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Long-Term Effects of Sustained Beef Feedlot Manure Application on Soil Nutrients, Corn Silage Yield, and Nutrient Uptake

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ABSTRACT

A field study was initiated in 1992 to investigate the long-term impacts of beef feedlot manure application (composted and uncomposted) on nutrient accumulation and movement in soil, corn silage yield, and nutrient uptake. Two application strategies were compared: providing the annual crop nitrogen (N) requirement (N-based rate) or crop phosphorus (P) removal (P-based rate), as well as a comparison to inorganic fertilizer. Additionally, effects of a winter cover crop were evaluated. Irrigated corn (*Zea mays* L.) was produced annually from 1993 through 2002. Average silage yield and crop nutrient removal were highest with N-based manure treatments, intermediate with P-based manure treatments, and least with inorganic N fertilizer. Use of a winter cover crop resulted in silage yield reductions in four of ten years, most likely due to soil moisture depletion in the spring by the cover crop. However, the cover crop did significantly reduce NO_3–N accumulation in the shallow vadose zone, particularly in latter years of the study. The composted manure N-based treatment resulted in significantly greater soil profile NO_3–N concentration and higher soil P concentration near the soil surface. The accounting procedure used to calculate N-based treatment application rates resulted in acceptable soil profile NO_3–N concentrations over the short term. While repeated annual manure application to supply the total crop N requirement may be acceptable for this soil for several years, sustained application over many years carries the risk of unacceptable soil P concentrations.

The concentration of beef cattle in large feedlots lends efficiency in feeding operations, but also results in large quantities of manure that can be challenging to utilize effectively. Historically, many feedlots have overapplied manure on land adjacent to feedlots because transportation costs to spread manure on more land area were higher than the perceived fertilizer value of the manure. With excessive rates of manure application, N, P, salts, and other manure constituents can accumulate in soil (Evans et al., 1977; Wood et al., 1996; Whalen and Chang, 2001). Manure for which the nutrient supply is not accurately credited for, or which is applied at excessive rates, has significant potential to degrade both surface and ground water quality (Burkart and James, 1999; Smith et al., 2001a, 2001b; Boesch et al., 2001). Generally, ground water quality concerns relate to NO_3–N leaching from manure. Nitrate N concentrations in the root zone beneath cropland receiving manure application in excess of crop removal are often elevated (Patni and Culley, 1989; Davis et al., 1997). Chang et al. (1990) found the change in soil properties following beef feedlot manure application to be mostly linear, varying with application rate and irrigation regime. Surface water quality concerns relate to both NO_3–N in leachate and runoff (Burkart and James, 1999) and both soluble and sediment bound P in runoff from manured fields (Heathwaite et al., 2000; Smith et al., 2001b). At excessive manure application rates on some soils, P leaching into the root zone can be found as well. Davis et al. (1997) found P movement into the root zone following manure application to be greater for sands than clay soils, although the primary water quality risk was surface runoff. Eghball (2003) found evidence of leaching of plant available P following four years of manure application on a silty clay loam soil to a depth of 30 cm. Following an additional four years of residual treatment where no manure was applied, Eghball et al. (2004) found evidence of further P movement to a depth of 60 cm.

However, manure application to land does not necessary result in degradation of water quality. Jokela (1992) found application of dairy manure for corn production resulted in soil profile NO_3–N concentrations similar to or slightly less than those found with agronomically equivalent rates of fertilizer N. Randall et al. (2000) in a study comparing equivalent amounts of available N as dairy manure or urea applied to corn, found NO_3–N and P concentrations, and NO_3–N losses, in tile drains to be similar for the two nutrient sources. Wood et al. (1996) found both commercial fertilizer and broiler litter applied at two rates to produce some NO_3–N concentrations in leachate above the drinking water standard, but on average leachate concentrations remained less than 10 mg L^{-1}. Although sustained application of high rates of manure increased soil P concentrations in a calcareous soil to as deep as 210 cm, James et al. (1996) felt there was no risk of ground water contamination by organic or inorganic P for their experimental situation.

Part of the risk to water quality from use of animal manure as a nutrient resource is significant uncertainty in the rate of nutrient mineralization from organic manure constituents. Mineralization rates of nutrients from manure or composted manure can vary widely. Motavalli et al. (1989) found first year availability of nutrients from injected dairy manure to range from 12 to 63% for N and 12 to 89% for P. In more recent work, Hadas and Portnoy (1994) found the rate of N release from composted manures ranged from 11 to 29% of their

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Abbreviations: CN, composted manure application rate to supply crop nitrogen requirement; CP, composted manure application rate to supply crop phosphorus removal; MN, manure application rate to supply crop nitrogen requirement; MP, manure application rate to supply crop phosphorus removal; NCK, inorganic nitrogen fertilizer check.

total N content after 32 weeks. Paul and Beauchamp (1994) found apparent N uptake in corn over an 8-wk period to be 2% for beef manure, 8% for composted beef manure, and 36% for ammonium sulfate, based on total N content of the organic residue. Smith et al. (1998) found N mineralized from organic fractions to range as high as 70% (solid chicken manure) over a 132-d period. Eghball and Power (1999) found first year availability of N to be approximately 38% from beef manure and 20% for composted beef manure. Eghball et al. (2002) found the availability of organic N in the year of application to range from around 18% for composted manure to 55% for poultry manure, and for beef cattle feedlot manure to have first year P availability ranging from 73% for compost to 85% for noncomposted manure.

Two practices that can increase the attractiveness of manure as a nutrient resource, and reduce the risk to water quality, are composting and the use of a winter cover crop. Composting manure can result in a significantly reduced-volume product that is more stable, with fewer pathogens and weed seed (Rynk, 1992). Total transportation costs are less, and the product is more attractive to producers applying it to fields. However, the process also loses significant carbon and nitrogen to the atmosphere as CO_2, CH_4, N_2O, as well as NH_3, resulting in less available C and N to be added back to soil and contributing to the total atmospheric greenhouse gas load (Eghball et al., 1997; Hao et al., 2001). The use of a fall-seeded, nonlegume cover crop, such as winter wheat (*Triticum aestivum* L.) or cereal rye (*Secale cereale* L.), can be an effective practice to reduce residual NO_3–N and the potential for NO_3–N leaching (Sainju et al., 1998).

