SITE-SPECIFIC MANURE APPLICATION EFFECTS ON CORN YIELD AND N STATUS

Bahman Eghball, Christopher J. Bauer, James S. Schepers, and Charles A. Shapiro[1]

Manure, a renewable resource, is an excellent source of nutrients that can be substituted for synthetic types of fertilizers. The organic matter in manure can enhance the physical and chemical properties of soils, especially infertile soils, as these soils typically contain low levels of organic matter and nutrients, and have low water holding capacities. The objective of this study was to evaluate the ability of manure application for improving crop yield and N status in less productive areas within a field. The treatments included applications of site-specific manure (SSM), uniform manure (UM), uniform commercial fertilizer, and a no treatment check. Field strips 40 ft (16 corn rows) wide and 2200 ft long were used in three years (1998 to 2000). For the SSM treatment, manure was applied to areas within the field where organic C was < 1.4%. Chlorophyll meter readings and leaf tissue samples were collected from all treatments. Averaged across years, the UM and SSM treatments produced significantly greater grain yields than the commercial fertilizer treatment. The UM and SSM treatments also resulted in higher levels of N uptake than the commercial fertilizer treatment. Stalk NO_3-N was less for uniform manure than fertilizer application indicating over-application of N with the fertilizer treatment. Site-specific manure application is a good method of improving less productive soils or sites within a field.

Introduction

Sufficient water and available nitrogen (N) are the two most important factors in optimizing corn (*zea mays L.*) growth and grain production. However, adequate levels of these substances can vary significantly across agricultural landscapes with fluctuating levels of soil organic matter. This is especially true with sandy soils, as they typically contain low levels of organic matter, low nutrients, low water holding capacities, and overall poor soil structure. Sandy soils can lead to nutrient and water stress during important crop growth stages, potentially leading to substantial yield declines. As shown by Sims et al. (1994), N deficiency by V6-V7 growth stage can lead to a 20% reduction in grain dry matter production. Denmead and Shaw (1960) indicated that water stress at the R1 stage affected the grain yield by as much as 50%. By increasing organic matter levels in less productive soils, the chemical and physical properties of those soils can be improved.

Manure is a valuable nutrient source and soil amendment for crop production (Freeze and Sommerfeldt, 1985; Campbell et al, 1986). Eghball and Power (1994) estimated that the value of N, P, and K in beef cattle feedlot manure in the U.S. to be approximately 461 million dollars. Sahs and Lesoing (1985) reported greater corn yield with manure application than that for synthetic fertilizer. Overall, studies show that the beneficial effects of manure in restoring soil productivity are much greater in manure compared to those of synthetic fertilizers (Whitney et al., 1950; Herron & Erhart, 1965; Aina & Egolum, 1980; Dormarr et al., 1988). Manure is an excellent source of organic matter. Sommerfeldt and Chang (1985) found that manure application to irrigated land tended to decrease the amount of soil aggregates <1 mm while increasing the amount of aggregates >1 mm in the 6-12 in soil depth. The formation of larger

---

[1] USDA-ARS and University of Nebraska, 121 Keim Hall, University of Nebraska
68583 Email: **beghball1@unl.edu**

soil aggregates as a result of the addition of organic matter in manure can lead to better soil structure and in turn lead to an increased water holding capacity, increased infiltration (reduced runoff), and reduced surface erosion. By reducing erosion, the amounts of P transported by runoff is also reduced (Eghball and Gilley, 2001), thus reducing the potential for eutrophication of surface waters from P contamination. Hornik and Parr (1987), Hornik (1988) and Larney and Jenzen (1996 and 1997) used manure to improve productivity of sandy or infertile soils.

With the advent of yield monitors and Global Positioning Systems (GPS), site-specific manure applications can allow a producer to apply manure and needed nutrients to less productive areas of the field. This should improve crop productivity in deficient areas while limiting the over-application of manure and nutrients to productive sites within a field. The objective of this study was to evaluate the ability of site-specific manure application to improve crop productivity and N uptake in less productive areas within a field.

