff, less DRP was precipitated and more DRP could have been transported offsite in runoff to nearby surface water (Tisdale and Nelson 1975). Calcium in run-

Figure 1

Dissolved reactive phosphorus (DRP) loads in sprinkler irrigation runoff affected by manure application rates. Dissolved reactive phosphorus loads have been averaged across irrigations (interaction not significant at $p > 0.35$).



off, soil, or both can lead to the formation of relatively insoluble calcium phosphate species that would minimize the loss of reactive P ions in surface runoff, though only where sufficient Ca is present (Tisdale and Nelson 1975; Olson et al. 2010). The decreasing Ca loads with increasing application rates of compost and manure (figures 2a and 2b, respectively) suggest that Ca was not present in excess in our runoff.

The Ca concentrations in the amendments we applied (table 1) and even in our unamended calcareous Portneuf soil (164 mg kg⁻¹; as reported by Lehrs [2013], for the nearly identical Rad soil) likely limited, though only to a slight degree, the P concentrations in our sprinkler irrigation runoff (Turner et al. 2004) and, thereby, the DRP loads measured in our study (table 6). Moreover, our runoff's Ca—an effective flocculating agent—may have decreased the runoff's suspended sediment concentrations. In calcareous soils of the western United States, the Ca concentration (or activity) and the quantity and particle size of free CaCO₃ largely control soil solution P (Tisdale and Nelson 1975; Turner et al. 2004).

Runoff loads of Na, unlike those of Ca, increased with increasing manure applica-

tion rates (figure 3). Moreover, Na loads were highly correlated with DRP loads ($r_k = +0.52$; $p < 0.001$). Sodium in the runoff may have increased the dispersion of entrained aggregates or aggregate fragments leading to the dissolution of newly exposed compounds and the release of additional orthophosphate to the runoff. Sodium loads in runoff from the compost and manure treatments were similar to the control (table 6).

Flow-Weighted Constituent Concentrations.

Flow-weighted mean concentrations varied from one constituent to another (table 7). In addition to that of sediment, mean concentrations of DOC, TP, and K were the greatest among all measured constituents. Not one of the remaining seven constituents exhibited a mean flow-weighted concentration that exceeded 1 mg L⁻¹ (1 ppm). The standard deviation exceeded the arithmetic mean for all constituents except DOC, TP, and FeO P (table 7), suggesting that the flow-weighted concentrations of most measured parameters in our study were not normally distributed.

The flow-weighted mean concentrations for sediment, TP, and DRP in our study (table 7) lay well within the respective ranges for the same soil given by Turner et al. (2004). In contrast, the average runoff we measured

ranged from 3.6% to 6.2% (table 6), 93% to 87% less than the average 48% runoff reported by Turner et al. (2004). Much of the discrepancy can be attributed to the 2.5-fold greater water application rate used by Turner et al. (2004).

Our flow-weighted mean concentrations of TP, DRP, NO₃-N, and NH₄-N were 3.28, 0.16, 0.36, and 0.14 mg L⁻¹ (3.28, 0.16, 0.36, and 0.14 ppm), respectively, while long-term averages reported by Gilley et al. (2007) in sprinkler runoff from similarly tilled and manured plots were 2.2, 1.3, 1.6, and 0.6 mg L⁻¹ (2.2, 1.3, 1.6, and 0.6 ppm), respectively. The DRP, NO₃-N, and NH₄-N concentrations of Gilley et al. (2007) were 4- to 8-fold greater than the respective mean concentrations we measured (table 7). The greater concentrations were likely due to five factors: (1) the concentrations of Gilley et al. (2007) were measured soon after manure was applied, with five of their six tests occurring within four months of application; (2) their plots were short (2 m [6.5 ft] long), allowing for little if any sediment deposition within the plots; (3) their plots were prewetted, greatly increasing runoff; (4) compared to the plots in the current study, their plots were more than twice as steep, again increasing both runoff rates and volumes; and (5) the sediment losses reported by Gilley et al. (2007) were an order of magnitude greater than those we measured.

Many of the flow-weighted mean concentrations in sprinkler runoff given in table 7 are similar to those measured in the region's furrow irrigation runoff. Our TP was 3.28 mg L⁻¹ (3.28 ppm), similar to the 1.08 mg L⁻¹ (1.08 ppm) reported for our soil by Westermann et al. (2001), and within the range of 0.3 to 17 mg L⁻¹ (0.3 to 17 ppm) reported by Fitzsimmons et al. (1972). Similarly, the DRP we measured, (0.16 mg L⁻¹ [0.16 ppm]) lies within the commonly observed range of 0.04 to 0.18 mg L⁻¹ (0.04 to 0.18 ppm) (Fitzsimmons et al. 1972; Bjerneberg et al. 2006; Lentz and Lehrs 2010). In contrast, our NO₃-N and NH₄-N concentrations in sprinkler runoff (table 7) were only 30% and 7%, respectively, of the mean concentrations in the region's furrow runoff reported by Fitzsimmons et al. (1972).