This study was initiated in 1992 to evaluate the long-term impacts of annual application of beef feedlot manure and composted beef feedlot manure on soil accumulation and movement of applied nutrients for irrigated corn silage. Few long-term studies had been conducted at the time evaluating sustained high rates of manure application under irrigated conditions. The use of irrigation potentially increases the risk of N and P leaching, but also allows the production of high yielding crops that can remove greater amounts of N and P from soil. Also, we wished to evaluate the cumulative effects, beginning with initial manure application, of manure applied at "disposal" rates as practiced by many feedlots. Specific questions we sought to investigate were:

- Do beef manure and composted beef manure differ in their potential for N and P to accumulate in soil following land application, if proper crediting procedures are used?
- Will the application of manure to match crop removal of P allow soil P concentrations to remain relatively constant and below levels of environmental concern?
- Can the use of a winter cover crop reduce NO_3–N accumulation and leaching potential in the root zone following manure application?

MATERIALS AND METHODS

A center-pivot irrigated field, which had previously been in corn silage production, was selected for the research site in 1992. Soil at the site is a Crete silt loam (fine, smectitic, mesic Pachic Argiustolls). This deep soil is formed from loess, and the site is relatively level and moderately well-drained. Soil samples were collected before study initiation to a depth of 3 m, and afterward annually in the fall after silage harvest to a depth of 1.5 m, and analyzed for pH (water pH; Thomas, 1996), soil organic matter (loss-on-ignition method; Nelson and Sommers, 1996), ammonium N and nitrate N (KCl extraction, flow-injection colorimetric analysis with cadmium reduction of NO_3–N; Mulvaney, 1996), P (Bray-1 extraction; Kuo, 1996), K (ammonium acetate extraction; Helmke and Sparks, 1996), and Cl (specific ion electrode; Frankenberger et al., 1996). Soil samples were also collected to 3 m in 1998 and 2002. Applications of two manure sources (beef feedlot manure and composted beef feedlot manure) were made each spring according to two strategies: to approximately supply the total crop demand for N (N basis: 252 kg available N ha^{-1} annually), or to supply the approximate crop removal of P (P basis: 45 kg available P ha^{-1} annually) based on an expected yield of 20 Mg ha^{-1}. To account for soil and climate effects on rates of N mineralization from prior years' manure application, credit for residual NO_3–N to 1.5 m from samples taken in the fall after harvest were used to adjust manure application rates for the following spring.

The study was a split-plot design, with four replications of the presence or absence of a winter cover crop as the main plot, and organic treatments of manure at nitrogen rate (MN), manure at phosphorus rate (MP), compost at nitrogen rate (CN), compost at phosphorus rate (CP), as well as a commercial fertilizer check (NCK) as subplot treatments. Individual subplots were 6.1 m wide (eight rows) and 244 m long. The winter cover crop, either winter wheat or rye, was planted in September after forage harvest, then destroyed with a combination of glyphosate and tillage in March. For beef feedlot manure, 35% of the total N and 22% of the total P was considered available the first year. For composted beef feedlot manure, 25% of the total N and 22% of total P was considered available in the year of application. These mineralization rates were conservative estimates based on the investigators' experience at the time, and were chosen to maximize crop nutrient uptake.

From 1993 through 1997, manure from research feedlot pens of the U.S. Meat Animal Research Center (USMARC) was scraped, transported to near the experimental site, and stockpiled with a portion being composted. Compost windrows were turned six to eight times until the windrow temperature remained relatively stable. From 1998 on, compost was purchased from a commercial feedlot, while manure was obtained from the USMARC research feedlot. Before application, samples of manure and composted manure were analyzed for total N, NH_4–N, NO_3–N, and P (AOAC International, 2003a, 2003b; Mulvaney, 1996). From 1993 through 2002, the beef feedlot manure averaged 1.4% total N (range 0.8–1.8%), 1.1% P_2O_5 (range 0.5–3.2%), with a C to N ratio of 10.3:1 (range 9:1–12:1) on a dry basis. The composted beef feedlot manure averaged 1.2% total N (range 0.7–1.8%), 0.9% P_2O_5 (range 0.1–1.7%), with a C to N ratio of 9.8:1 (range 9:1–11:1) on a dry basis. Figure 1 and Table 1 provide the average annual application rates for manure and composted manure. Earlier analysis of data from this study has shown that the conservative credit allowed for P mineralized from compost or manure (22% of total P) was too low (Ferguson and Nienaber, 1998), resulting in increasing soil test P values in the MP and

