EFFECTS OF LIQUID HOG MANURE APPLICATION RATES ON SILAGE CORN YIELD AND NUTRIENT UPTAKE

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The objective of this work was to determine the response of corn to liquid hog manure surface applied at rates of 28, 56 and 112 tonnes/ha. In greenhouse trials, yield of corn grown for 4 wk on St. Jude loamy sand was not affected by manure application. On Kamouraska silty clay, only manure applied at a rate of 112 tonnes/ha increased corn yield, as compared to the non-treated control. Corn response on Janvier sandy clay loam improved with increasing rate of manure application up to 56 tonnes/ha. Application of 112 tonnes/ha (325 kg N/ha) manure increased N content of corn and had a significant residual effect as noted by the high yield obtained at the second harvest. In a 2-yr field experiment on Kamouraska soil, corn yield was significantly higher at 112 tonnes/ha (avg 432 kg N/ha) than chemical fertilizer application at 150 kg N/ha, and manure-treated soil contained more P, Ca and Mg after the first year. Nutrient uptake by corn increased with amount of manure applied. However, corn whole plant composition was not affected by rate of manure application. N recovery was higher from manure at 28 or 56 tonnes/ha than from a chemical fertilizer (150 kg N/ha, 65.5 kg P/ha and 125 kg K/ha). At the rates applied, the liquid hog manure did not result in reduced corn yield.

Key words: Corn yield, hog manure, nutrient uptake, silage corn

Le but de ce travail était de déterminer l'effet de l'application du lisier de porc aux doses de 28, 56 et 112 tonnes/ha sur la croissance et la composition chimique du maïs. Dans un essai en serres, l'application du lisier n'a eu aucun effet significatif sur le rendement du maïs cultivé pendant 4 semaines sur le sable loameux St-Jude. Sur l'argile Kamouraska, le rendement du maïs n'a significativement augmenté qu'avec l'addition d'une dose de 112 tonnes/ha de lisier. Sur le loam sablo-argileux Janvier, le rendement du maïs a augmenté avec l'application de doses croissantes de lisier jusqu'à 56 tonnes/ha. A un taux de 112 tonnes/ha (325 kg N/ha), le lisier a augmenté le contenu en N du maïs et a eu un effet résiduel important tel qu'indiqué par le rendement élevé obtenu lors de la 2e récolte. Dans un essai de 2 ans au champ sur le sol Kamouraska, l'addition de 112 tonnes/ha (moy. 432 kg N/ha) de lisier a augmenté le rendement du maïs fourrager, ainsi que le contenu du sol en P, Ca et Mg après une année de culture, comparativement à un engrais chimique (150 kg N/ha, 65.5 kg P/ha et 125 kg K/ha). Le prélèvement des éléments nutritifs par le maïs a augmenté avec l'addition de doses croissantes de lisier. Cependant, la variation des doses de lisier n'a eu aucun effet sur la composition chimique du maïs. Aux taux utilisés dans cette étude le lisier de porc n'a pas réduit le rendement du maïs.

The increasing swine production in Canada in recent years has made manure disposal a major problem. In 1980, Canadian farmers had to manage 16.9 million metric tons of hog manure, 34% of which was produced in the province of Quebec (Culley 1981). Land application of manure is a cost effective means of disposal and improves soil productivity (Barnett 1981).

As swine production increases, manure will become available at quantities in excess of crop requirement (Culley and Barnett 1984). Excessive application of hog manure could result in nutrient accumulation in soils, thereby increasing the hazards of phytotoxicity and reduced crop yields. However, most studies in North America on crop response to manure application were conducted with cattle or poultry wastes (Culley 1981). Few attempts have been made to document crop response to hog manure. Liquid hog manure, when applied for 2 consecutive years on a silt loam in Minnesota at a rate of 636 tonnes/ha, was not detrimental to corn but resulted in salt levels high enough to cause wilting of young plants (Evans et al. 1977). However applications of up to 270 tonnes/ha did not lead to phytotoxicity or to soil contamination by salts or Cu (Sutton et al. 1983, 1984). In a 2-yr field experiment on two silt loam soils of Indiana, corn yields were higher on plots treated with liquid hog manure or inorganic fertilizers as compared with non-treated plots (Sutton et al. 1978). Yields increased with manure applications of up to 90 tonnes/ha (252 kg N/ha, 76 kg P/ha and 109 kg K/ha), and leveled off afterwards. Concentrations of N, P and K in ear leaf tissue also increased as a result of manure application (Sutton et al. 1978). When grown in the field on a clay and two sandy loam soils of southern Quebec, corn did not respond significantly to hog manure or hog manure plus straw applied at the soil surface in amounts of 150 kg/ha of total N (Miller and MacKenzie 1978). This lack of response was attributed to loss of N through volatilization and to slow mineralization of organic N.