Materials and Methods

The experiment was conducted from 1998 to 2000 on a private farm in Hamilton County near Phillips, Nebraska on a center pivot irrigated field with continuous corn (*Zea mays L.)*. A ridge-till system, consisting of stalk chopping, cultivation, and ridging was utilized. The experimental area consisted of Hord silt loam, Invale loamy sand, Thurman fine sandy loam, Ortello fine sandy loam, Uly silt loam, and Alda loam soils.

The experimental design was a randomized complete block with four blocks and four treatments within each block. Treatments included strips (40 ft wide and 2200 ft long) of site-specific manure application, uniform manure application, uniform commercial fertilizer application, and a no-treatment check. Each year, organic C levels were determined by grid sampling of the area, with two samples taken, 20 to 30 in apart, to a depth of 6 in at each grid point. Samples were collected every 80 ft in the middle of each strip. Each point was geo-referenced using a differential global positioning system (DGPS). Samples were air-dried in a greenhouse drying room. Dried samples were hand ground using a mortar and pestle and analyzed for organic C. In the site-specific manure treatment, manure was applied to areas within the strips with a soil C concentration < 1.4%.

Beef cattle feedlot manure was uniformly applied to manure strips on December 9, 1997 and December 15, 1998 using a manure spreader at a rate of 25 ton ac^{-1} wet weight basis to provide for 170 lb N ac^{-1}. Manure was applied on January 18, 2000 at a rate of 15.4 ton ac^{-1} to provide for 137 lb N ac^{-1}. Manure analysis results are reported in Table 1. Nitrogen availability in the first year after application was assumed to be 40% of total manure N (Eghball and Power, 1999a, 1999b). Nitrogen availability in subsequent years was estimated by soil sampling for nitrate. In 1997, the site-specific manure strips received uniform application of manure to the entire strip since almost all of the strips had soil organic C content <1.4%. Therefore, the site-specific manure and uniform manure treatments were essentially the similar during this first year.

The N rate was chosen to provide for a corn production level of 170 bu ac^{-1} (Hergert et al.,1995) in compliance with the land owners request. Starter fertilizer as liquid ammonium polyphosphate (10-34-0, N-P-K+ Zn) was band applied at planting to fertilizer strips only at a rate of 9 lb P ac^{-1} in all three years. Anhydrous ammonia (82-0-0) was side dressed to fertilizer

Table 1. Manure analysis results for beef cattle feedlot manure applied to plots in December 1997 for growing season of 1998 (Average of four samples).

Element	1997	1998	1999
Organic Nitrogen, %	**2.15**	**0.75**	**1.38**
Ammonium-N, ppm	**1462**	**1871**	**1462**
Nitrate-N, ppm	**71**	**64**	**67**
Total N (TKN), %	**2.30**	**1.52**	**1.54**
Phosphorous, %	**0.65**	**0.34**	**0.72**
Potassium, %	**1.82**	**1.67**	**1.33**
Sulfur, %	**0.34**	**0.29**	**0.37**
Calcium, %	**1.52**	**1.12**	**2.08**
Magnesium, %	**0.55**	**0.64**	**0.54**
Sodium, %	**0.23**	**0.20**	**0.18**
Zinc, ppm	**167**	**134**	**238**
Iron, ppm	**7761**	**15137**	**7157**
Manganese, ppm	**171**	**242**	**227**
Copper, ppm	**36**	**30**	**33**
EC, mmho cm^{-1}	**24**	**15**	**20**
pH 1:1	**8.2**	**8.7**	**8.3**
Moisture, %	**26.2**	**44.0**	**27.4**
Dry Matter, %	**73.8**	**56.0**	**72.6**
Ash, %	**50.9**	**-**	**69.4**
Organic Matter, %	**49.1**	**18.6**	**30.6**
Organic Carbon, %	**28.5**	**10.8**	**17.8**
C:N ratio	12	12	12

strips on June 22, 1998 at a rate of 180 lb N ac^{-1}. Anhydrous ammonia was applied pre-plant at a rate of 190 lb N ac^{-1} on April 29, 2000.

In 1998, manure was applied to areas < 1.4% soil organic C on the site-specific manure strips. All areas within the site-specific strips not receiving manure were fertilized in the same manner as the fertilizer treatments. Weed control was achieved by cultivation in 1998. In 1999 and 2000 a post emergence herbicide (Spirit) was also applied to the field on 14 June, 1999.

