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Compost and Manure Effects on Fertilized Corn Silage Yield and Nitrogen Uptake under Irrigation

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Abstract: Dairy manure increases the yields of dry bean (*Phaseolus vulgaris* L.) and spring wheat (*Triticum aestivum* L.) from eroded, furrow-irrigated soils and may increase corn (*Zea mays* L.) silage yield from steeper eroded areas under sprinkler irrigation. In a 2-year field study in southern Idaho on Portneuf silt loam (coarse silty, mixed, superactive, mesic Durinodic Xeric Haplocalcid), the effects of a one-time, fall application of 29 or 72 Mg ha⁻¹ of dry manure or 22 or 47 Mg ha⁻¹ of dry compost on subsequent silage yield and nitrogen (N) uptake from previously eroded, sprinkler-irrigated hill slopes were evaluated. In October 1999, stockpiled or composted dairy manure was disked to a depth of 0.15 m into plots with slopes from 0.8 to 4.4%. After planting field corn in 2000 and 2001, a low-pressure, six-span traveling lateral sprinkler system was utilized to apply water at 28 mm h⁻¹ in amounts sufficient to satisfy evapotranspiration to 6.4- × 36.6-m field plots. Yields in 2000 were 27.5 Mg ha⁻¹, similar among all rates of all amendments and a fertilized control. In 2001, compost applied at oven-dry rates up to 47 Mg ha⁻¹ increased yield compared to controls. Silage yield in 2001 increased initially then decreased with increasing manure applications. Where compost or manure was applied, regardless of rate, 2-year average N uptake was 15% greater than controls. Regardless of treatment or year, yields decreased linearly as soil slope increased.

Keywords: Corn, erosion, slope, sprinkler irrigation, *Zea mays* L.

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INTRODUCTION

Approximately 45.4 million Mg of manure were produced annually in the mid 1990s by dairy and beef cattle, *Bos* sp. (Walker, southworth, and Rubin 1997, cited by Edwards and Someshwar 2000). In Idaho, the livestock industry has expanded rapidly, with the waste generated becoming a concern. Statewide, Idaho's dairy and beef cattle produce more than 4.5 million Mg of air-dry manure annually (A. A. Araji, 2005, personal communication). About 70% of the state's dairy cows and 30% of the beef cattle are in southcentral Idaho. The growth of the dairy industry in southern Idaho to supply milk for cheese production has significantly increased manure production. The cattle in southern Idaho alone produce more than 2.2 million Mg of air-dry manure annually. The characteristics and beneficial uses of many different manures were reviewed recently (Edwards and Someshwar 2000; Sumner 2000).

In the intermountain region of the Pacific northwest, much of the manure produced becomes compost. Compost refers to organic constituents, usually wastes, that have been mixed, piled, and moistened and undergo thermophilic decomposition that alters or decomposes the original organic materials (Soil Science Society of America 1997). To ease waste disposal, many local dairy owners compost manure, then recycle the compost as bedding for their cows. In many areas, landscapers, home gardeners, horticulturalists, and others prize compost (Richard 2005). DeLuca and DeLuca (1997) compared the nitrogen (N), phosphorus (P), and potassium (K) concentrations in composted manure with fresh manure and feedlot manure. The compost, and the processes used to produce it, have been described in detail (Richard 2005, Keener et al. 2000).

Organic amendments are often applied to soils to increase crop productivity, crop quality, or both (Bresson et al. 2001; Edmeades 2003; Risse et al. 2001). Compared to noneroded soils, dairy manure applications increased yields of dry bean and spring wheat from eroded soils on a 1.1% slope in southern Idaho and may increase yields of other crops as well (Robbins, Freeborn, and Mackey 1997; Tarkalson et al. 1998). Fall-applied manure and compost increased corn grain yield and biomass at tasseling for two growing seasons after being applied (Eghball, Ginting, and Gilley 2004). Dairy manure applications increased corn silage yields and soil nitrate (NO_3)-N in an Enosburg fine sandy loam (Mollic Haplaquent) in proportion to the application rate (Jokela 1992).