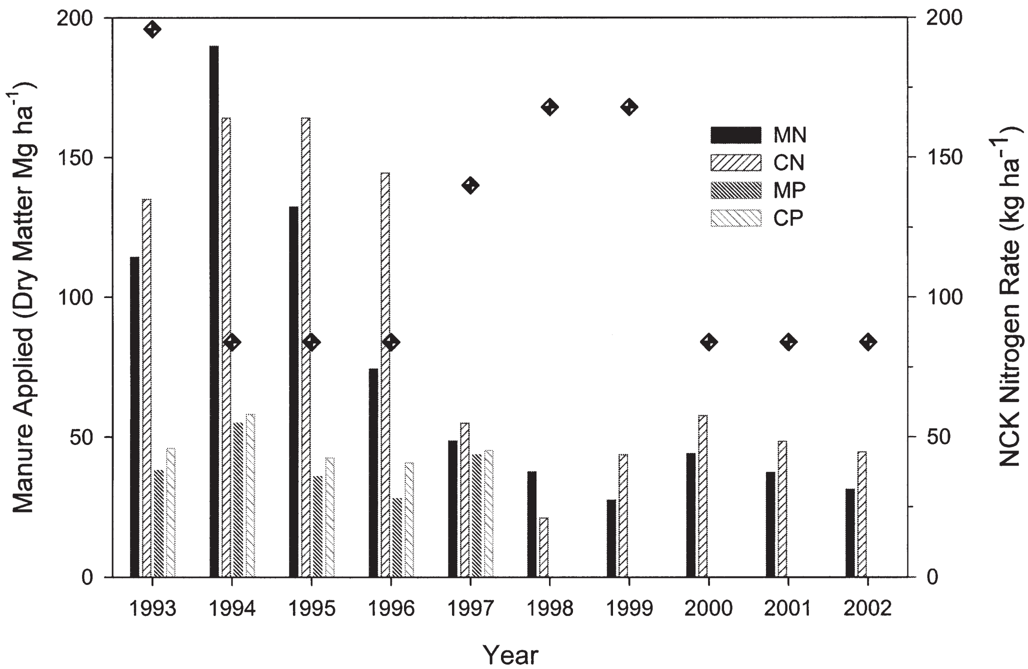

Fig. 1. Annual manure application rates (bars) and NCK treatment fertilizer application rate (diamond). CN, composted manure application rate to supply crop nitrogen requirement; CP, composted manure application rate to supply crop phosphorus removal; MN, manure application rate to supply crop nitrogen requirement; MP, manure application rate to supply crop phosphorus removal; NCK, inorganic nitrogen fertilizer check.

CP treatments. Beginning in 1998, no manure was applied to the MP and CP treatments, since soil test P levels were well above the critical level (15 mg kg^{-1} Bray-1 P) where supplemental P fertilization would be recommended for optimum yield (Shapiro et al., 2003). Fertilizer N was applied to the MP and CP treatments in subsequent years at the same rate as the NCK treatment.

Manure was broadcast in the spring with a truck-based, rear discharge flail spreader and incorporated after application with a tandem disc. The NCK treatment received 84 kg N ha^{-1} as sidedressed NH_3 in June. No phosphorus fertilizer was applied to the NCK treatment, since soil test P levels were above the critical level of 15 mg kg^{-1} Bray-1 P. Chlorophyll meter readings were taken from each strip (SPAD-502 m; Minolta, Tokyo, Japan) beginning at approximately V6 through V14 (leaf stages according to the uppermost fully expanded leaf). Chlorophyll meter readings from treatment strips were compared to small, hand-fertilized reference plots embedded within the NCK strips. If chlorophyll meter readings indicated a developing N deficiency (<95% of chlorophyll meter readings in fully fertilized N reference plots) in the NCK, MP, or CP treatments, supplemental N was applied (up to 112 kg N ha^{-1}) with a high clearance applicator as 28% N UAN (urea–ammonium nitrate) solution.

Corn forage was harvested each August, with weights of forage recorded from each strip, and subsamples retained from each strip for moisture and nutrient analysis. Subsamples were weighed, oven-dried at 105°C, then reweighed to determine stover moisture content at harvest, from which silage dry matter yield was calculated. Dried subsamples were ground with a mill to pass a 2-mm sieve, and a subsample retained for laboratory determination of total N and P content (AOAC International 2003a, 2003b).

Statistical analysis was performed using PROC GLM in

Table 1. Mean annual application rates and treatment response over ten years (1993–2002).†

	Applied dry matter	Total N applied	Total P applied	Silage dry matter yield	Silage N uptake	Silage P uptake
	Mg ha^{-1}	kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}	
			Manure treatment‡			
MN	74b	696a	259b	17.3a	214a	42a
CN	92a	711a	311a	17.1a	214a	42a
MP	20c	233b	60c	16.5b	193bc	40b
CP	23c	261b	89c	16.6b	196b	40b
NCK	0d	118c	0d	16.0c	190c	33c
CV, %	19.4	15.1	17.8	5.9	8.5	8.4
n	80	80	80	80	80	80
			Cover crop treatment			
No cover				16.8a	203a	38b
With cover				16.6b	200a	40a
CV, %				5.9	8.5	8.4
n				160	160	160

† Means followed by different letters are significantly different at a probability level of 0.05.
‡ CN, composted manure application rate to supply crop nitrogen requirement; CP, composted manure application rate to supply crop phosphorus removal; MN, manure application rate to supply crop nitrogen requirement; MP, manure application rate to supply crop phosphorus removal; NCK, inorganic nitrogen fertilizer check.

SAS (Version 8.02; SAS Institute, 2001). Treatment means were separated using Duncan's Multiple Range Test at a probability level of 0.05.

RESULTS AND DISCUSSION

Application Rates

Table 1 illustrates the treatment average application rates, and Fig. 1 the annual manure and fertilizer application rates for the study. Manure application rates were adjusted annually based on residual NO_3–N from the preceding year, so the MN and CN application rates declined substantially as NO_3–N levels increased (Fig. 1). The ten-year mean dry matter application rate for the MN treatment was 74 Mg ha^{-1}, while the CN treatment ten-year mean was 92 Mg ha^{-1}, reflecting the difference in assumed credit for the rate of N mineralization from the two materials. Averaged over the first ten years of the study, there were no significant differences in total N applied between the MN and CN treatments, or the MP and CP treatments (Table 1). While the MN and CN treatments supplied the same amount of total N, the total P applied over the ten-year period was significantly greater for the CN treatment. The MP and CP manure dry matter application rates ranged from 28 to 58 Mg ha^{-1} in the first five years of the study when manure was applied to those treatments. Over the first ten years of the study, there were not significant differences ($P > 0.05$) in the total P applied between MP and CP treatments. Nitrogen fertilizer applied to the NCK treatment averaged 118 kg N ha^{-1} (Table 1), but ranged from 84 to 196 kg N ha^{-1} (Fig. 1). Annual NCK N rates were most commonly 84 kg N ha^{-1}. In four of the ten years when chlorophyll meter readings (data not shown) indicated a developing N deficiency between V6 and V14 for the NCK treatment, additional N was applied with a high clearance applicator (Fig. 1). Supplemental fertilizer N was also added to MP and CP treatments in 1993 (112 kg ha^{-1}), 1997 (56 kg ha^{-1}), and 1999 (84 kg ha^{-1}) when chlorophyll meter readings indicated a developing N deficiency. (Supplemental N rates were based on estimates of the N required to optimize yield, given the crop growth stage when N was applied.)

