Corn Silage Yield, Shallow Groundwater Quality and Soil Properties Under Different Methods and Times of Manure Application

N. K. Patni, J. L. B. Culley

ABSTRACT

The effects of four method-and-time combinations of dairy cattle liquid manure application on corn silage yields, shallow groundwater quality, and soil composition were studied in a *Typic Haplaquent* soil during a three-year period and for two additional residual years when no treatments were applied. Manure was applied at the rate of 90 t ha^{-1} y^{-1} by fall plowdown, preplant broadcast followed by disking, and post-emergent sidedressing by injection and broadcasting between rows. Additional treatments included a control and preplant broadcast chemical fertilizer application to provide approximately the same smount of NH_4^+-N as the manure. Manure applied by the above methods had no significant effect on yields. This was mainly attributed to the previous alfalfa crop at the experimental site. Yields tended to be slightly higher with the two post-emergent sidedress treatments compared to the fall-plow and preplant broadcast treatments. Shallow (1.2 m deep) groundwater NO_3^--N concentrations were always greater than the drinking water limit of 10 mg L^{-1} with all treatments, including the control, indicating that this limit is unlikely to be met with the normally recommended manure and fertilizer applications for corn production. Treatment effects on soil composition were not significant at the moderate manure application rate used in this study.

INTRODUCTION

Land is usually the ultimate disposal site for the large quantities of manure produced in confined-livestock operations. For economic reasons, it is desirable to utilize manure in lieu of chemical fertilizers in feed crop production. For efficient utilization, manure nutrient application rate should match the crop nutrient requirement. Several studies of crop response to manure have shown that high application rates do not result in improved crop uptake but usually lead to a loss of efficiency in manure nutrient utilization (Overcash et al., 1983). In a six-year study at Ottawa, Ontario, there was no significant increase in corn silage yield from dairy cattle liquid manure (DCLM) applied at average rates of 560 and 897 kg N ha^{-1} y^{-1} compared to 224 kg N ha^{-1} y^{-1} (Phillips et al., 1981). A five-year study in Indiana indicated no significant increase in corn grain yield from DCLM applied at average rates of 403 and 605 kg N ha^{-1} y^{-1} compared to 202 kg N ha^{-1} y^{-1} (Sutton et al., 1986). For most effective use of manure N, spring application and immediate incorporation is recommended (OMAF, 1986). In a cold, humid climate such as that of eastern Ontario, the soil water content is near saturation in early spring. Since the time available for manure spreading prior to spring cultivation and planting is very limited, there is a tendency to spread manure on relatively wet soil. Compared to chemical fertilizer, the weight application rate of manure has to be very high because of the low concentration and availability of nutrients in manure. For example, about 40,000 kg of as-produced dairy cattle manure would be required to supply 100 kg of crop-available N compared to only 217 kg of urea. Additional traffic associated with the use of heavy tankers for land spreading of liquid manure, particularly in the spring, could therefore lead to undesirable compaction of soil and depressed crop yields. Late spring or fall application of manure may be preferable not only to reduce possible compaction effects but also for convenience to the farmer.

Objective

The objective of this study was to compare the effect of four method-and-time combinations of DCLM application on corn silage yield, soil chemical composition and shallow-groundwater quality over a three-year period using commercial-scale equipment under farm conditions. The residual effect of the previous three years of manure application was also determined for a further one year on silage yield and two years on shallow groundwater quality. Soil compaction as a result of liquid manure tanker traffic was also studied, and has already been reported (Culley and Patni, 1987).

MATERIALS AND METHODS

The Study Procedure

The study was conducted at the Animal Research Centre Farm near Ottawa, Ontario during 1982-1986. The experimental site had poorly-drained *Typic Haplaquent* (Dalhousie Association, Brandon Series) soil with a loamy-textured Ap horizon and clay loam B and C horizons. It was tile-drained in 1974, and cropped continuously since 1971 in a rotation using chemical fertilizers only and appropriate pesticides for weed control (Table 1).

A randomized complete-block design with six treatments and four replications was used. The treatments, applied for three years, consisted of a control, preplant broadcast and disked-in urea to supply 140 kg ha^{-1} of N, and DCLM

Article was submitted for publication in March 1989; reviewed and approved for publication by the Structures and Environment Div. of ASAE in August 1989.

Contribution No. 1603 from Animal Research Centre and 88-22 from Land Resource Research Centre.