The field was planted on May 5, 1998 using the corn hybrid Circle 6215 with an 8-row planter at ~29,000 plants ac^{-1}. In 1999, the field was planted on May 11, using the corn hybrid Pioneer 33A63 (waxy corn) with an 8-row planter at ~28,000 plants ac^{-1}. In 2000, the plots were planted on April 29 using Wilson 1851 (white corn) hybrid. Row spacing of 30 in was used in all years.

Half of each strip (1100 ft long) was divided into 13 subplots (40 ft wide and 80 ft long each). Greenness was determined on the subplots using a (Minolta SPAD 502) chlorophyll meter. Readings were made on several dates each year during the growing season. Readings were made on the upper most collared leaf until the ear was visible, after which readings were made on the ear leaf. Thirty readings per plot were made and averaged.

Ear leaves were collected from 20 plants within each subplot (80 by 40 ft). The mid-rib and collar of each leaf were removed and the remaining tissue was placed into paper bags and placed in the oven to dry. Grain was harvested from two rows of corn (20 ft long each). Stover was collected from one of these rows (20 ft long). Plants were then weighed for total wet weight. Stalks from the harvested plants (bottom 0-6 in) were collected for NO_3-N analysis after weighing the entire plant. Remaining plants were ground and placed in the oven to dry at 113°F. These results were compared to the yield recorded from a combine equipped with an Ag Leader yield monitor and GPS unit at harvest. Grain yield was adjusted to 15.5% water content. Ear leaf samples were analyzed for N, P, K, Mg, Ca, Na, S, Zn, Mn, Cu, Fe, B, and Al using the ICP emission spectroscopy method described by Hunge and Schulte (1985).

Statistical Analysis Systems (SAS) was performed on all data using the Proc-Mixed procedure (Littell et al., 1996). Least Significant Difference (LSD) was then used to separate the means. A probability level ≤ 0.05 was considered significant.

Results and Discussion

Weather conditions and initial soil

Rainfall during the growing season from planting to the end of September in 1998, 1999, and 200 were 14.6, 20.2 and 11.4 in, respectively. Growing degree days (50/85) from May through

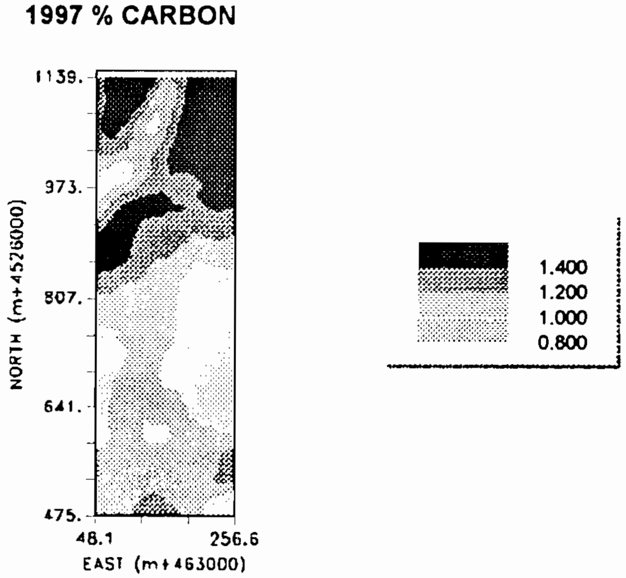
1997 % CARBON

Fig. 1. Soil carbon distribution within the experimental area before initiation of the treatments in 1997.