Silage Yield and Nutrient Uptake

Corn silage yield, N uptake, and P uptake are shown in Table 1. Annual silage yield and silage uptake of N and P are shown in Fig. 2, 3, and 4. Over the ten year duration of the study, the MN and CN treatments yielded significantly greater than the MP and CP treatments, which also yielded significantly greater than the NCK treatment. Annual total N application averaged 696 kg ha^{-1} for the MN treatment, and 711 kg ha^{-1} for the CN treatment (Table 1). For the MN treatment, 244 kg N ha^{-1} (35%) was considered available in the year of application, while 178 kg N ha^{-1} (25%) was considered available for the CN treatment. Both values are less, on average, than the target of providing 252 kg ha^{-1} available N each year. Silage yield exceeded the yield goal of 20 Mg ha^{-1} in three years, and was less than the yield goal in seven years. Crop removal for both MN

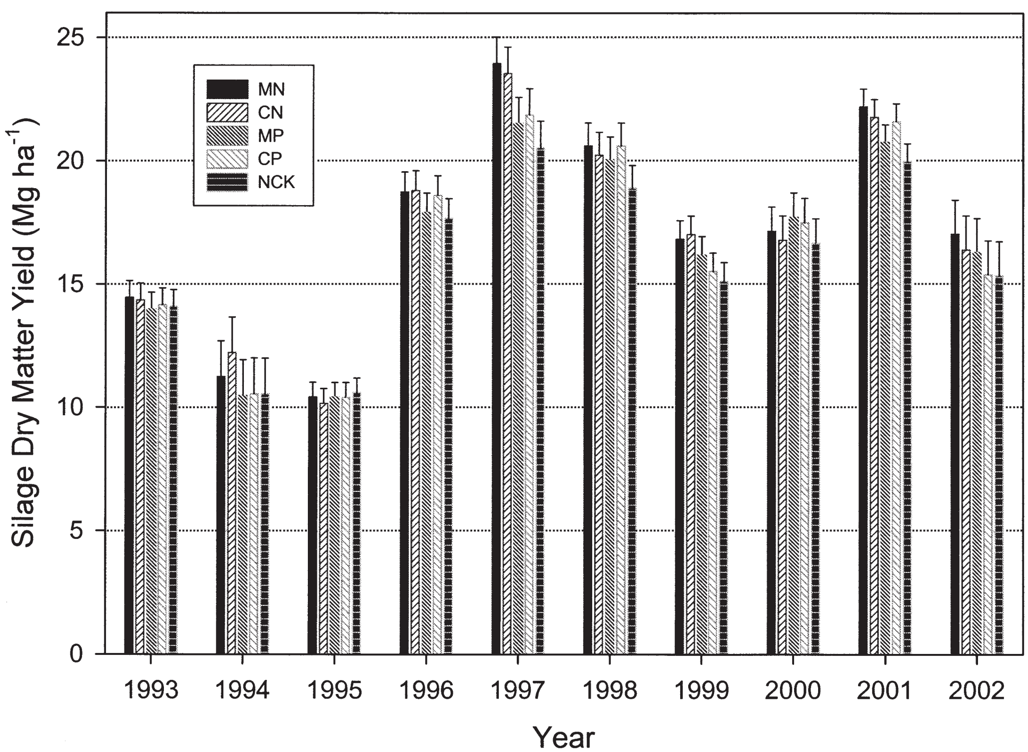

Fig. 2. Silage dry matter yield as influenced by manure treatment. Error bars that do not overlap indicate treatment means that are significantly different at a probability level of 0.05. CN, composted manure application rate to supply crop nitrogen requirement; CP, composted manure application rate to supply crop phosphorus removal; MN, manure application rate to supply crop nitrogen requirement; MP, manure application rate to supply crop phosphorus removal; NCK, inorganic nitrogen fertilizer check.

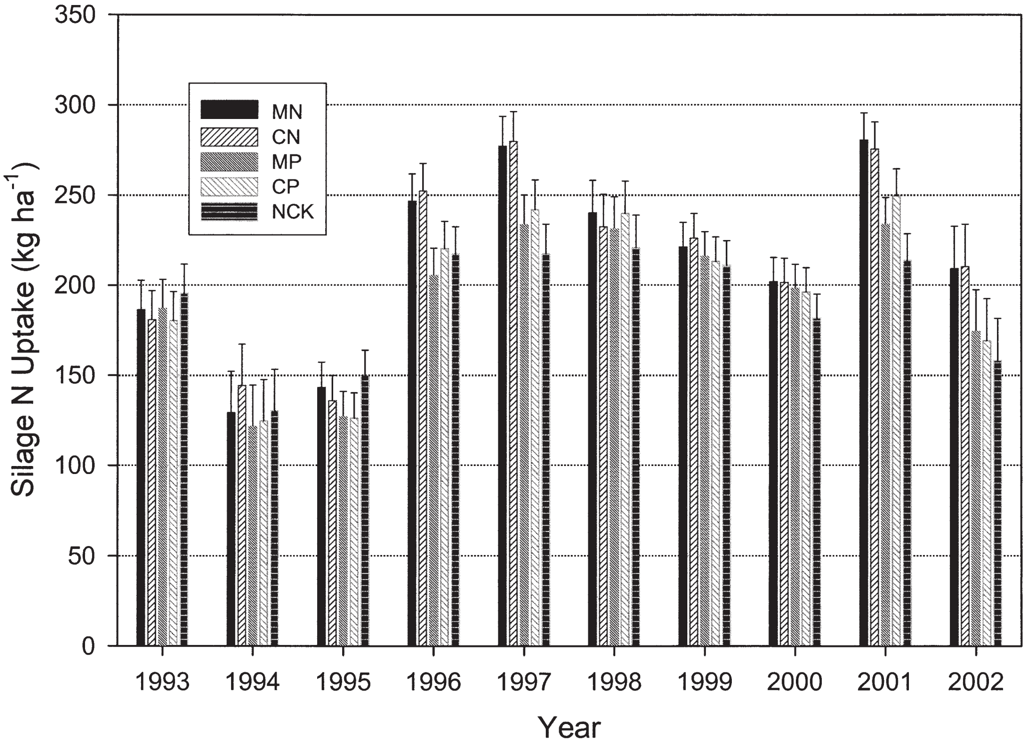

Fig. 3. Silage N uptake as influenced by manure treatment. Error bars that do not overlap indicate treatment means that are significantly different at a probability level of 0.05. CN, composted manure application rate to supply crop nitrogen requirement; CP, composted manure application rate to supply crop phosphorus removal; MN, manure application rate to supply crop nitrogen requirement; MP, manure application rate to supply crop phosphorus removal; NCK, inorganic nitrogen fertilizer check.