The authors are: N. K. PATNI, Research Scientist, Animal Research Centre, and J. L. B. CULLEY, Research Scientist, Land Resource Centre, Research Branch, Agriculture Canada, Ottawa, Ontario, Canada.

TABLE 1. Cropping history of the experimental site

Year	Crops grown*	Nutrient application rate		
		N	P	K
		------ (kg ha^{-1}) ------		
1971	Barley	0	0	0
1972	Oats undersown with alfalfa, timothy, brome	17	29	56
1973	Alfalfa, timothy, brome	0	29	56
1974	Alfalfa, timothy, brome	0	29	56
1975	Barley undersown with red clover, timothy, brome	6	10	19
1976	Corn	133	34	86
1977	Corn	82	34	43
1978	Corn	116	10	19
1979	Corn	131	23	0
1980	Barley undersown with alfalfa	20	23	56
1981	Alfalfa	0	12	0
1982 †		–	–	–

* Barley - *Hordeum vulgare* L.; oats - *Avena sativa* L.; alfalfa - *Medicago sativa* L.; timothy - *Phleum pratense* L.; brome - *Bromus inermis* Leyss; red clover - *Trifolium pratense* L; corn - *Zea mays* L.

† Alfalfa crop was plowed under on May 18 and corn was planted on May 20 to initiate this study.

application according to four alternative schedules and methods. These were postharvest broadcast with plowdown, preplant-broadcast followed by disking, post-emergent sidedress injection, and post-emergent sidedress without incorporation. First-year residual effects from the treatments on yields were also evaluated. Manure was applied at the rate of 90 t ha^{-1} y^{-1} to provide nearly the same amount of ammonium N as the N supplied by the chemical fertilizer. Because the study commenced in the spring (May 1982), there was no fall plowdown treatment during year 1 (1982) of the three-year treatment period.

The 24 plots used for the study were each 67.1 m long by 14.6 m wide with 16 rows of corn in each plot as described by Culley and Patni (1987). Manure was applied using pressure/vacuum operated 8.2 m^3 tankers (Clay Equipment Corporation, Georgetown, Ontario). For spring disking and fall plowdown treatments, manure was broadcast using a spreader hood at the rear of the tankers, located about 1 m above the ground surface. For sidedress injection and surface applications, a two-row injector (Clay Equipment Corporation) fed by 100 mm flexible pipes was used to apply manure between each row. In the injection mode, two 250 mm sweep knives injected the manure to a 0.15 to 0.20 m depth. In the surface application mode, the knives were kept 10 cm above the soil surface. The DCLM was obtained from outdoor, covered, concrete storage tanks after prior mixing.

All plots were moldboard-plowed in the fall and disked twice in the spring except during the first year (1982) when the plot area was plowed in both the spring and fall. Corn *(Zea mays* L.) was planted at the rate of 65,000 plants ha^{-1}, in rows 0.91 m apart, between 13 May and 3 June during the different years depending on field conditions. The corn varieties used were COOP 259 (year 1) and Hyland 2219 (years 2 and 3); COOP 2645 was used in the residual year. Atrazine was used each year for weed control. Sidedress injection and surface applications of manure were made about four to five weeks after planting. In late September each year, 2.5 m lengths of the middle eight rows in the centre of each plot were hand-harvested for silage yield and composition determinations. The remaining crop was then mechanically harvested for silage, after which two 1.2 m deep, 50 mm diameter soil columns per plot were collected using a hydraulically operated coring machine. The soil columns were subdivided into five depth sections of 0-15, 15-30, 30-60, 60-90, and 90-120 cm and composited. Fall manure plowdown was completed by early October.

To collect shallow groundwater samples, porous ceramic cups were installed at 1.2 m depth near the centre of each plot in June of 1982. These cups were connected to pairs of plastic tubes that ran across the width of the plots 0.6 m below the surface and emerged from the ground at the edge of the experimental area for sample collection by suction. In the subsequent years, groundwater samples were obtained from 50 mm diameter, 1.6 m long PVC pipe sampling wells that were installed to a depth of 1.2 m near the centre of each plot. Samples were collected weekly, when available, which was in the spring before planting, and in the fall after harvest, when there was flow in the 0.6 to 0.9 m deep tile drains. Samples were not available during the growing season. In addition to the three-year treatment period, groundwater samples were also collected during the first residual year, and before planting in the second residual year.