Never did the flow-weighted concentrations of NO₃-N measured in the current study (table 7) exceed the Environmental Protection Agency's (USEPA) drinking water standard of 10 mg NO₃-N L⁻¹ (10

Figure 2

Calcium (Ca) loads in sprinkler irrigation runoff affected by application rates of (a) compost and (b) manure. Calcium loads have been averaged across irrigations (interaction not significant at $p > 0.46$).

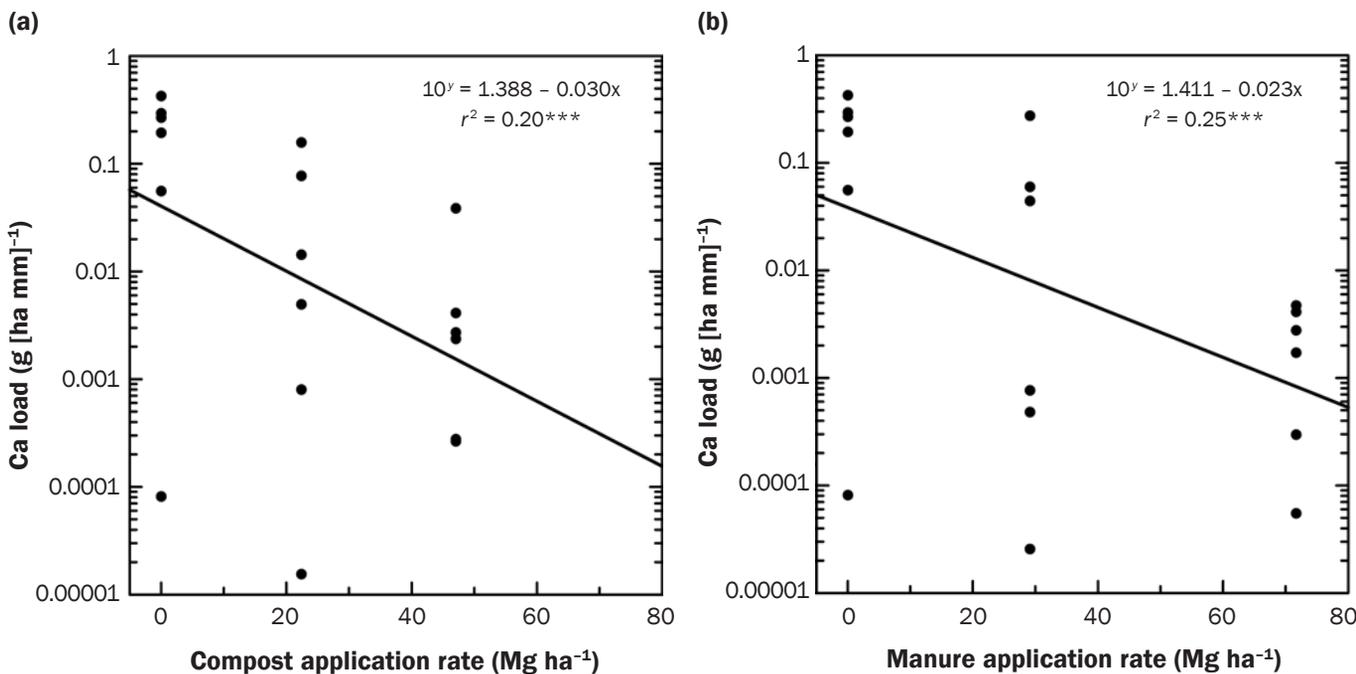
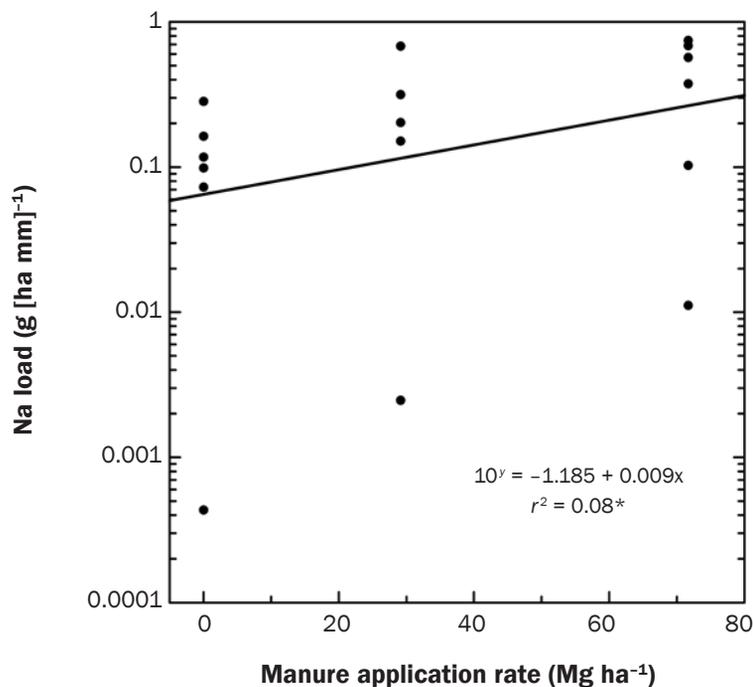