and CN treatments averaged 214 kg N ha^{-1} (Table 1); in only two years (1997 and 2001) did crop N removal exceed the target N availability rate for the MN and CN treatments (Fig. 3). The lower average yield for the NCK treatment (Table 1) suggests N availability may have reduced yield potential for that treatment. Although in six of the ten years, chlorophyll meter readings at sidedress time did not indicate a need for additional N, the average N applied for the NCK treatment (118 kg ha^{-1}) was well below crop removal in all years (Fig. 3). Nitrogen uptake in the crop was not affected by treatment in the first three years of the study (Fig. 3). As the pool of potentially mineralizable N increased with high rates of manure application, there was a trend for greater N uptake with the MN and CN treatments compared to other treatments from 1996 on. Average annual total P application for the MP and CP treatments (including years when no manure was applied) was 60 kg ha^{-1} for the MP treatment, and 89 kg ha^{-1} for the CP treatment (Table 1). Using the initial P availability credit of 22% in the year of application, P availability would average 13 and 20 kg P ha^{-1} annually for MP and CP treatments, respectively. However, using a more realistic value of 70% P availability in the year of application (Eghball et al., 2002), P availability would average 42 and 63 kg P ha^{-1} for the MP and CP treatments, respectively. These values are closer to the annual average crop removal of 40 kg P ha^{-1} for these treatments. Phosphorus uptake by silage in most individual years was not significantly influenced by manure treatment (Fig. 4), but the average P uptake over ten years was significantly different between the high and low manure rate treatments (Table 1). Silage P uptake from the NCK treatment, which received no P fertilization, was significantly lower in most years than treatments receiving manure (Fig. 4).

In five of the ten years of the study, there was a significant cover crop effect on silage yield (Fig. 5). In four of those years (1995, 1999, 2000, and 2002) the presence of the winter cover crop reduced silage yield, most likely due to soil moisture depletion by the cover crop, although soil moisture was not measured. This was especially pronounced in the drought year of 2002, when the cover crop reduced silage yield by 2.2 Mg ha^{-1}. Averaged over ten years, the presence of a winter cover crop significantly reduced silage yield by 0.2 Mg ha^{-1} (Table 1). There were no significant interactions between nutrient and cover crop treatments for silage yield or nutrient uptake, except in 2001, when the high rate manure treatments (MN, CN) had greater N uptake following the cover crop. All other treatments in that year had lower N uptake following the cover crop.

Soil Residual Nitrate Nitrogen

Manure treatment effects on soil residual NO_3–N are shown in Fig. 6. Before study initiation, the site was sampled to a depth of 3 m in 1992. This sampling depth was repeated in 1998 and 2002. In all other years of the study, samples were collected to a depth of 1.5 m. In 1993 there were no significant treatment effects on residual NO_3–N, so the mean of all treatments is shown. In subsequent years, there were significant treatment effects on residual NO_3–N for at least one of the depth increments.

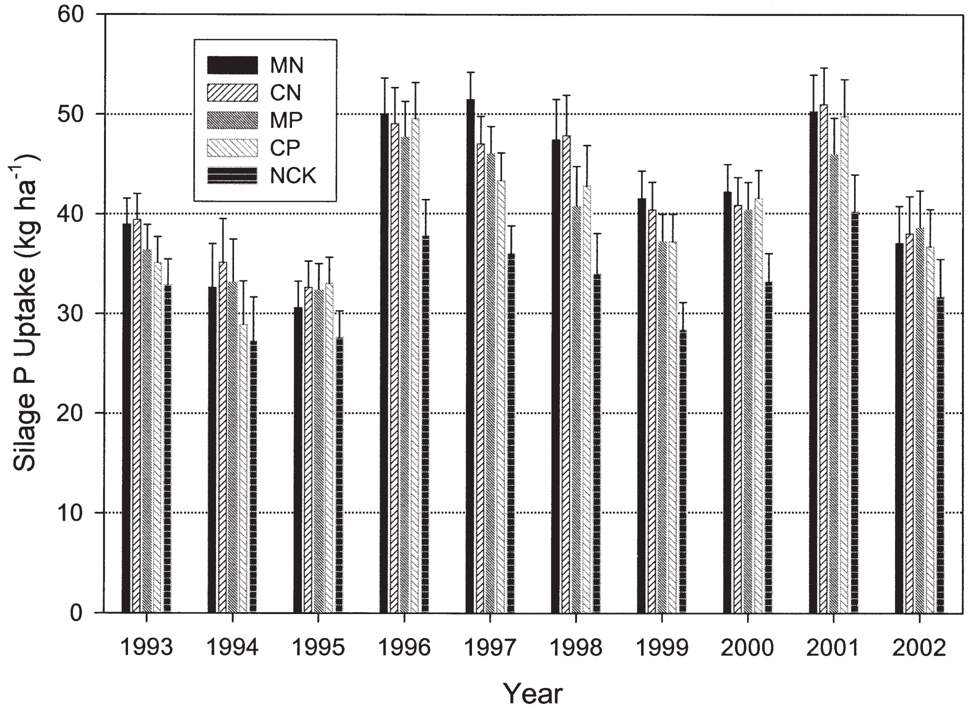

Fig. 4. Silage P uptake as influenced by manure treatment. Error bars that do not overlap indicate treatment means that are significantly different at a probability level of 0.05. CN, composted manure application rate to supply crop nitrogen requirement; CP, composted manure application rate to supply crop phosphorus removal; MN, manure application rate to supply crop nitrogen requirement; MP, manure application rate to supply crop phosphorus removal; NCK, inorganic nitrogen fertilizer check.