Sample and Data Analysis

Manure, crop, and soil samples were analysed using methods described by Culley et al. (1981) and Sheldrick (1984). Manure samples were analyzed for dry matter (DM), total Kjeldahl N (TKN), ammonium N (NH_4^+-N), total phosphorus (TP), potassium (K), calcium (Ca), and magnesium (Mg). Silage samples were analyzed for DM, and total N, P, and K. Soil subsamples from the five depth sections were analyzed for 2M KCl-extractable inorganic N ($NO_3^- + NO_2^- + NH_4^+$). Subsamples from the top two depth sections only at the end of the three-year treatment period were analyzed additionally for organic C and N, $NaHCO_3$ extractable P, exchangeable cations (Ca, Mg, and K), and pH.

Groundwater samples were analyzed for pH and specific conductivity immediately following collection using a Radiometer Model PHM 29 pH meter (Radiometer A/S, Copenhagen, Denmark) and a YSI Model 33 conductivity meter (Yellow Springs Instrument Co., Yellow Springs, OH). Subsamples were then preserved according to recommended methods (APHA, 1981; USEPA, 1979) for analyses later. Nitrate and ammonium N were determined using Model 93-07 and Model 95-10 specific ion electrodes, respectively (Orion Research Incorporated, Cambridge, MA). Total P in filtered subsamples (Whatman GF/C glass-fibre filter paper) was determined by ascorbic acid reduction using Technicon AutoAnalyzer II after manual digestion using persulfate (USEPA, 1979). Potassium was determined by atomic absorption spectroscopy. Daily and weekly rainfall at the experimental site were recorded using

TABLE 2. Nutrient application rates

Land treatment		TKN	NH_4^+-N	P	K	Ca	Mg
		Application rate*					
		(kg ha^{-1})					
Year 1							
Fertilizer		149					
Manure	- fall plow †	-	-	-	-	-	-
	- spring disk	305	157	68	187	103	42
	- sidedress inject	279	131	63	188	96	43
	- sidedress surface	229	104	53	146	87	34
Year 2							
Fertilizer		127					
Manure	-fall plow	327	159	77	251	95	47
	- spring disk	223	121	44	184	60	32
	- sidedress inject	173	94	42	121	77	34
	- sidedress surface	185	101	41	153	53	27
Year 3							
Fertilizer		148					
Manure	- fall plow	390	197	53	300	139	51
	- spring disk	278	142	44	182	67	38
	- sidedress inject	254	142	36	167	91	30
	- sidedress surface	262	146	37	172	94	31
Cumulative to Year 3 end							
Fertilizer		424	-	-	-	-	-
Manure	-fall plow	717	356	129	550	234	98
	- spring disk	806	420	156	553	230	112
	- sidedress inject	706	366	141	475	263	106
	- sidedress surface	676	351	131	472	233	91

* Additionally, starter fertilizer was applied banded near the seed in all plots, including the control plots, to provide N, P, and K at the rates of 11, 10 and 0 kg ha^{-1} in the Year 1; 20, 23, and 0 kg ha^{-1} in Year 2; 10, 11, and 0 kg ha^{-1} in Year 3, and 8, 14, and 13 kg ha^{-1} in the residual year.

† Fall plow treatment refers to manure application in the previous calendar year. There was no fall plow treatment for the year 1, when the study was initiated.

continuously recording Belfort Universal rain gages.

Data were subjected to analysis of variance (ANOVA) using the SAS (1985) program; the Tukey procedure was used to test for differences in means.

RESULTS AND DISCUSSION

Nutrient Applications

The average application rate of DCLM for all manure treatments over the three-year period, as determined by tanker weighings, was 89.8 ± 6.6 t ha^{-1} y^{-1}. One tonne DCLM application was essentially equivalent to 1 m' application. Manure nutrient application rates (Table 2) varied slightly, mainly because of composition variations (Table 3) due to differences in dilution, age of manure and the environmental conditions during storage. Such variations have been noted before in studies involving both solid and liquid manure from cattle and swine (Evans, 1979; Klausner and Guest, 1981; Safley et al., 1981, 1986; Sutton et al. 1978, 1982, 1986; Wolt et al., 1984).

The average application rate of manure N for all treatments over the three-year period was 264 ± 63 kg ha^{-1} y^{-1} with extremes of 173 and 390 kg ha^{-1} y^{-1} (Table 2). Application rates were higher for the fall-applied compared to the spring-applied manure because the former tended to be fresher at the time of application and therefore had higher DM and N concentrations. The DCLM used for the sidedress applications had the lowest DM and N concentrations.