Manure increases soil fertility. In the short-term manure stimulates microbial activity that improves soil structure and in the long-term supplies NO_3 -N and ammonium (NH_4)-N to aid crop production (Edwards and Someshwar 2000; Sumner 2000). In a review of literature, Loveland and Webb (2003) noted that annual manure applications may increase yields, even where fertilizer is applied, possibly because of increases in soil organic carbon or available water. Increased available water may have played a role, given that Arriaga and Lowery (2003) found that annual

manure applications increased water retention proportionally more on eroded than noneroded sites. They attributed the increased yields where manure was applied to greater water retention in amended soils. Manure applications may also increase the productivity of soils degraded by erosion from irrigation or rainfall (Arriaga and Lowery 2003; Carter 1990). Compost and fresh manure provide similar benefits for both crop production and soil management, along with others as well. Compared to manure, compost contains few viable weed seeds, less water, and occupies 30 to 60% less volume, thus decreasing transportation costs (Richard 2005). Organic amendments also stimulate microbes to produce polysaccharides and other exudates that increase aggregate stability (Lehrsch 1995; Lehrsch et al. 1991). Stable aggregates at and near the soil surface resist breakdown from raindrop or sprinkler droplet kinetic energy and sustain infiltration rates (Lehrsch and Kincaid 2001; 2006).

Caution must be exercised, however, when applying large quantities of organic amendments to soil (Amlinger et al. 2003; Edwards and Someshwar 2000). Depending upon the proportion of monovalent cations, principally K^+ and sodium (Na^+), to divalent cations in the waste, additions on the order of 100 Mg ha^{-1} or more can disperse aggregates and destroy surface soil structure, reducing both infiltration and hydraulic conductivity as a consequence (Haynes and Naidu 1998; Lehrsch and Kincaid 2001; Tiarks, Mazurak, and Chesnin 1974). If the added amendments contain large proportions of straw, high in C but low in N, soil N may be immobilized (Brown 1988).

Manure from cattle feedlots can contain high concentrations of soluble salts, principally sodium chloride. If applied at high rates in arid or semi-arid areas, manure can increase salinity sufficiently to hinder the germination of salt-sensitive crops (Eghball, Ginting, and Gilley 2004; Haynes and Naidu 1998; Sumner 2000). Ammonium ions, added with manure or formed as organic N compounds are mineralized, will react with water in calcareous soils to form ammonia that, if present in sufficiently high concentrations, will be toxic to germinating seeds and seedlings (Robbins and Gavlak 1989; Tisdale and Nelson 1975). Hao and Chang (2003) reported that annual applications of cattle feedlot manure to an irrigated clay loam in semi-arid southern Alberta increased the electrical conductivity of a saturated paste extract, EC_e . Soluble Na^+ , K^+ , magnesium (Mg^{2+}), chloride (Cl^-), bicarbonate (HCO_3^-), and sodium adsorption ratio (SAR) all increased with fall manure applications ranging from 60 to 180 Mg ha^{-1} . Potassium became the dominant cation on the exchange complex where manure was applied. Hao and Chang (2003) concluded that high manure application rates were not sustainable, leading to salinization without irrigation and possible groundwater contamination with irrigation.

Sustainable crop production in the western United States is made difficult not only by possible soluble salt accumulation but also by problems inherent with irrigating sloping fields. Many previously furrow irrigated fields with medium-textured soils have eroded areas with reduced infiltration capacity

and/or low fertility (Carter 1990; Rasmussen and Cary 1979). Furrow irrigation-induced erosion from slopes $<2\%$ is generally not serious if the flow rate is carefully controlled (Carter 1990). Under the outer spans of center pivot irrigation systems, however, one is less able to control runoff and erosion, particularly from slopes $\geq 2.5\%$ (Lehrs, Bjerneberg, and Sojka 2005; Lehrs and Kincaid 2005). Though center pivot systems are becoming common in the Pacific Northwest because of their low labor requirement and capability to irrigate large fields with rolling topography, they tend to produce runoff due to high application rates inherent with traveling lateral systems (Kincaid 2005).

Runoff also erodes soil (Lehrs, Bjerneberg, and Sojka 2005). After topsoil is eroded by runoff from irrigation, moldboard plowing or disking commonly mixes less fertile, poorly structured subsoil into the Ap horizon, with the proportion of subsoil increasing as erosion increases (Carter 1990). Compared to Portneuf silt loam topsoil, subsoil has half as much organic C, a higher pH, and three times as much calcium carbonate (CaCO_3) (Robbins, Freeborn, and Mackey 1997). Subsoil also hinders root growth and requires much more P fertilizer to reach adequate levels for crop production (Rasmussen and Cary 1979). Corn growth and development are hindered where topsoil has been eroded by irrigation (Carter 1990).

This research was part of a larger investigation in which amendment effects on runoff, sediment loss, soil structure, nutrient losses in runoff, and to a lesser degree silage yield from sloping field areas were studied. In the research reported here, the effects of stockpiled or composted dairy manure, each at two rates, on corn silage yield and N uptake from sprinkler irrigated plots with slopes from 0.8 to 4.4% were determined.