Figure 3

Sodium (Na) loads in sprinkler irrigation runoff affected by manure application rates. Sodium loads have been averaged across irrigations (interaction not significant at $p > 0.65$).



ppm) (USEPA 2009). In our study (table 7) all flow-weighted $\text{NH}_4\text{-N}$ concentrations were below 2.5 mg L^{-1} (2.5 ppm), a concentration not to be exceeded in order to protect aquatic organisms (USEPA 1986). In contrast, our flow-weighted mean, total P concentration exceeded by nearly 33-fold the limit of 0.1 mg P L^{-1} (0.1 ppm P) suggested by the USEPA to limit eutrophication in streams and rivers (USEPA 1986).

As we conducted our experiment, analyzed our findings, and compared our results to those in the literature, a number of points became clear. The finding that runoff, sediment loss, and constituent loads varied from irrigation to irrigation for two years calls into question estimates of season-long, chemical constituent losses based upon data from only one or two rainfall simulations or monitored irrigations within a growing season. The study of large, moderately sloped plots irrigated with moving laterals is best for adequately characterizing runoff and nutrient losses because it allows for concentration of runoff (overland flow) as it moves downslope and integrates the effects of temporally and spatially varying infiltration, detachment, and deposition. Similarly, using stationary plot sprinklers to generate

Table 7

Flow-weighted sediment and constituent concentrations. Values are shown without regard to treatments or irrigations.

Constituent	n	Minimum value	Maximum value	Arithmetic mean	Standard deviation
Sediment (g L ⁻¹)	240	0	34.81	2.95	4.18
Dissolved organic carbon (mg L ⁻¹)	103	0	43.10	28.98	7.20
Nitrate-nitrogen (mg L ⁻¹)	180	0	7.04	0.36	0.72
Ammonium-nitrogen (mg L ⁻¹)	180	0	1.54	0.14	0.19
Total phosphorus (mg L ⁻¹)	180	0	16.19	3.28	2.50
Ferric oxide phosphorus (mg L ⁻¹)	180	0	3.34	0.82	0.60
Dissolved reactive phosphorus (mg L ⁻¹)	180	0	1.86	0.16	0.22
Potassium (mg L ⁻¹)	180	0	61.04	7.56	7.57
Calcium (mg L ⁻¹)	180	0	8.40	0.96	1.68
Magnesium (mg L ⁻¹)	180	0	4.08	0.57	0.72
Sodium (mg L ⁻¹)	180	0	10.99	0.96	1.35

data applicable to moving lateral irrigation systems would be invalid since the former do not adequately capture the changing hydrologic regime of lateral-move systems. The timing of manure and compost applications affects subsequently measured runoff, sediment losses, and nutrient loads. By delaying the irrigation of fields treated with organic amendments, such as manure, compost, or both, runoff nutrient losses will be reduced, leading to producer cost savings and, potentially, increased nutrient use efficiencies. As a societal benefit, water quality in receiving waters will also be improved. Sprinkler irrigation with moving laterals, due to relatively short irrigation durations, greater water application intensities, higher kinetic energy input, and more turbulent overland flow, affects nutrient loads differently than does furrow irrigation.

Summary and Conclusions

In a two-year field study, runoff, sediment losses, and nutrient loads in sprinkler irrigation runoff were measured eight times after a one-time, fall application of either stockpiled or composted dairy manure. The following conclusions were drawn from this study:

1. A one-time, fall application of compost, manure, or both, at two rates affected the loads of DRP, as well as K and Ca, in sprinkler irrigation runoff for two years, when averaged across irrigations.
2. Manure, but not compost, applications increased DRP loads relative to the control. Runoff loads of DRP were five to six times greater from manure treatments than the control.
3. Treatments did not differ in their effects upon runoff, sediment losses, or loads of DOC, NO₃-N, NH₄-N, TP, FeO P, or Mg.

4. Loads of Ca decreased but Na increased with increasing manure application rates.
5. Runoff, sediment loss, and loads of every constituent varied from irrigation to irrigation through two consecutive growing seasons.
6. To lessen DRP loads in subsequent seasons' sprinkler irrigation runoff, one-time applications of dry manure in fall should not exceed 57 Mg ha⁻¹ (25.4 tn ac⁻¹).

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Disclaimer

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