TABLE 3. Composition of the applied dairy cattle manure

Manure component		Mean concentration* ± Std Deviation	Range
Dry matter (DM)	% wet basis	7.68 ± 1.34	5.40 - 9.20
TKN	% wet basis	0.31 ± 0.07	0.22 - 0.42
NH_4^- N	% wet basis	0.16 ± 0.03	0.12 - 0.22
P	% of DM	0.79 ± 0.21	0.52 - 1.05
K	% of DM	2.86 ± 0.44	1.92 - 3.36
Ca	% of DM	1.24 ± 0.33	0.83 - 1.89
Mg	% of DM	0.57 ± 0.10	0.43 - 0.74

* Mean concentration in 40 samples over the three-year treatment period.

Application rates of N for the preplant spring-disk treatment were intermediate. The cumulative N, P, and K application rates for each treatment at the end of year 3 were within 12% of the mean value for all treatments (Table 2). The relatively higher application rates in years 2 and 3 for the fall plowdown compared to the other treatments tended to compensate for the absence of this treatment in year 1. Manure nutrient application rates were not controlled in this study, thus simulating farm conditions under which the volume, and hence the weight, rather than the nutrient application rate is usually controlled. Also, a constant weight application rate was required for the simultaneous study of soil-compaction from tanker traffic (Culley and Patni, 1987). The average fertilizer-N application rate was 141 kg ha^{-1} y^{-1} compared to the target rate of 140 kg $ha^{-1}y^{-1}$.

Silage Yields

Silage DM yields were not significantly ($P > 0.05$) affected by the treatments during the three-year experiment (Table 4). In the residual year, only the fall plowdown treatment gave a significantly ($P < 0.05$) higher yield than the control. Yields obtained with manure were not significantly ($P > 0.05$) different from those obtained using fertilizer. Yields for all treatments in years 1 and 2 were below the farm normal of 11 t ha^{-1}. Yields in the third and residual years were higher than in the previous years. Both sidedress treatments tended to give higher yields than the other treatments with yields from sidedress treatments 18% greater than those for the control. There was no apparent benefit from injecting the sidedress manure. Yields from the spring-disked manure and the chemical fertilizer treatments were nearly identical, and were about 11% greater than the control. Fall plowdown of manure had relatively lower yields during the treatment years, but the highest yield in the residual year.

The lack of a significant ($P > 0.05$) treatment effect on yield for the entire three-year treatment period was surprising. The experimental site was seeded to alfalfa *(Medicago sativa* L.) two years prior to the initiation of this study. It would appear that nutrient reserves in the soil at the initiation of this study were such that the added fertilizer and manure nutrients had only a small effect on the corn crop. Studies in Ontario (Bruulsema and Christie, 1987; Bolton et al., 1976) have shown that corn yields resulting from the plow-down of one-to-two year old alfalfa are equivalent to those from fertilizer-N applications ranging from 90 kg to 125 kg ha^{-1}. Similar results have been obtained in the northern U.S. cornbelt. (Triplett et al., 1979) and Pennsylvania (Fox and Piekielek, 1983).

TABLE 4. Corn silage yields and nutrient contents

Silage component	Year	Treatment						
				Manure				
		Control	Fertilizer	Fall plow	Spring disk	Sidedress inject	Sidedress surface	MSD*
		kg ha^{-1}						
Dry matter	1	7537 a †	7914 a	—	9137 a	8344 a	8547 a	1811
	2	8030 a	8527 a	8044 a	8027 a	8741 a	9453 a	1773
	3	8731 a	10605 a	8485 a	9865 a	11021 a	11426 a	2984
	Residual	9668 b	10468 ab	11067 a	10692 ab	10542 ab	10511 ab	1305
Nitrogen	1	98 b	107 ab	—	137 a	120 ab	118 ab	35
	2	102 ab	108 ab	92 b	98 ab	113 ab	123 a	29
	3	84 b	132 a	113 ab	96 ab	134 a	125 a	39
	Residual	96 a	106 a	115 a	109 a	104 a	110 a	30
Phosphorus	1	11 a	12 a	—	15 a	13 a	14 a	5
	2	12 a	13 a	10 a	12 a	13 a	14 a	5
	3	12 a	13 a	13 a	14 a	14 a	15 a	4
	Residual	13 a	13 a	16 a	14 a	14 a	13 a	4
Potassium	1	63 b	62 b	—	85 ab	100 a	73 ab	31
	2	96 a	97 a	88 a	116 a	111 a	125 a	78
	3	58 b	65 ab	75 ab	59 b	92 a	83 ab	29
	Residual	70 a	83 a	78 a	87 a	99 a	82 a	49

* MSD = minimum significant difference

† Mean values in a row followed by the same letter are not significantly different (P>0.05) based on the Tukey procedure.