MATERIALS AND METHODS

The experiment was conducted for 2 years on structurally unstable Portneuf silt loam about 2.1 km southwest of Kimberly, ID ($42^\circ 31'N$, $114^\circ 22'W$, and elevation of 1190 m). The Portneuf's Ap horizon contained about 560 g silt kg^{-1} , 220 g clay kg^{-1} , pH (in a saturated paste) of 7.7, an EC_e of 1.1 dS m^{-1} , 75 g CaCO_3 equivalent kg^{-1} , and about 9.3 g kg^{-1} of organic carbon (C). Though the Portneuf's underlying Bk horizon was similar in many respects, it commonly contained nearly three times as much CaCO_3 and half as much organic C. Other properties of a nearby Portneuf pedon were given by Lehrs, Sojka, and Westermann (2000). After harvesting wheat in August 1999, the stubble was chopped and disked on 14–15 September 1999 before the amendments were applied.

Treatments consisted of two amendments, compost and manure, each applied air dry at a medium and high rate, along with an unamended but fertilized control that was duplicated in each block. Compost was applied once at an equivalent oven-dry rate of 22 or 47 Mg ha^{-1} , whereas the manure was

applied once at an oven-dry rate of 29 or 72 Mg ha⁻¹. The medium and high rates for each amendment were chosen based upon supplying mineral N as fertilizer in moderate and in excessive amounts, respectively. Because the primary purpose of the larger investigation was to evaluate compost and manure effects on runoff, sediment loss, soil structure, and runoff nutrient losses, an unfertilized check was not included.

Each of the four amendment treatments and the duplicated control were randomly assigned to one of the six, 6.4-m-wide by 36.6-m-long plots under each of the six spans of the irrigation system (described later). After harvesting wheat (*Triticum aestivum* L.) in August 1999, the stubble was chopped and disked on 14–15 September 1999. On 14 October 1999, the amendments were applied in a broadcast manner with an 18-Mg truck equipped as a manure spreader. Amendment application rates were measured using a 2.24-m-wide by 1.70-m-long tarp placed across each plot. The spreader passed repeatedly across a plot until that plot had received its nominal allotment of either compost or manure. After applying 23 mm of water with a traveling lateral sprinkler system (described later) the next day, the amendments were incorporated on 18–19 October 1999 by disking the entire area to a depth of 0.15 m three times in two directions.

When the amendments were applied, three samples of compost and five samples of manure were collected for chemical characterization. For collection, the material on a tarp was mixed, then sampled. At the laboratory, a subsample was removed to determine dry-matter content, and then the remainder was immediately air dried at about 30°C in a forced-air drying cabinet. The air-dry material was stored at room temperature until, just before analysis, it was ground in a Wiley¹ mill to pass an 865- μ m stainless steel screen. On each ground sample, pH (Wolf 2003b), electrical conductivity (EC) (Wolf 2003a), and total C and N by the combustion of a 25-mg sample in a Thermo-Finnigan FlashEA1112 CNS analyzer (CE Elantech Inc., Lakewood, N.J.) were determined. An automated flow injection analyzer was utilized to colorimetrically determine each sample's NO₃-N concentration after cadmium reduction of a potassium chloride (KCl) extract (method 12-107-04-1-B, Lachat Instruments, Loveland, Col) and NH₄-N concentration using a salicylate-hypochlorite method (method 12-107-06-2-A, Lachat Instruments, Loveland, Col).

On 21 April 2000 before planting, soil samples were collected to a depth of 0.3 m from the controls and analyzed for phosphorus (P), K, and zinc (Zn). Upon analysis, the macronutrient concentrations were 7 mg P kg⁻¹ and 110 mg K kg⁻¹. The soil's Zn concentration was adequate to produce corn, *Zea mays* L. (Brown and Westermann 1988). After tilling the site with an offset disk to a depth of 0.15 m on 28 April and again on 2 May, soil samples were collected to 0.3 m from every plot of the study. Thereafter,

¹Manufacturer or trade names are included for the readers' benefit. The USDA-ARS neither endorses nor recommends such products.