The primary manure treatment effect on residual NO_3–N is higher root zone and shallow vadose zone concentrations for MN and CN treatments in most years. Also, the CN treatment has significantly higher NO_3–N concentrations in some years at some depths than the MN treatment. This trend is particularly evident in 1998 and 2002 at deeper sampling depths. Higher composted manure application rates were targeted for the CN treatment due to the supposedly lower mineralization rate of composted manure (25% of total N available in the year of application) compared to noncomposted manure (35% of total N available in the year of application). However, these data suggest that the N mineralization rate from composted manure was similar to or greater than noncomposted manure. Total N applied per year on average was statistically the same for the MN and CN treatments (Table 1). However, in some years the CN treatment resulted in the accumulation of excess NO_3–N in the root zone (0–1.5 m) and greater leaching into the shallow vadose zone (1.5–3 m). Still, soil NO_3–N concentrations for all treatments were relatively low below a depth of 0.5 m, suggesting that the accounting procedure used to develop manure application rates effectively minimized the potential for substantial NO_3–N leaching out of the root zone.

Winter cover crop effects on soil residual NO_3–N for the high manure rate treatments (MN, CN) are shown in Fig. 7. In early years of the study, there were no effects of the winter cover crop on residual NO_3–N. After 1998, there was consistently less NO_3–N at deeper depths of the root zone following the presence of a winter cover crop. There have been no cover crop effects on NO_3–N at depths below 1.5 m. These data (particularly 2001 and 2002) suggest that the winter cover crop is immobilizing NO_3–N in the upper portion of the soil profile, preventing NO_3–N accumulation in the lower portion of the root zone and leaching into the vadose zone. This supports the hypothesis that the use of a winter cover crop with high rates of manure application can reduce the potential for NO_3–N loss to ground water.

Soil Phosphorus

Trends in soil P concentration with manure treatment in the root zone are shown in Fig. 8 and 9. There was a substantial increase in P concentration at shallow depth

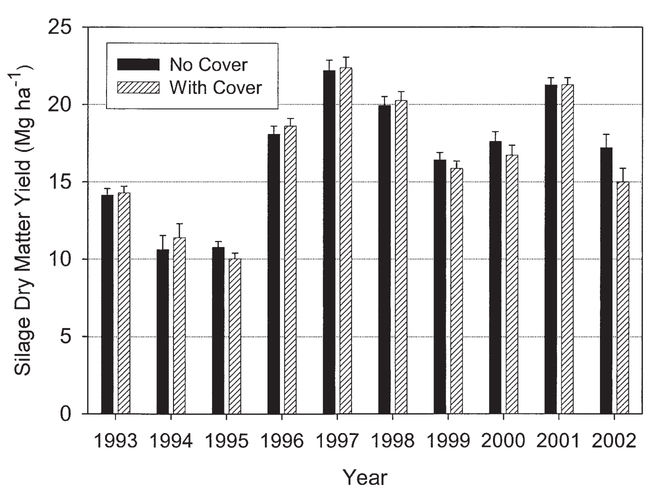

Fig. 5. Silage dry matter yield as influenced by cover crop treatment. Error bars that do not overlap indicate treatment means that are significantly different at a probability level of 0.05.