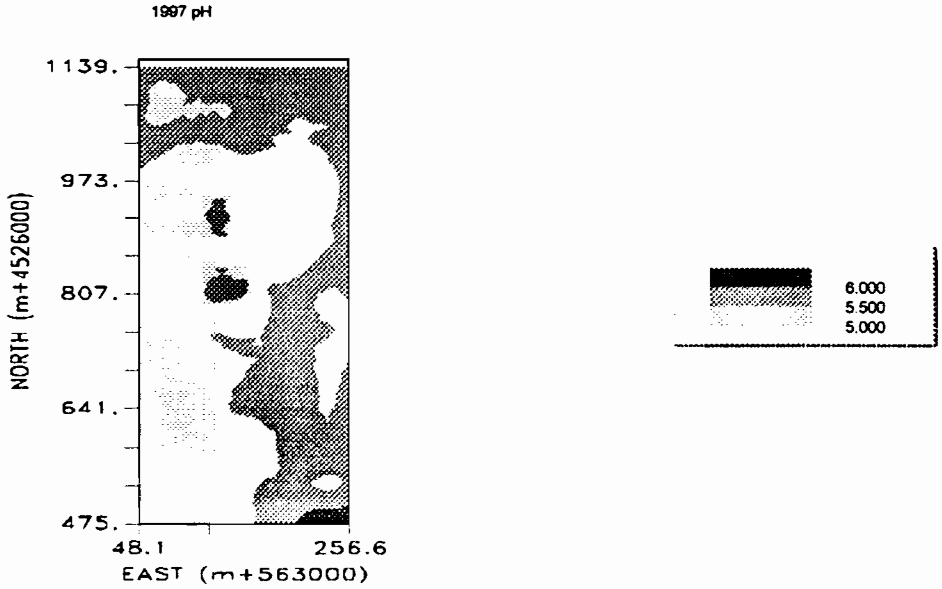

Fig. 2. Soil pH distribution within the experimental area before initiation of the treatments in 1997.

September were 3091, 2823, and 3135 in 1998, 1999, and 2000, respectively. The average initial soil surface (0-6 in) pH was 5.3 and the average soil organic C was 1.19% in the experimental area. Carbon and pH distributions are displayed in Fig. 1 and 2.

Grain yield

In all three years, there were significant differences among all treatments for grain yield (Table 2). Commercial fertilizer and manure treatments resulted in greater grain yield than the untreated check. No significant yield difference was observed between the UM and the SSM treatments but both yielded significantly greater than the commercial fertilizer treatment in 1998 and 1999 (Table 2). In 2000, however, fertilizer application resulted in greater grain yield than uniform manure application. This was because manure was applied to provide N (137 lb ac^{-1}) for a corn yield of 170 bu ac^{-1} while the farmer applied fertilizer N at a rate of 195 lb ac^{-1}. Across years, site-specific and uniform manure application resulted in 12 and 7 bu ac^{-1} more yield than fertilizer application, respectively, even though the average available N application rate was 31 lb ac^{-1} greater for fertilizer than manure. This indicates that the added nutrients and organic matter from the application of manure to less productive areas within this field increased productivity. The increase in grain yield may also be attributed to improved soil health due to manure application by improving the physical properties of the soil, such as increased water holding capacities, increased aeration and better overall soil structure. In addition to N, manure also contains other nutrients and calcium carbonate (Eghball 1999). The average pH in the soil was approximately 5.3 and would have benefited from manure lime application.

N uptake

There were significant differences in N uptake among all treatments in 1998 (Table 2). No significant N uptake difference was observed between the UM and the SSM treatments but both resulted in greater N uptake than the commercial fertilizer treatment (Table 2). The application of manure and fertilizer resulted in higher N uptake levels than the check. Manure treatments resulted in higher corn N uptake than chemical fertilizer probably because of the slower rate at which manure N becomes available to the plant. When inorganic types of fertilizer are applied, almost all of that fertilizer will immediately be available to the plant for uptake. The slow release of manure N during the growing season would probably result in more N uptake and less N lost due to leaching.

In 1999, significant differences among treatments were observed for N uptake (Table 2). Commercial fertilizer and manure treatments resulted in greater N uptake than the check. Differences detected between the commercial fertilizer and manure treatments were also significant (Table 2). Uniform manure application resulted in similar corn N uptake to that of the site-specific manure treatment. Manure treatments resulted in significantly greater N uptake than the fertilizer treatment in 1999. Overall, the same trend was observed for corn N uptake even though different hybrids were used each year.