fertilizer was broadcast applied (202 kg N ha^{-1} , 98 kg P ha^{-1} , and 139 kg K ha^{-1}) equally to all plots per University of Idaho soil-test recommendations for irrigated field corn (Brown and Westermann 1988). All fertilizer was incorporated by roller-harrowing to 65 mm. Pioneer 3751 corn, a cultivar adapted best for silage production, was planted at a depth of 51 mm to a nominal plant population of $68,900 \text{ plants ha}^{-1}$ on 12 May into 0.76-m rows oriented perpendicular to the irrigation system lateral (described later). Subsequent cultivation produced small furrows between adjacent corn rows that directed runoff downslope. Each plot's long axis was perpendicular to the irrigation lateral. Plot slopes faced south and ranged from 0.8 to 4.4%, increasing gradually, in general, from span 1 to 6. Plants from 3.05 m of an interior row about 12 m upslope from the downslope plot border and another 3.05 m of row about 24 m upslope from the same border in late September, were hand-harvested for silage yield and N uptake. Subsamples of the harvested silage were weighed, dried at 60°C , and then weighed again. Dry silage was ground in a Wiley mill to pass a $380\text{-}\mu\text{m}$ stainless steel screen. Thereafter, its total N concentration was determined from a 25-mg sample in the CNS analyzer described previously. Yields and N uptake from the two rows were averaged prior to statistical analysis. In 2001, field operations and timing were similar. All plots were disked to 0.15 m twice in the spring. On 25 April, 101 kg N ha^{-1} (as urea, $0.45 \text{ kg N kg}^{-1}$) and 98 kg P ha^{-1} were broadcast onto the entire study site, then incorporated with a roller harrow prior to planting corn on 9 May. In both 2000 and 2001, standard cultural practices were employed to control insects and weeds (Brown and Westermann 1988). Despite efforts, yields in 2001 were reduced somewhat by green foxtail, *Setaria viridis* (L.) P. Beauv.

All plots were irrigated using a 247-m, six-span traveling lateral sprinkler system equipped with spray heads having spinning, six-groove deflector plates and 138-kPa pressure regulators. The sprinklers were mounted 2.4 m above the soil surface and 3.05 m apart. Spray pattern width was about 16 m, resulting in an average application rate of about 28 mm h^{-1} (Kincaid 2005) and a peak rate of 40 mm h^{-1} where sprinkler patterns overlapped along the lateral. Automatic valves controlled the flow to each span. The lateral's discharge rate was $7.45 \text{ L (min m)}^{-1}$, representative of middle spans of a typical center pivot lateral in southern Idaho. On average, corn was irrigated two to three times per week in amounts sufficient to replace calculated evapotranspiration. Spans 1 to 5 received the same gross water application. Slightly less water was applied to steeper plots, particularly those in span 6, on only six days in 2000 and two in 2001, when runoff was measured. Each season, those plots received about 8% less water than the remaining plots. To spans 1 through 5, a total of 480 mm of water in 2000 and 530 mm in 2001 was applied. The irrigation water, withdrawn from the Snake River, commonly has a pH of 8.2, an EC of 0.5 dS m^{-1} , and SAR of 0.65. For most irrigations each year, the lateral traveled uphill.

The experimental design was a randomized complete block with one block under each of the six spans of the irrigation system. Before performing an analysis of variance (ANOVA), the relationship between each response variable's mean and standard deviation (SD) was examined to ensure that no transformation was needed to stabilize the variable's error variance before analysis. An ANOVA was performed using mixed-model procedures and a significance probability of 5%, for the most part (SAS Institute Inc. 1999). Random factors were span, span \times year, span \times treatment, and span \times year \times treatment. When each amendment was analyzed separately, random factors were span, span \times year, span \times rate, and span \times year \times rate. In the ANOVA for each amendment, contrasts were used to test for linear and quadratic (curvilinear) trends in yield response to increasing application rate each year. For the most complex trend found significant, a regression equation was fitted to the data. When the equation was curvilinear, the quadratic equation's first derivative was set equal to zero and solved for the amendment's application rate that maximized silage yield. Yield variation accounted for by the blocking factor span was included in each regression model's sum of squares by including span as a class variable in the fitted model, thus giving a more accurate R^2 estimate.

RESULTS AND DISCUSSION

Amendment Properties

The compost and manure that was applied were similar, in general, to that common in the area (Table 1). There were, however, three exceptions. The total N concentration of the compost was somewhat lower than the common 16.3 g N kg^{-1} in compost. The compost EC was 1.9 times the local

Table 1. Properties of the compost and manure (all measurements on a dry-weight basis)

Amendment property	Compost ($n = 3$)		Manure ($n = 5$)	
	Mean	SD ^a	Mean	SD
pH	9.26	0.03	8.6	0.5
Total C (g kg^{-1})	111	11	289	22
Total N (g kg^{-1})	11.7	1.0	21.2	1.5
NO ₃ -N (mg kg^{-1})	940	140	120	60
NH ₄ -N (mg kg^{-1})	85	5	326	20
C:N Ratio	9.5	0.2	13.6	0.2
Electrical conductivity (dS m^{-1})	10.9	1.0	11	2

^aSD = standard deviation.