Lower yields in years 1 and 2 than in the subsequent years may have resulted from a greater water deficit during the growing season in the former. Potential evapotranspiration exceeded precipitation in the June-to-August period by 182, 287, 117, and 146 mm in the first, second, third, and residual years, respectively. In addition, the yield may have been reduced in year 1 because of an infestation of quackgrass *(Agropyron repens)* which was controlled with atrazine, and in year 2 because of late (3 June) planting due to wet soil conditions in May. The growing period was 124, 103, 114, and 130 days in years 1, 2, 3 and the residual year, respectively, compared to an average of about 125 in the region. Relatively high yields in the residual year probably resulted from a better distribution of rainfall during the growing season, a longer growing period compared to the previous years, and from the use of a longer season corn hybrid. Rain was recorded on 40 d in the residual year compared to 30 d or less in the previous years in the June-to-August period.

The higher, albeit non-significant, yields from both sidedress treatments compared to the other treatments, in spite of the lower N application rates (Table 2), may be explained by manure application supplying available N just prior to the peak crop requirement. Yields from the two sidedress treatments were not significantly (P > 0.05) different in any year. Volatilization loss of NH_3-N from sidedress-surface application in this study was probably limited because of rainfall of 6 mm immediately after application in year 1, and of 6.5 and 12.0 mm within 24 h of application in years 2 and 3, respectively. Similar crop-available N from injection and surface applications would explain the non-significant yield difference from these two treatments. In preplant manure applications, yield advantage from injection over surface spreading has been attributed to manure NH_3-N conservation because of incorporation in contrast to loss by volatilization from unincorporated surface application (Safley et al., 1981; Sutton et al., 1982). However, in post-emergent manure applications, yield advantage from incorporation over surface spreading has been found to be non-significant (Xie and Mackenzie, 1986) or inconsistent because of variable weather conditions (Klausner and Guest, 1981).

Nutrient Uptake

There were few significant (P <0.05) treatment differences in N uptake during the three-year experimental period and none during the residual year (Table 4). With the exception of year 2, the lowest N uptake occurred in the control. Over the three-year treatment period, N fertilization increased the cumulative N uptake by 63 kg ha^{-1}, while preplant incorporation, post-emergent injection, and post-emergent surface application of manure increased the N uptake by 47, 83, and 82 kg ha^{-1}, respectively, compared with the control. For the two years when manure was fall-applied, the cumulative N uptake was increased by 19 kg ha^{-1} relative to the control. Phosphorus uptake by the crop was unaffected by the treatments. Potassium uptake varied widely between years, but treatment difference (P<0.05) were few. Uptake was highest in the two sidedress treatments although just 25 ± 11 kg ha^{-1} y^{-1} more K was removed in these treatments compared with the control. Uptake of manure K under sidedress injection was significantly (P<0.05) greater than in the control in two of the three experiment years.

TABLE 5. Groundwater quality at 1.2 m depth

Water quality parameter	Year(s)	Treatment: Control	Treatment: Fertilizer	Manure: Fall plow	Manure: Spring disk	Manure: Sidedress inject	Manure: Sidedress broadcast	MSD*
		mg L^{-1}						
NO_3-N	2	17.3 a†	26.8 a	29.2 a	27.4 a	28.2 a	21.9 a	18.2
	3	16.8 a	21.5 a	29.5 a	22.1 a	31.3 a	22.4 a	14.5
	1st Residual	22.1 a	42.3 a	34.1 a	24.9 a	28.5 a	27.1 a	21.8
	2nd Residual	13.3 b	23.5 ab	21.9 ab	19.5 ab	29.0 a	15.8 ab	14.0
Total P	2	0.05 a	0.08 a	0.08 a	0.07 a	0.07 a	0.08 a	0.04
	3	0.06 a	0.04 a	0.05 a	0.05 a	0.06 a	0.05 a	0.03
	1st Residual	0.03 a	0.03 a	0.03 a	0.02 a	0.02 a	0.02 a	0.01
	2nd Residual	0.03 a	0.04 a	0.03 a	0.03 a	0.03 a	0.03 a	0.02
		µS cm^{-1} (25ºC)						
Specific conductivity	2	322 b	501 a	426 ab	424 ab	413 ab	440 ab	166
	3	278 b	416 a	426 a	379 ab	448 a	408 a	121
	1st Residual	357 a	455 a	473 a	401 a	386 a	434 a	131
	2nd Residual	403 a	409 a	458 a	439 a	540 a	406 a	194