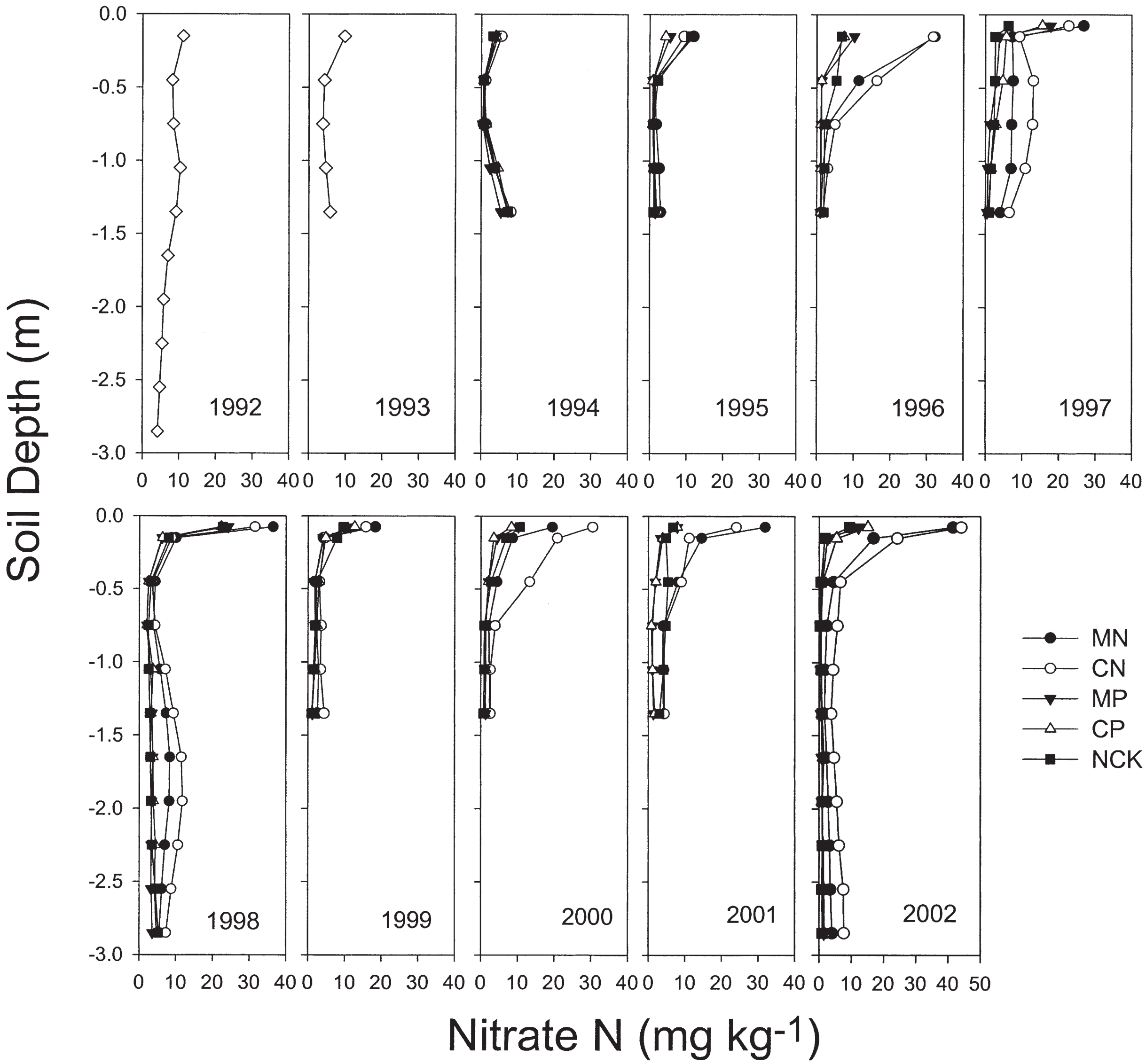

Fig. 6. Soil residual NO_3–N as influenced by manure treatment. CN, composted manure application rate to supply crop nitrogen requirement; CP, composted manure application rate to supply crop phosphorus removal; MN, manure application rate to supply crop nitrogen requirement; MP, manure application rate to supply crop phosphorus removal; NCK, inorganic nitrogen fertilizer check.

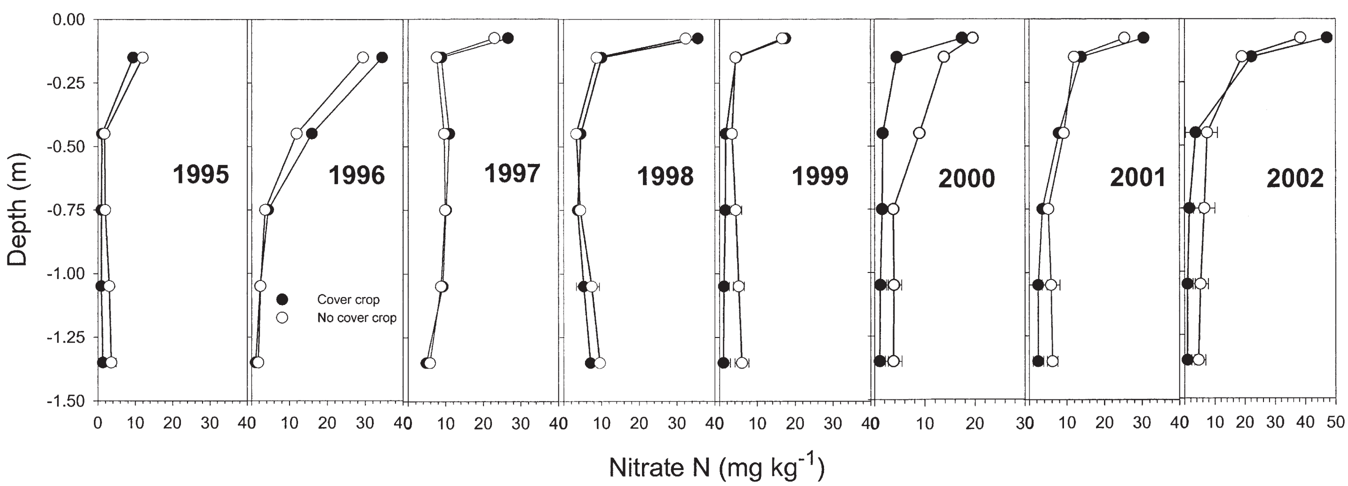

Fig. 7. Soil residual NO_3–N as influenced by cover crop, mean of MN and CN treatments. Error bars indicate means that are significantly different at a probability level of 0.05. CN, composted manure application rate to supply crop nitrogen requirement; MN, manure application rate to supply crop nitrogen requirement.

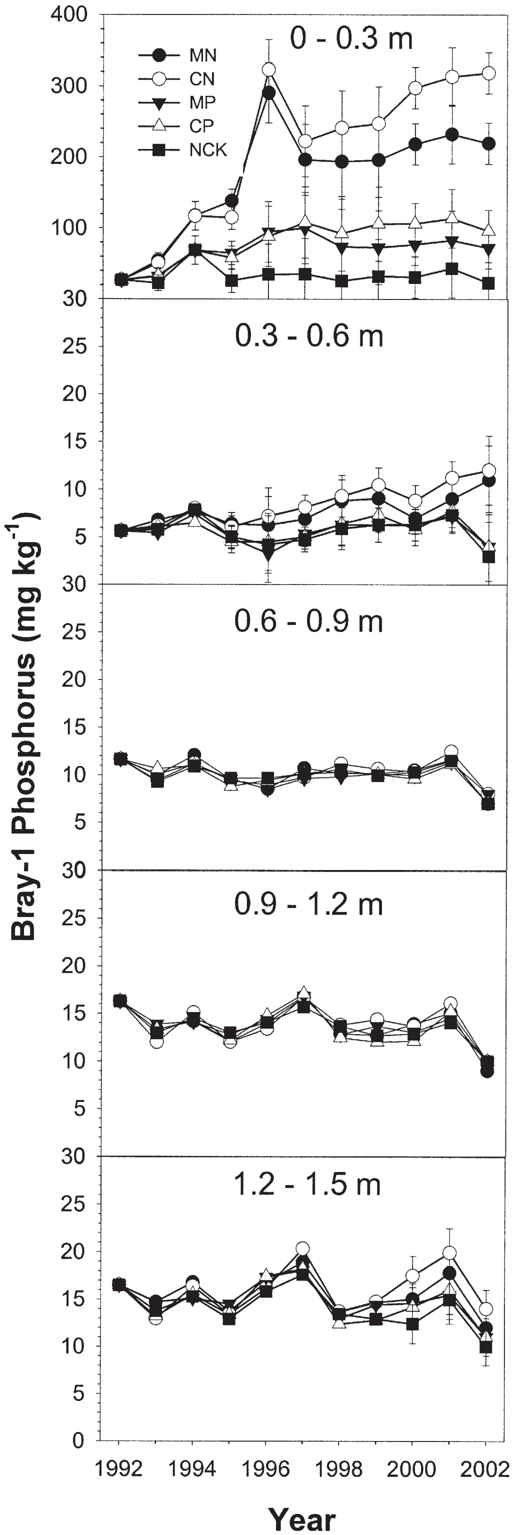

Fig. 8. Soil Bray-1 P as influenced by manure treatment. Error bars that do not overlap indicate treatment means that are significantly different at a probability level of 0.05. CN, composted manure application rate to supply crop nitrogen requirement; CP, composted manure application rate to supply crop phosphorus removal; MN, manure application rate to supply crop nitrogen requirement; MP, manure application rate to supply crop phosphorus removal; NCK, inorganic nitrogen fertilizer check.