Table 2. Amendments applied with the plant-available N added in each for the first year

Amendment ^a	Treatment	Application rate (dry material) Mg ha ⁻¹	Nitrogen added ^b (kg ha ⁻¹)			
			NO ₃ -N	NH ₄ -N	Min-N ^c	Total
None	None	0	0.0	0.0	0	0
Compost	Medium	22	21.1 (3.1)	1.9 (0.1)	50	73
Compost	High	47	44.3 (6.5)	4.0 (0.3)	100	148
Manure	Medium	29	3.6 (1.8)	9.5 (0.6)	270	283
Manure	High	72	8.9 (4.5)	23.4 (1.5)	670	702

^aAs applied, the compost was 0.71 kg dry matter kg⁻¹ and the manure was 0.53 kg dry matter kg⁻¹.

^bThe NO₃-N and NH₄-N contents were determined on three samples of compost and five samples of manure collected when applied. Figures in parentheses are standard deviations.

^cAn estimate, based upon each amendment's total N concentration, of the N mineralized in the 12 months after the amendment was applied. Total N averaged 11.7 g kg⁻¹ in compost and 21.2 g kg⁻¹ in manure (Table 1). We assumed that the N mineralized in the first year was 200 g kg⁻¹ from compost and 450 g kg⁻¹ from manure (DeLuca and DeLuca 1997; Moffitt 1992; Richard 2005).

compost average, 5.6 dS m⁻¹, whereas the manure EC was 1.5 times the local manure average, 7.2 dS m⁻¹ (Lehrs, unpublished). Each amendment's EC, however, was well within two standard deviations of its local average. As expected, the compost contained more NO₃-N and less NH₄-N than the manure. When applied, the dry-matter content was 0.71 kg kg⁻¹ for compost and 0.53 kg kg⁻¹ for manure. The manure's dry-matter content confirms that the material was stockpiled, rather than freshly scraped from a feedlot's surface, prior to application.

The N added in the medium and high rates of each amendment are shown in Table 2. The standard deviations reveal the variability inherent in estimating the N applied in these agricultural by-products (Risse et al. 2001). The greatest portion by far of the total plant-available N added in each amendment was the estimated, first-year mineralized N, being 68% for compost and 95% for manure. In total, the medium manure treatment added 3.9 times more N than the medium compost treatment, whereas the high manure treatment added 4.7 times more N than the high compost treatment.

Silage Yield

The ANOVA's year × treatment interaction was not significant at $P = 0.05$ but was at $P < 0.078$. Moreover, a single degree-of-freedom comparison

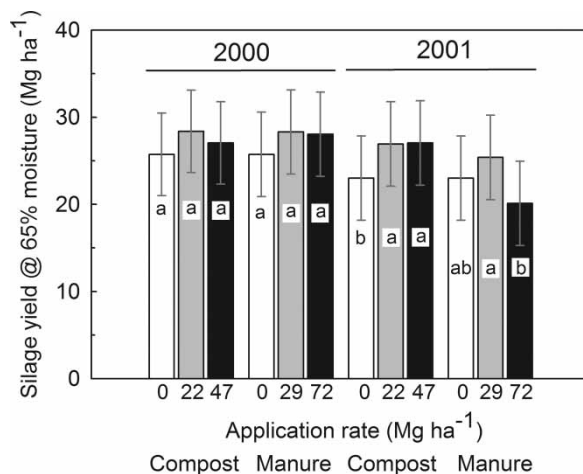


Figure 1. Compost and manure rate effects on silage yield in 2000 and 2001. Within amendments each year, means with a common letter are not significantly different according to *t* tests of pairwise differences at $P = 0.05$. Data from controls are shown twice each year to facilitate comparison with each amendment. Each mean ($n = 12$ for controls, else $n = 6$) is shown with its 95% confidence interval.

found that, averaged across medium and high rates, compost effects differed ($P < 0.006$) from manure effects in 2001. In addition, the 146 mm of precipitation in the first winter (November 1999 through April 2000) after amendment application were 30% greater than the precipitation in the second winter (November 2000 through April 2001). These factors led to the need to investigate amendment effects each year, particularly in view of the pre-planned analyses of trends in silage yield response to increasing amendment rates.

Though each rate of manure added much more N than each rate of compost, 2000 yields differed little (Figure 1). Moreover, there was little difference in 2000 silage yields between rates for each amendment. Yields in 2000 from all treatments, including the fertilized control, averaged 27.5 Mg ha^{-1} . Compared to the fertilized control, compost on average increased yields by 8% and manure by 9%, though neither increase was significant at $P = 0.05$. These increases were apparently in response to the amendments applied the preceding fall (Table 2).