* MSD = minimum significant difference.

† Mean values in a row followed by the same letter are not significantly different (P>0.05) based on the Tukey procedure.

Groundwater Quality

Concentrations of NH_4^+-N in shallow groundwater (1.2-m depth) never exceeded 0.5 mgL^{-1} and were essentially <0.1 mgL^{-1} (data not presented). Nitrate-N concentrations, however, were much greater than NH_4^+-N concentrations (Table 5). For the years 2 and 3, NO_3^--N averaged 29.4, 24.8, 29.8, and 22.2 mgL^{-1} from fall plowed, spring disked, sidedress injected, and sidedress broadcast treatments, respectively. Concentrations for the chemical fertilizer and control plots were 24.2 and 17.1 mgL^{-1}, respectively. While treatments increased NO_3^--N concentrations, the effects were not statistically (P>0.05) significant. With the exception of the sidedress injection treatment, NO_3^--N concentrations decreased significantly (P<0.05) between the first and the second residual years. It is noteworthy that NO_3^--N mean concentrations in all treatments, including the control, were higher than the drinking water limit of 10 mgL^{-1}. This indicates that under the normally recommended manure and fertilizer N applications for corn production, shallow groundwater quality is unlikely to meet the drinking water standard for NO_3^--N.

Concentrations of total P were low and unaffected by treatments. Concentrations of K were uniformly low (average 3.3 mgL^{-1}, data not presented). Mean specific conductivity values ranging from about 300 to 500 µS cm^{-1} indicated relatively low mineral content of the shallow groundwater. Control plots had generally lower conductivities than the treatment plots but the effects disappeared during the residual period. The N fertilizer treatment seemed to induce conductivity changes similar to those from the manure treatments despite substantial salt input from the manure. The pH of the shallow groundwater, ranging from 7.1 to 7.6 (data not presented), was unaffected by treatments.

Soil Composition

With the exception of exchangeable K, treatments did not affect soil chemical properties at the end of the three-year treatment period (Table 6). This is consistent with results from other studies which have also shown that at moderate rates of liquid manure application, soil P and exchangeable cations do not appear to be affected by the method or time of liquid manure application (Culley et al., 1981; Safely et al., 1981; Wolt et al., 1984). Significantly (P<0.05) higher concentration of K in the manured plots than in the control and fertilized plots (Table 6) appeared to be related to the higher K applications in the former than in the latter.

Extractable inorganic N content of the 1.2-m deep soil profile after harvest each year is shown in Table 7. With the exception of the sidedress-inject treatment, extractable inorganic N was the highest in year 1, and decreased steadily during the three-year treatment period, suggesting a generally declining influence of the previous alfalfa crop at the experimental site. The mean inorganic N content of the 1.2 m deep soil profile during the three-year period was 81 kg ha^{-1} for the control, and 162 kg ha^{-1} for the chemical fertilizer treatment. The corresponding value for the pooled manure treatments was 132 kg ha^{-1}. As with the groundwater NO_3^--N concentrations (Table 5), the control plots had the lowest inorganic N content every year. However, treatment differences were not significant (P>0.05) in two of the three treatment years. In year 2, the sidedress-injected plots had significantly (P<0.05) higher inorganic N than the spring-disk and control plots. In the residual year, the chemically fertilized plots had significantly (P<0.05) higher inorganic N than the control plots. The chemical fertilizer treatment was not significantly (P>0.05) different from any of the manure treatments in any year, including the residual year. Thus, three successive years of manure total N applications at approximately twice the rate of fertilizer N application did not lead to increased extractable inorganic N in the manured plots.