Stalk NO_3-N

In 1998, all stalk NO_3-N values were below the critical value of 2000 ppm and above 100 ppm which was established by Binford et al., (1990) and Varvel et. al, (1997) (Table 2). This indicates that all treatments provided adequate but not excessive amounts of N. The chemical fertilizer treatment resulted in higher stalk NO_3-N values than the manure treatments in 1998. These results suggested that adequate N was applied for the manure and fertilizer treatments with slightly more N being available in the fertilized treatment than the manure treatments at the end of the growing season.

Table 2. Treatment and soil C section effects on corn grain yield, total N uptake, stalk nitrate, and analysis of variance for each in 1998 and 1999.

		Grain yield			Total N uptake		Stalk nitrate	
Variable		**1998**	**1999**	**2000**	**1998**	**1999**	**1998**	**1999**
			bu ac^{-1}		lb ac^{-1}		ppm	
Treatments								
Uniform manure (UM)		150	166	132	152	190	1340	1870
Site-specific manure (SSM)		152	164	147	151	191	780	3030
Fertilizer (FER)		136	143	149	135	179	1900	5580
Check (CHK)		111	123	100	97	113	90	210
Analysis of variance	**df**				P>F			
Treatment	3	0.0002	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
All Treat. vs. CHK	1	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
SSM + UM vs. FER	1	0.0186	0.0001	0.0018	0.0299	0.0341	0.0111	0.0001
UM vs. SSM	1	0.7790	0.2761	0.0001	0.8574	0.8906	0.1243	0.0841

The mean stalk NO_3-N levels for 1999 were much higher than those observed in 1998 (Table 2). The stalk NO_3-N concentrations for the commercial fertilizer and SSM treatments were well above the critical stalk NO_3-N value of 2000 ppm in 1999 (Table 2). The highest stalk NO_3-N values were observed in the fertilizer and SSM treatments with 5580 and 3030 ppm, respectively, both higher than the UM treatment in 1999 (1870 ppm)(Table 2). The SSM treatment had higher stalk NO_3-N values than the uniform manure because the SSM received chemical fertilizer in non-manure areas. The higher stalk NO_3-N levels for the fertilizer and SSM treatments indicated that there was an over-application of chemical fertilizer in 1999.

Chlorophyll meter readings

Chlorophyll meter readings were made on five dates during the growing season in 1998 (Table 3). Check strips had significantly lower readings than manure and commercial fertilizer treatments for most of the growing season (Table 3). However, on 25 June (V9-V10), comparable values were observed between the check and fertilizer treatments. This is likely due to the late application of anhydrous ammonia (June 22, 1998). Chlorophyll meter readings after 25 June 1998 indicated that the manure and fertilizer treatments had sufficient N to maintain their chlorophyll production while the check treatments did not (Table 3).

In 1999, chlorophyll meter readings were made only on three dates (Table 4). There was no significant difference among the manure and commercial fertilizer treatments for chlorophyll meter readings taken on 6 July, 1999 (Table 4). The check treatment resulted in lower chlorophyll meter readings than the manure and fertilizer treatments in 1999 (Table 4). On the 20 July readings, the fertilizer treatment resulted in higher readings than the UM (Table 4). The 3 August showed no significant differences among the manure and fertilizer treatments but all were higher than the check (Table 4).

Leaf nutrient analysis

In addition to N, P, K, manure also contains secondary and micronutrients. Ear-leaf nutrient concentration means for each treatment, along with corresponding least significant difference (LSD) and correlation coefficients (with grain yield) values in 1998 are given in Table 5. Significant correlation was observed between grain yield and ear-leaf concentrations of N, P, Ca, Na, Mn, and Cu (Table 5). Ear-leaf N concentration best correlated with grain yield ($r = 0.71$), and other nutrients displayed lower r-values (Table 5). Manure application resulted in greater ear-leaf concentrations of P, K, Mg, Ca, Na, and B than those for chemical fertilizer in 1998 (Table 5) indicating possible positive effects of these nutrients on grain yield. Chemical fertilizer resulted in greater ear-leaf concentrations of Zn, Mn, Cu, Fe, and Al than manure application in 1998 (Table 5) indicating impurities in the ammonium polyphosphate used. In 1999, ear-leaf tissue samples were analyzed for the same nutrients as in 1998. Ear-leaf nutrient concentration means for each treatment, along with corresponding LSD and correlation coefficients (with grain yield) in 1999 are given in Table 6. Significant correlation between grain yield and ear-leaf concentrations of N, P, K, Mg, Ca, Na, and S was observed in 1999 (Table 6). Leaf N correlated best with yield ($r = 0.54$), and other nutrients showed lower r-values with grain yield (Table 6). Manure application resulted in greater ear-leaf concentrations of P and Mg than chemical fertilizer in 1999 (Table 6).