In 2000, compost treatments tended to yield more silage than the control (Figure 1). That tendency continued and strengthened the succeeding year. Yield from each of the compost treatments in the second year after application exceeded that of the fertilized control by about 4 Mg ha^{-1} , significant at $P = 0.051$ for the medium treatment and at $P = 0.045$ for the high. In contrast, neither manure rate affected silage yield in 2001. In fact, the high

manure rate, 72 Mg ha^{-1} , tended to decrease silage yield, compared to the control.

Though the 2001 yields from the medium and high compost treatments did not differ from one another, the corresponding yields from the manure treatments did (Figure 1). For the manure, the 72 Mg ha^{-1} treatment yielded less ($P < 0.013$) than the 29 Mg ha^{-1} treatment. Perhaps the additional straw added in the high manure treatment led to continued microbial immobilization of available soil N that reduced silage yield (Brown 1988). Another possible explanation is that reduced arbuscular mycorrhizal fungi colonization of the corn as a consequence of the additional nutrients added with the high manure rate may have reduced yields (Tarkalson et al. 1998). Larney et al. (2000), in contrast, found that $75 \text{ Mg manure ha}^{-1}$ restored productivity on simulated eroded areas, though for spring wheat rather than corn silage and grown under predominantly dryland rather than irrigated conditions. In this study, the silage yield from the high manure treatment in 2001 was less than ($P < 0.001$) that from the high compost treatment in 2001. This was surprising, given that all plots of the study received a uniform application of conventional N and P fertilizer on 25 April 2001 prior to planting.

Silage yield in 2001 responded in a quadratic manner ($P < 0.005$) to increasing manure rates (Figure 2). Indeed, data shown in Figure 1 reveal that the yield response to manure in 2000, the first growing season after application, was also curvilinear, though not significant at $P < 0.05$. One might speculate that soluble salts were responsible for the 2001 yield decrease where

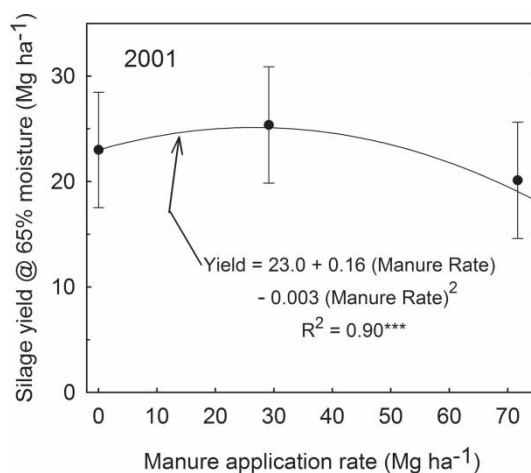


Figure 2. Manure effects on silage yield in 2001. Each mean ($n = 12$ for controls, else $n = 6$) is shown with its 95% confidence interval. The reported R^2 is that found after including yield variation accounted for by the blocking factor span in the fitted model's sum of squares.

72 Mg manure ha⁻¹ were applied. Based upon the amendments' EC values, however, the loads of soluble salts (as total dissolved solids) added directly in the compost and manure were not great. The medium rate added 0.32 Mg soluble salts ha⁻¹ in compost and 0.83 Mg ha⁻¹ in manure. The high rate added 0.68 Mg ha⁻¹ in compost and 2.06 Mg ha⁻¹ in manure. Portneuf silt loam under irrigation typically contains about 0.54 Mg soluble salts ha⁻¹ in the upper 0.15 m where no amendments have been applied. Salt added with the high manure treatment, in the absence of leaching, could have hindered the yield of some salt-sensitive crops, such as dry bean (*Phaseolus vulgaris* L.), if planted shortly after amendment incorporation. In this experiment, however, 2001 yield decreases from soluble salt loads were unlikely because corn was planted, a more salt-tolerant crop than dry bean. Moreover, soluble salts were surely leached from the seeding depth by 1) the 23-mm irrigation one day after applying the amendments in fall 1999, 2) precipitation in the winters of 1999–2000 and 2000–2001, and 3) percolation during the 2000 growing season (Wright, Westermann, and Lehrs 1998).

Decreased infiltration is not responsible for yield decreases shown in Figure 2 because a preliminary analysis of runoff (not reported) suggested that infiltration increased slightly with increasing manure rates as Rasmussen and Cary (1979) speculated. Increased infiltration, with attendant leaching of NO₃-N, however, could explain the decrease in yield at high manure application rates if the corn was N deficient but no symptoms of N deficiency were observed. Robbins, Freeborn, and Mackey (1997), 3 years after applying fresh manure to the same soil near the experimental site, found that manure increased dry bean yields compared to those from nonmanured plots. However, they applied manure at a greater (air-dry) rate, 137 Mg ha⁻¹, in a split application with 44 Mg ha⁻¹ applied in the spring and the balance in the fall.