TABLE 6. Selected soil chemical properties after harvest in a year 3 for 0.0-0.15 m and 0.15-0.30 m soil depths

Treatment	Organic C	Organic N	Bicarbonate P	Exchangeable cations Ca^{2+}	Exchangeable cations Mg^{2+}	Exchangeable cations K^+	pH
			– mg kg^{-1} –	— cmol (+) kg^{-1} –			
			0.0-0.15 m				
Manure	1.53a*	0.11a	17.7a	10.6a	4.9ab	0.3a	6.5a
Fertilizer	1.42a	0.10a	9.8bc	9.4a	3.4a	0.2b	6.2a
Control	1.56a	0.11a	13.1ab	11.2a	4.7ab	0.2b	6.4a
			0.15-0.30 m				
Manure	0.78b	0.04bc	5.7c	11.2a	5.5b	0.3ab	6.3a
Fertilizer	0.80b	0.04b	5.8c	10.1a	5.5b	0.2b	6.3a
Control	0.92b	0.07bc	6.0c	10.5a	5.4b	0.2b	6.6a
MSD †	0.28	0.03	6.4	2.4	1.7	0.1	0.4

* Means within each column followed by the same letter are not significantly different (P>0.05) based on the Tukey procedure.

† MSD = minimum significant difference

TABLE 7. Extractable inorganic nitrogen in 1.2 m deep soil profile after harvest*

Year	Control	Fertilizer	Manure: Fall plow	Manure: Spring disk	Manure: Sidedress inject	Manure: Sidedress surface	MSD †
1	101 a‡	229 a	-	180 a	165 a	151 a	143
2	97 b	149 ab	138 ab	129 b	189 a	136 b	53
3	46 a	109 a	115 a	77 a	113 a	54 a	79
Residual	38 b	97 a	82 ab	52 ab	76 ab	61 ab	49

* - N extractable with 2M KCl.

† MSD = minimum significant difference.

‡ Mean values in a row followed by the same letter are not significantly different (P>0.05) based on the Tukey procedure.

Concentrations of soil inorganic N by depth at harvest were similar for both fertilized and manured plots (Fig. 1). Compared with the control, the fertilized plots had significantly (P<0.05) higher concentrations in the 0.0-0.15-m surface layer but just slightly greater concentration between 0.9 and 1.2 m at the end of the year 2. Soil N concentration in the deepest layer of the fertilizer treatment was double that of the control at the end of year 3, but this difference was not significant (P>0.05) using the conservative Tukey test. A trend towards increasing soil inorganic N concentration with increasing depth below 0.3-0.6 m was noticeable in year 3.

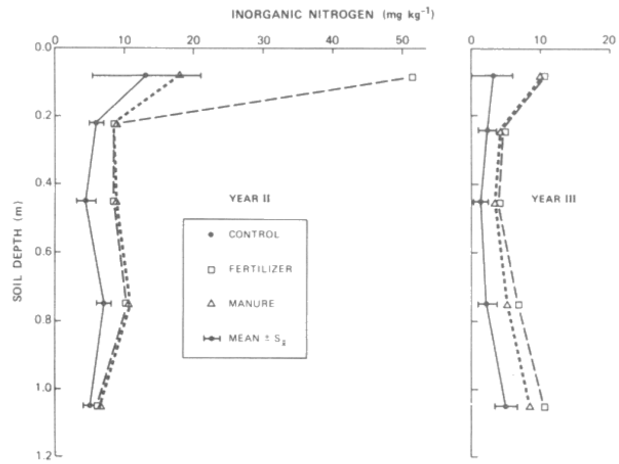

Fig. 1-Extractable nitrate plus nitrite plus ammonium concentrations in soil profiles after harvest in years 2 and 3. Standard errors associated with the pooled manure means for each depth are one-half those for either control (indicated) or fertilizer treatments.

CONCLUSION

Under the conditions similar to those of this study, there is little apparent agronomic benefit for corn silage production when dairy cattle liquid manure is applied by a range of methods on fields previously cropped to alfalfa for two years or more. Nitrate -N concentrations exceeding 10 mg L^{-1} in shallow (1.2 m deep) groundwater in all treatments, including the control, indicate that this concentration limit for drinking water is unlikely to be met in shallow groundwater in corn fields that are fertilized or manured at agronomically recommended rates. Different methods and times of manure application at moderate rates did not appear to have significant effect on soil composition in corn fields under the generally cool, humid climatic conditions of eastern Ontario.

References

1. APHA. 1981. Standard methods for the examination of water and wastewater. 15th ed. American Public Health Association, Washington, DC.