Table 3. Leaf chlorophyll meter readings at five dates during the growing season in 1998 for all treatments.

Treatment	25 June	9 July	16 July	31 July	13 August
	Index				
Uniform manure	45.90 a[†]	46.75 a	52.72 a	51.80 ab	52.72 a
Site-specific manure	44.77 a	46.10 a	51.85 a	53.45 ab	54.67 a
Fertilizer	36.30 b	49.30 a	54.20 a	56.42 a	55.00 a
Check	35.72 b	36.72 b	45.40 b	47.07 b	41.75 b

[†] Treatments with the same letter are not significantly different.

Table 4. Leaf chlorophyll meter readings at three dates during the growing season in 1999 for all treatments.

Treatment	6 July	20 July	3 August
	Index		
Uniform manure	42.1 ab[†]	49.5 b	57.4 a
Site-specific manure	43.6 ab	52.9 ab	59.1 a
Fertilizer	48.6 a	57.1 a	60.9 a
Check	40.6 b	43.9 c	50.1 b

[†] Treatments with the same letter are not significantly different.

Table 5. Leaf nutrient concentration means for each treatment, least significant difference, and coefficient for correlation between the element concentration and corn grain yield in 1998.

		Treatments					Correlation
Element	Unit	UM	SSM	FERT	CHECK	$LSD_{0.10}$	with yield
							r
N	%	0.274	0.279	0.278	0.202	0.008	0.71[**]
P	%	0.024	0.024	0.017	0.018	0.001	0.47[**]
K	%	0.126	0.124	0.107	0.125	0.007	0.03
Mg	%	0.018	0.018	0.014	0.016	0.001	-0.01
Ca	%	0.054	0.053	0.050	0.047	0.002	0.22[**]
Na	%	0.002	0.002	0.001	0.001	0.0002	0.31[**]
S	%	0.020	0.020	0.021	0.019	0.001	0.05
Zn	ppm	23.5	24.6	31.9	22.5	2.1	0.02
Mn	ppm	51.0	53.6	73.5	36.7	5.2	0.44[**]
Cu	ppm	11.4	11.2	16.1	8.0	0.9	0.28[**]
Fe	ppm	104.0	98.2	136.9	96.3	20.1	0.01
B	ppm	10.7	11.8	4.8	8.7	1.2	-0.01
Al	ppm	55.4	43.2	64.6	52.3	13.1	-0.11

[**] *Indicates significance at the 0.01 level.*

Table 6. Leaf nutrient concentration means for each treatment, least significant difference, and coefficient for correlation between the element concentration and corn grain yield in 1999.

Element	Unit	Treatments					Correlation with yield
		UM	SSM	FERT	CHECK	$LSD_{0.10}$	
							r
N	%	0.334	0.346	0.341	0.271	0.011	0.54^{**}
P	%	0.030	0.030	0.027	0.026	0.001	0.32^{**}
K	%	0.137	0.142	0.153	0.133	0.006	0.24^{**}
Mg	%	0.020	0.018	0.016	0.020	0.001	-0.14^{*}
Ca	%	0.053	0.052	0.050	0.050	0.002	0.15^{*}
Na	%	0.003	0.002	0.002	0.002	0.001	0.13^{*}
S	%	0.021	0.022	0.023	0.018	0.001	0.22^{**}
Zn	ppm	20.7	21.0	20.7	18.1	1.4	0.08
Mn	ppm	49.0	59.5	76.7	48.7	5.7	-0.12
Cu	ppm	9.1	11.0	10.3	9.0	0.9	-0.05
Fe	ppm	173.0	188.0	204.0	160.0	63.0	0.10
B	ppm	9.0	8.2	9.0	7.6	1.1	-0.10
Al	ppm	101.9	105.3	131.0	91.2	74.6	0.13