Compared to medium or more moderate rates, high rates of either compost or manure did not increase yields, and in some cases, decreased them (Figures 1 and 2). Where excessive rates of compost or manure are applied to produce crops, dispose of agricultural by-products, or both, caution should be exercised not only because of yield reductions but also because of nutrient-use inefficiencies and possible contamination of both surface and groundwater.

Nitrogen Uptake

Both compost and manure significantly increased 2-year average N uptake by corn silage (Figure 3). Wherever compost or manure was applied, regardless of rate, N uptake averaged 230 kg ha⁻¹, 15% more than controls. Uptake did not differ between amendments or rates. The fact that similar amounts of N were taken up is somewhat surprising given that the amendments added from

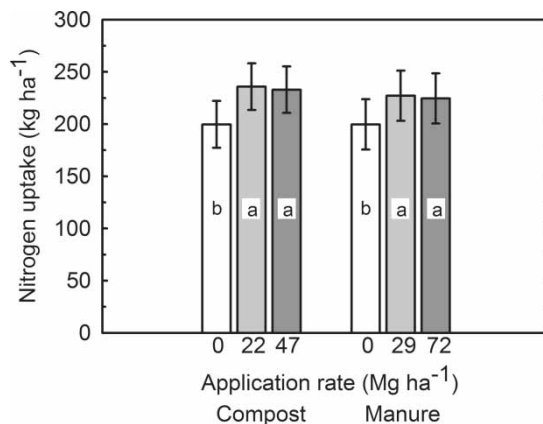


Figure 3. Nitrogen uptake affected by amendment and rate. Data are averaged across years. Means with a common letter are not significantly different according to *t* tests of pairwise differences at $P = 0.05$, with one exception. N uptake from 72 Mg manure ha^{-1} differed at $P = 0.057$ from the control. Data from controls are shown twice to facilitate comparison with each amendment. Each mean ($n = 24$ for controls, else $n = 12$) is shown with its 95% confidence interval.

73 to 702 kg ha^{-1} of plant-available N in the first year, a ten-fold range (Table 2). Uptake efficiency obviously decreased as application rate increased.

As expected, more N was taken up (significant at $P = 0.029$) in the first year after amendment application, compared to the second year (not shown). In 2000, all treatments including controls took up an average of 245 kg N ha^{-1} but only 203 kg N ha^{-1} 1 year later. Decreased uptake in the second year was likely a consequence of 1) less N available because some had been removed in the silage the year before, 2) less N mineralized from the amendments' organic matter (Moffitt 1992), and 3) possible N leaching losses during the first year's growing season and subsequent nongrowing season (Liang, Remillard, and Mackenzie 1991; Wright, Westermann, and Lehrs 1998).

A single degree-of-freedom comparison of 2001 data revealed, however, that corn growing in compost-amended plots took up 225 kg N ha^{-1} , nearly 17% more (significant at $P = 0.022$) than in manure-amended plots. This finding is in part a consequence of the relatively low silage yield from the manure-amended plots in 2001 (Figure 1). Greater uptake in 2001 from compost-treated than manure-treated plots could also be attributed to the slower but steadier mineralization of N from the more recalcitrant organic matter added in the compost. Also, soil and fertilizer N may have been immobilized in microbial tissues as a consequence of the straw added in the manure, particularly for the low-yielding, high manure treatment in 2001 (Figure 1), rendering the N unavailable for uptake. Compared to compost, manure had a C:N ratio 43% greater and 2.6 times as much total C

(Table 1). In addition, earthworm activity, stimulated by the manure's organic matter, may have increased both macroporosity (not measured) and infiltration in manure-treated plots, leading to the leaching of $\text{NO}_3\text{-N}$ from the corn's root zone through preferential flow paths (Amlinger et al. 2003; Richard 2005). Infiltration did tend to increase with increasing manure rates in 2001 (data to be reported later in a manuscript in preparation).

Slope Effects on Yield

As noted previously, soil slope increased nearly 5.5-fold from span 1 to span 6. Therefore, silage yield was characterized as a function of slope for each treatment without regard to the span on which the yield was measured. Silage yield decreased as slope increased for each treatment each year. These effects are illustrated in Figure 4 for the control and high manure treatments in 2000. The compost treatments are not shown because the slopes of their fitted relationships were similar to the control. Both relationships show a highly significant decrease in yield as slopes increased from 0.8 to 4.4%. These decreases are a consequence, in part, of past years' irrigation-induced erosion (Carter 1990). In this study, silage yield decreased with increasing sediment losses in both 2000 and in 2001, with the decrease more pronounced the second year (Lehrsch and Kincaid, unpublished). Losses of surface soil likely removed nutrients, thus limiting yields.