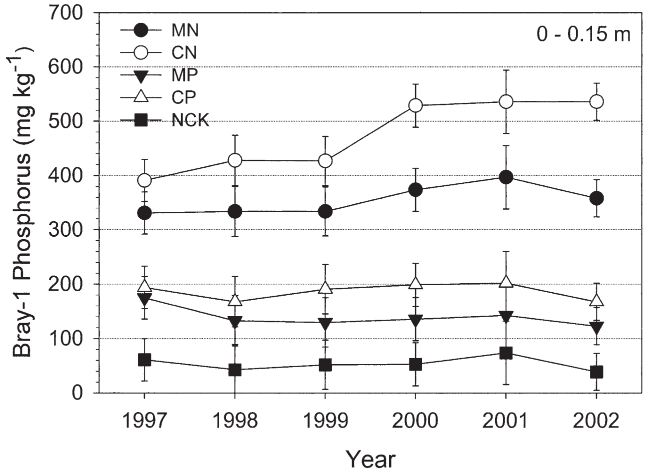

Fig. 9. Soil Bray-1 P as influenced by manure treatment, 0- to 0.15-m depth increment. Error bars that do not overlap indicate treatment means that are significantly different at a probability level of 0.05. CN, composted manure application rate to supply crop nitrogen requirement; CP, composted manure application rate to supply crop phosphorus removal; MN, manure application rate to supply crop nitrogen requirement; MP, manure application rate to supply crop phosphorus removal; NCK, inorganic nitrogen fertilizer check.

increments for all treatments other than NCK. Soil P concentrations for the MN and CN treatments have increased over the duration of the study. At the end of the study period in 2002, the shallow, 0- to 0.15-m (6-inch) depth P concentration exceeded 500 mg kg^{-1} for the CN treatment and was over 300 mg kg^{-1} for the MN treatment (Fig. 9). (Sampling in the 0- to 0.15-m layer began in 1997.) These concentrations are well above reporting and/or regulatory limits in Nebraska and other states. The significant difference (Duncan's Multiple Range Test, $p \leq 0.05$) in soil P concentration between CN and MN treatments from 2000 on reflect the higher application rates for the CN treatment, based on the assumption that N mineralization would be less from composted manure than uncomposted manure. Manure application to the MP and CP treatments was discontinued in 1998, and soil P concentrations for the MP and CP treatments at depths of 0.15 and 0.3 m have remained relatively steady.

Sustained manure application to provide all of the crop N requirement (MN and CN treatments) resulted in significant P movement into the 0.3- to 0.6-m depth increment (Fig. 8), while the lower application rate manure treatments (MP and CP) were not significantly different from NCK, which received no manure or fertilizer P over the duration of the study. This is a similar depth of P movement following N-based manure application found by Eghball et al. (2004). There were no treatment effects on soil P in the depth intervals of 0.6 to 1.2 m. There was an *apparent* significant treatment effect on soil P in the 1.2- to 1.5-m depth increment, with higher Bray-1 P concentrations for the CN and MN treatments. However, there is no treatment effect on soil P at depth increments above (Fig. 8) or below (data not shown) this depth. A likely explanation for this apparent increase is soil contamination from shallow depths. A sampling tube 1.2 m long was used to collect soil samples. Consequently, the tube was re-inserted into the borehole to collect samples from 1.5- to 3-m depths, allowing the potential for soil high in P content from the surface to fall into the borehole. Samples that were obviously contaminated were deleted from the dataset before analysis. However, some contaminated samples probably remained in the 1.2- to 1.5-m dataset, and are the most likely explanation for this apparent treatment effect on soil P. There were no cover crop treatment effects on soil P concentration.

CONCLUSIONS

This study evaluated the impacts of more than a decade of high application rates of beef feedlot manure on the accumulation and movement of NO_3–N and P in soil. We found little difference between the effects of manure and composted manure on crop yield, nutrient uptake, or soil nutrient accumulation in soil. Differences were related primarily to manure application rate rather than source. Silage yield was increased most years by the application of manure compared to commercial N fertilizer. Crop uptake of N was increased with manure application relative to commercial N fertilizer after the first three years of the study, reflecting an increasing labile pool from which to mineralize N for those treatments. In general, the accounting procedures used to develop manure application rates for the MN and CN treatments (based on annual root zone sampling for residual NO_3–N) resulted in relatively low soil NO_3–N concentrations throughout the root zone, although higher than commercial N fertilizer levels. However, commercial fertilizer rates in most years may have been suboptimal for yield. This suggests that successive applications of manure to supply the entire crop N requirement may be acceptable over the short term if soil nitrate levels are closely monitored and credited when calculating manure application rates. The use of a winter cover crop was effective at reducing potentially leachable NO_3–N near the bottom of the root zone, but also reduced silage yield in some years even with irrigation, most likely due to reduced soil moisture early in the growing season.

Longer-term application of manure to supply the entire crop N requirement will lead to excessive soil P accumulation, and the potential for P movement into the soil profile or off-site. While soil surface P concentrations at or above 500 mg kg^{-1} are of concern for this site, the flat landscape position, silt loam soil with calcareous subsoil, and distance from waterways reduce the potential for surface water contamination with soluble or sediment-bound P, or leaching of P to ground water. Application of manure to match crop P removal, and basing application rates on at least 70% of total manure P being available to the crop in the year of application, effectively utilizes nutrient resources from manure and minimize the environmental risk of manure application.

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