** and * Indicate significance at the 0.01 and 0.05 levels respectively.

Soil properties

In 1997 (before treatment application), there were no differences among treatments for Bray and Kurtz No. 1 P and EC but differences were observed for soil pH indicating inherent soil pH variability within the field (Table 7). Soil NO_3-N was similar among manure and fertilizer treatments but was greater for both than the check in 1998 (Table 7). In 1999, soil NO_3-N was greatest for fertilizer and site-specific manure treatments than uniform manure and the check indicating over-application of N fertilizer in the fertilizer and site-specific manure (received N fertilizer in the non-manure sections) strips. Nitrate level in the uniform manure treatment was similar to the check after harvest in 1999 (Table 7) indicating less potential for nitrate leaching when uniform manure was applied. This is because most of manure-N is mineralized during the growing season (Eghball 2000) when the need for N is the greatest.

Soil P level increased from 24 ppm to about 60 ppm with two-years of manure application (Table 7). The increase in soil P level is expected when N-based manure application is made (Eghball and Power, 1999b) but the level was not high enough to create runoff water quality problem. Soil pH and EC also increased with manure application (Table 7). Manure contains lime (calcium carbonate is added to the diet) and its application should increase soil pH (Eghball, 1999).

Conclusions

Manure application resulted in greater grain yield and N uptake than fertilizer application. Averaged across years, uniform and site-specific manure applications resulted in 7 and 12 bu ac^{-1} more yield than fertilizer application, respectively, even though average available N application rate was 31 lb ac^{-1} greater for fertilizer than manure treatment . The uniform manure and site-specific manure treatments had similar grain yields and N uptakes. This suggests that the

Table 7. Soil properties in the 0 to 15 cm depth in 1997 (before treatment application), 1998, and 1999.

	1997			1998	1999			
Treatment	BKP[†]	pH	EC	NO_3-N[‡]	NO_3-N[‡]	BKP[†]	pH	EC
	ppm		mmho cm^{-1}	ppm		ppm		mmho cm^{-1}
Uniform manure	23.7 a[#]	5.37 b	0.23 a	2.0 ab	4.6 bc	59.7 a	6.1 a	0.35 a
Site-specific manure	23.6 a	5.50 a	0.23 a	2.9 a	6.2 b	61.3 a	5.9 a	0.37 a
Fertilizer	22.1 a	5.43 ab	0.22 a	2.5 a	9.9 a	20.0 b	5.7 c	0.24 b
Check	23.1 a	5.39 b	0.21 a	0.9 b	3.9 c	21.4 b	5.8 b	0.24 b

[†] BKP is Bray and Kurtz No. 1 P.

[‡] Nitrate concentrations to a soil depth of 3 ft.

[#] Treatments with the same letter are not significantly different at the 0.05 level.

application of manure was successful in increasing productivity in infertile or unproductive soils within the field.

Post-harvest stalk nitrate concentration test and soil nitrate level indicated over-application of chemical fertilizer in 1999. Residual soil nitrate for uniform manure was lower than fertilizer and site-specific manure (received N fertilizer in non-manure sections) treatments in 1999 indicating slow release of N from applied manure. Soil pH, EC and P levels increased with manure application. The increase in soil P level was not high enough to have adverse effects on runoff water quality.

Manure application to less productive sites increased productivity as compared to synthetic fertilizer application. It seems that manure not only provided macronutrients for the crop but also provided organic mater, lime, secondary and micronutrients. Manure application can improve the soil quality and enhance water holding capacity and nutrient availability.

References

Binford, G. D., A. M. Blackmer, and N. M. El-Hout. 1990. Tissue test for excess nitrogen during corn production. Agron. J. 82:124-129.

Campbell, C. A., M. Schnitzer, J. W. B. Stewart, V. O. Biederbeck, and F. Selles. 1986. Effect of manure and P fertilizer on properties of a Black Chernozem in southern Saskatchewan. Can. J. Soil Sci. 66:601-613.

Denmead, O. T., and R. H. Shaw. 1960. The effects of soil moisture stress at different stages of growth on the development and yield of corn. Agron. J. 52:272-274.