The objectives of this study were: (1) to measure the effect of application of up to 112 tonnes/ha of liquid hog manure on yield and nutrient content of corn grown on three Quebec soils of different textural classes under greenhouse conditions; and (2) to assess under field conditions the influence of hog manure on silage corn yield and nutrient content, and on the properties of a Quebec soil.

MATERIAL AND METHODS

Greenhouse Experiment

The effect of surface application of liquid hog manure on corn (*Zea mays* L. 'Acco Dc 108') was assessed on three soils (Table 1). Hog manure used had the following composition (wet basis): total-N, 0.29%; N-NH_4^+, 0.20%; P, 0.026%; and K, 0.03%; dry matter content, 1.6%; pH, 7.4. Manure was collected fresh from buildings where the animals were confined on slats. Manure was surface-applied at rates of 28, 56 and 112 tonnes/ha to pots (17 cm diameter) containing 6 kg of soil. Two days after manure application, each pot received 10 corn seeds. Upon emergence, the seedlings were thinned to five plants per pot. The experimental design used was a split-plot(soils as main plots and manure rates as subplots) with four replications. Plants were harvested 4 wk later after which pots were re-seeded to appraise the residual effect of the manure previously applied. The photoperiod was 16 h a day and the greenhouse temperature was maintained at 28°C. Plants were dried at 70°C for 48 h in a forced-air oven, ground and analyzed as described below.

Field Trials

An imperfectly-drained Kamouraska silty clay field, located at Laval University experimental farm at St-Louis de Pintendre Quebec, was di-

Table 1. Some properties of the three soils selected for the greenhouse study

Soils	Texture	pH	Organic matter (%)	P (kg/ha)	K (exchangeable) (kg/ha)
Kamouraska	Silty clay	7.7	3.1	148	287
Janvier	Sandy clay loam	7.4	2.7	74	49
St. Jude	Loamy sand	5.8	1.6	105	76

vided into 20 plots of 3.0 × 7.6 m. Prior to commencement of the experiment the 0- to 15-cm layer of the soil had a pH of 7.2 and contained 4.7% organic matter. Phosphorus and exchangeable K amounted to 99 and 161 kg/ha, respectively. Pioneer 3992 corn was seeded with a hand planter on 24 May 1982 and on 19 May 1983. By selective thinning, healthy plants were spaced 15 cm from one another, in four rows per plot (86 000 plants/ha). Manure used in field trials was collected from outdoor storage tanks. Three surface applications of manure were made to reach the highest rate of 112 tonnes/ha. In 1982, the first application (28 tonnes/ha) took place 1 wk before planting. For higher rates manure was applied broadcast between corn rows at 1-wk intervals. Chemical fertilizer plots received 150 kg N/ha as NH_4NO_3, 65.5 kgP/ha as superphosphate and 112 kg K/ha as KCl. Because of heavy rainfall in May 1983 (23.6 cm as compared to 5.0 cm in 1982), the first application of manure and the chemical fertilizer was made 2 wk after seeding. The other manure applications followed at 1-wk intervals. Treatments were arranged in a randomized complete block design with four replicates. During application, manure samples were taken and analyzed as described below. Analyses of hog manure applied during the spring of 1982 and 1983 indicated a large variability in chemical composition (Table 2). Therefore, the exact amount of nutrients added at each application was calculated instead of using mean values. Corn was harvested on 6 Oct. 1982 and 30 Sept. 1983 in the two central rows along 5.3 m. The wet weight of the entire plants was determined. Dry weights were obtained after drying subsamples of the mechanically chopped plants at 70°C. Subsequent analyses were conducted on subsamples of the ground plant material.

Before manure application and corn planting, and at harvest time in 1982, soil aggregate stability in water was determined as described by Kemper (1965).

The Tukey's honestly significant difference procedure was applied to test differences between treatment means as described by Steel and Torrie (1960).

Manure, Soil and Plant Analysis

Total N in manure was determined by Kjeldahl method (Bremner and Mulvaney 1982). N-NH_4^+ was determined by steam distillation (Keeney and Nelson 1982). Other elements in the manure were analyzed, as described for plants, after digestion of manure (dried at 70°C) with concentrated HNO_3-$HClO_4$ (4:1).

Soil pH was measured in water (1:1) and available P was assessed by Bray's P_2 method after extraction with 0.03 N NH_4F + 0.1 N HCl (McKeague 1978). Exchangeable K, Ca and Mg were determined by atomic absorption spectrophotometry after extraction with 1 N NH_4OAc. Soil organic matter was estimated by the Walkley and Black modified method (McKeague 1978).