Another cause, perhaps more likely, of yield decreases with increasing slope may have been water stress. Irrigation-induced erosion, particularly

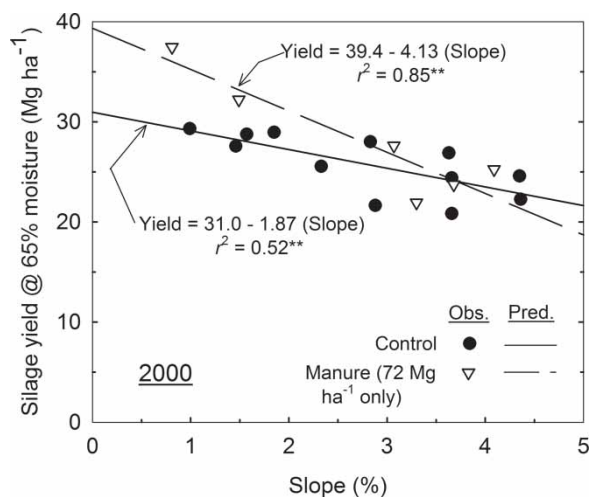


Figure 4. Slope effects on silage yield in 2000 from the 72 Mg manure ha^{-1} rate and control treatments.

from the steeper portions of the study site, removed portions of the Portneuf's relatively thin Ap horizon and, with subsequent tillage, increased the proportion of the Bk horizon in the corn's root zone. Rasmussen and Cary (1979) reported that when subsoil was mixed with topsoil, infiltration rates were about 38% less into mixed soil than surface soil. Lower infiltration rates lead to less recharge of the soil water reservoir, reduced water-use efficiency, more frequent water stress, lower yields, and increased runoff (Rasmussen and Cary 1979). Battiston, Miller, and Shelton (1987) attributed decreases in maize grain yield from eroded sites to 1) nutrient deficiencies, 2) moisture stress, and 3) reduced plant populations and seedling vigor due to poor seedbed conditions.

As slope increased, silage yield where 72 Mg manure ha⁻¹ were applied decreased at a rate more than twice that where no manure was applied (Figure 4). Nonetheless, the slopes of the two fitted relationships were not different at the $P = 0.05$ level, revealing that slope effects on yield were statistically similar from treatment to treatment. Where no amendments were applied, yield decreased on average nearly 1.9 Mg ha⁻¹ with every unit increase in slope. Such findings highlight the requirement for controlling irrigation-induced erosion with polyacrylamide or other practices, particularly on steeper slopes, to sustain silage yields in the future (Larney et al. 2000; Lehrs, Bjorneberg, and Sojka 2005). Producers must control or eliminate erosion that may increase field slope (Carter 1990; Lehrs, Bjorneberg, and Sojka 2005). Management practices such as vegetated filter strips or buried minidrainage decrease slopes by increasing deposition to eliminate convex slopes near field edges (Carter 1990). Findings illustrated in Figure 4 do not suggest that manure should not be applied to sloping fields. Indeed, data that account for slope effects shown in Figure 1 reveal that, compared to controls, yield increased, at times slightly and at times significantly, where moderate rates of both manure and compost were applied. Data in Figure 2 show that manure applied at rates up to about 29 Mg ha⁻¹ increased yields more than controls. When producing corn silage, manure applications are recommended to replace nutrients taken off in silage and to improve soil structure (Rasmussen and Cary 1979; Tisdale and Nelson 1975).

CONCLUSIONS

In the first growing season after fall application of compost and manure, silage yields were similar for both amendments at both rates. In the second growing season, about 20 months after amendments were applied, compost at each rate increased yield compared to controls. Also in the second year, yield was less from the high manure rate than the medium. In 2001, yield increased initially, then decreased with increasing manure rates. Nitrogen uptake, averaged across years, was 230 kg ha⁻¹ from all amendment-treated plots, 15% more than controls. Yield for each treatment decreased linearly as slope

increased. Yield tended to decrease at a greater rate with slope where excessive amounts of manure were applied, particularly in the first growing season after manure application.

In conclusion, silage yield increased in the second growing season after compost and manure were applied in the fall. Compost, applied at oven-dry rates up to 47 Mg ha⁻¹, increased yields. Manure, on the other hand, increased yields only where applied at oven-dry rates up to 29 Mg ha⁻¹.

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