Eghball, B. 1999. Liming effects of beef cattle feedlot manure or compost. Commun. Soil Sci. Plant Anal. 30: 2563-2570.

Eghball, B. 2000. Nitrogen mineralization from field-applied beef cattle feedlot manure or compost. Soil Sci. Soc. Am. J. 64: 2024-2030.

Eghball, B., and J. F. Power. 1994. Beef cattle feedlot manure management. J. Soil Water Conserv. 49:113-122.

Eghball, B., and J. F. Power. 1999a. Composted and noncomposted manure application to conventional and no-tillage systems: Corn yield and nitrogen uptake. Agron. J. 91:819-825.

Eghball, B., and J. F. Power. 1999b. Phosphorus- and nitrogen-based manure and compost application: Corn production and soil phosphorous. Soil Sci. Soc. Am. J. 63: 895-901.

Eghball, B., and J. E. Gilley. 2001. Phosphorus risk assessment index evaluation using runoff measurements. J. Soil Water Conserv. (Submitted March 2000).

Freeze, B. S., and T. G. Sommerfeldt. 1985. Breakeven hauling distances for beef feedlot manure in southern Alberta. Can. J. Soil Sci. 65:687-693.

Hergert, G. B., R. B. Ferguson, and C. A. Shapiro. 1995. Fertilizer suggestions for corn. NebGuide G74-174-A, Cooperative Extension, University of Nebraska.

Hornik, S.B. 1988. Use of organic amendments to increase the productivity of sand and gravel spoils: Effect on yield and composition of sweet corn. Amer. J. Alternative Agriculture. 3(4):156-162.

Hornik, S. B., and J. F. Parr. 1987. Restoring the productivity of marginal soils with organic amendments. Amer. J. Alternative Agric. 2(2):64-68.

Hunge, Chao-Wong Luh and E. E. Schulte. 1985. Digestion of plant tissue for analysis by ICP emission spectroscopy. Commun. Soil Sci. Plant Anal. 16:943-958.

Larney, F. J., and H. H. Janzen. 1996. Restoration of productivity to a desurfaced soil with livestock manure, crop residue, and fertilizer amendments. Agron. J. 88:921-927.

Larney, F. J., and H. H. Janzen. 1997. A simulated erosion approach to assess rates of cattle manure and phosphorus fertilizer for restoring productivity to eroded soils. Agriculture Ecosystems and Environment, 65:113-126.

Littell, R. C., G. A. Milikens, W.W. Stroup, and R.D. Wolfinger. 1996. SAS system for mixed models. SAS institute. Cary, NC.

Lohry, R. D. 1989. Effect of N fertilizer rate and nitrapyrin on leaf chlorophyll, leaf N concentration, and yield of three irrigated maize hybrids in Nebraska. Ph.D. Diss. Univ. of Nebraska, Lincoln.

Sahs, W. W., and G. Lesoing. 1985. Crop rotations and manure versus agricultural chemicals in dryland grain production. J. Soil Water Conservation, 40:511-516.

Sims, A. L., J. S. Schepers, and D. D. Francis. 1994. Corn yield response to early growing season stresses. p. 319. Agronomy Abstracts. American Society of Agronomy, Madison, WI.

Sommerfeldt, T. G., and C. Chang. 1985. Changes in soil properties under annual applications of feedlot manure and different tillage practices. Soil Sci. Soc. Am. J. 49:983-987.

Varvel, G. E., J. S. Schepers, and D. D. Francis. 1997. Chlorophyll meter and stalk nitrate techniques as complimentary indices for residual nitrogen. J. Prod. Agric. 10:147-151.

PROCEEDINGS OF THE

THIRTY-FIRST NORTH CENTRAL EXTENSION-INDUSTRY SOIL FERTILITY CONFERENCE

Volume 17

November 14-15, 2001
Holiday Inn University Park
Des Moines, IA

Program Chair:
Keith Reid
Ontario Ministry of Ag, Food & Rural Affairs
581 Huron Street
Stratford, Ontario N5A 5T8
519/271-9269

Published by:
Potash & Phosphate Institute
772 – 22nd Avenue South
Brookings, SD 57006
605/692-6280