2. Bolton, E.F., V.A. Dirks and J.W. Aylesworth. 1976. Some effects of alfalfa, fertilizer and lime on corn yield in rotations on clay soil during a range of seasonal moisture conditions. *Can. J. Soil Sci.* 56:21-25.

3. Bruulsema, T.W. and B.R. Christie. 1987. Nitrogen contribution to succeeding corn from alfalfa and red clover. *Agronomy J.* 79:96-100.

4. Culley, J.L.B., P.A. Phillips, F.R. Hore and N.K. Patni. 1981. Soil chemical properties and removal of nutrients by corn resulting from different rates and timing of liquid dairy manure applications. *Can. J. Soil Sci.* 61:35-46.

5. Culley, J.L.B. and N.K. Patni. 1987. Soil compaction from liquid manure tanker traffic. *Transactions of the ASAE* 30(5):1214-1218.

6. Evans, S.D. 1979. Manure application studies in west central Minnesota. ASAE Paper No. 79-2119. St. Joseph, MI: ASAE.

7. Fox, R.H. and W.P. Piekielek. 1983. Response of corn to nitrogen fertilizer and the prediction of soil nitrogen availability with chemical tests in Pennsylvania. Bull. 843, The Pennsylvania State University College of Agriculture, University Park.

8. Klausner, S.D. and R.W. Guest. 1981. Influence of NH_3 conservation from dairy manure on yield of corn. *Agronomy J. 73:720-723.*

9. OMAF. 1986. Field crop recommendations. Publication 296, Ontario Ministry of Agriculture and Food, Toronto, Ontario.

10. Overcash, M.R., F.J. Humenik, and J.R. Miner. 1983. *Livestock Waste Management,* Vol. II. Boca Raton, FL: CRC Press, Inc.

11. Phillips, P.A., J.L.B. Culley, F.R. Hore and N.K. Patni. 1981. Pollution potential and corn yields from selected rates and timing of liquid manure applications. *Transactions of the ASAE* 24(1):139-144.

12. SAS. 1985. SAS® User's Guide: Statistics, Version 5 Ed. SAS Insititute Inc., Cary, NC.

13. Safley, L.M., G.M. Lessman, J.D. Wolt and M.C. Smith. 1981. Comparison of corn yields between broadcast and injected applications of swine-manure slurry. 1n Livestock Waste: A Renewable Resource, 178-180. ASAE, St. Joseph, MI.

14. Safley, L.M., P.W. Westerman, J.C. Barker, L.D. King and D.T. Bowman. 1986. Slurry dairy manure as a corn nutrient source. *Agricultural Wastes* 18:123-136.

15. Sheldrick, B.H. 1984. Analytical Methods Manual 1984. Land Resource Research Institute, Agriculture Canada, Ottawa, Ontario.

16. Sutton, A.L., D.W. Nelson, V.B. Mayrose and J.C. Nye. 1978. Effects of liquid swine waste applications on corn yield and soil chemical composition. *J. Env. Qual.* 7:325-333.

17. Sutton, A.L., D.W. Nelson, J.D. Hoff and V.B. Mayrose. 1982. Effects of injection and surface applications of liquid swine manure on corn yield and soil composition. *J. Env. Qual.* 11:468-472.

18. Sutton, A.L., D.W. Nelson, D.T. Kelly and D.L. Hill. 1986. Comparison of solid vs. liquid dairy manure applications on corn yield and soil composition. *J. Env. Qual.* 15:370-375.

19. Triplett, G.B., Jr., F. Haghiri and D.M. Van Doren, Jr. 1979. Legumes supply nitrogen for no tillage corn. Ohio Report on Research and Development in Agriculture, Home Economics, and Natural Resources, Ohio Agricultural R. & D. Center, Wooster, OH. 64(6):83-85.

20. USEPA. 1979. Methods of Chemical Analysis of Water and Wastes. EPA-600/4-79-020. U.S. Environmental Protection Agency, Cincinnati, OH.

21. Wolt, 7.D., L.M. Safley, G.M. Lessman and M.C. Smith. 1984. Influence of time of injection of liquid swine waste on silage yield and nutrient content of corn. *Transactions of the ASAE* 27(4):1135-1139.

22. Xie, R. and A.F. Mackenzie. 1986. Urea and manure effects on soil nitrogen and corn dry matter yields. *Soil Sci. Soc. Am. J.* 50:1504-1509.