Total N content of the plants was determined by an automated Kjeldahl method (Foss Electric, Hillerd, Denmark). Other elements in the corn tissue were determined by atomic absorp-

Table 2. Composition of hog manure used in field trials (dry matter basis)

		1982		1983	
		Mean	Range	Mean	Range
N	(%)†	0.36	0.12–0.56	0.49	0.29–0.52
N-NH_4^+	(%)†	0.20	0.09–0.28	0.28	0.24–0.32
P	(%)	2.80	2.40–3.10	3.00	2.20–3.50
K	(%)	5.45	2.28–7.50	4.45	2.39–7.57
Na	(%)	2.99	0.92–4.90	3.21	1.32–6.54
Ca	(%)	3.03	2.92–3.18	2.66	1.90–3.05
Mg	(%)	1.13	0.84–1.34	1.34	0.56–1.82
Fe	(%)	0.49	0.43–0.56	0.62	0.12–1.00
Zn	(%)	0.16	0.15–0.17	0.14	0.04–0.21
Cu	(mg/kg)	419	147–642	470	408–504
Mn	(mg/kg)	302	215–348	312	104–441
Dry matter	(%)	2.78	0.51–5.73	3.81	0.90–6.19
pH		7.4	7.2–7.6	7.6	7.5–7.8

†Wet basis.

tion spectrophotometry of 1.86 N HCl extracts of the plant ash (Gaines and Mitchell 1979). Phosphorus was determined colorimetrically by vanado-molybdate method (Tandon et al. 1968).

RESULTS AND DISCUSSION

Response of Corn to Manure in Greenhouse Trials

Surface application of liquid hog manure to St. Jude loamy sand had no significant effect on corn yield. On Kamouraska silty clay, only manure applied at a rate of 112 tonnes/ha (325 kg N/ha) increased corn yield, as compared to the non-treated control (Table 3). Corn grown on Janvier soil responded to manure up to a rate of 56 tonnes/ha. On Kamouraska and Janvier soils, the application of 112 tonnes/ha manure had a significant residual effect as indicated by higher yields obtained at the second harvest (Table 3). Among the three soils tested, the Kamouraska silty clay had the highest pH, organic matter content, available P and exchangeable K (Table 1). With all treatments, corn grown on Kamouraska soil gave the highest yield. The lowest yield was obtained on the slightly acid St. Jude loamy sand which had the lowest organic matter content (Tables 1 and 3). On Kamouraska and St. Jude soils, corn leaf and stalk N were significantly higher on treatment receiving 112 tonnes/ha manure, as compared to the non-treated soils (Table 4). Similar results were obtained on Janvier and St. Jude soils for corn P and on Kamouraska soil for corn K. The greenhouse study shows that initial corn response to the application of increasing amounts of manure depends on the type of soil used. It also indicates that at the early stage of growth, a rate of hog manure of up to 112 tonnes/ha (325 kg N/ha) is not phytotoxic and increases corn N, P or K content on some soils. On Kamouraska and St. Jude soils the application of more than 28 tonnes/ha (81 kg N/ha) exceeded corn nutrient requirements during the first 4 wk of growth. The significant residual effect observed with 112 tonnes/ha at the second harvest indicates that on some soils, mature corn may benefit from this rate of manure.

Field Crop Yields in 1982 and 1983

In 1982, plants grown on soils treated with

Table 3. Dry matter yields of 4-wk-old corn grown on three soils treated in the greenhouse with hog manure

Soils	Manure (tonnes/ha)†	Dry matter yields (g/pot) 1st harvest	Dry matter yields (g/pot) 2nd harvest
Kamouraska silty clay	0	8.87	1.70
	28	9.70	2.42
	56	9.96	2.22
	112	10.48	3.19
Janvier sandy clay loam	0	3.68	2.09
	28	4.93	2.32
	56	6.47	2.87
	112	6.40	3.56
St. Jude loamy sand	0	2.49	1.32
	28	3.45	1.56
	56	3.90	1.50
	112	3.58	2.45
LSD			
Manure (within soils)		1.13	1.18
F *values*			
Soils		191.0**	11.5**
Manure		14.2**	8.2**

†Rate of N application: 81.2, 162.4 and 324.8 kg/ha for 28, 56 and 112 tonnes/ha of manure.
**Significant at 1% level.

Table 4. Effect of hog manure on chemical composition of 4-wk-old corn grown on three different soils in the greenhouse

		% in leaves and stalks (dry basis)					
		1st harvest			2nd harvest (residual)		
Soils	Manure (tonnes/ha)	N	P	K	N	P	K
Kamouraska silty clay	0	1.74*a*	0.16*a*	3.36*a*	1.76*a*	0.77*a*	3.46*a*
	28	1.99*ab*	0.14*a*	3.07*a*	1.58*a*	0.73*a*	3.01*a*
	56	2.09*ab*	0.16*a*	3.10*a*	1.58*a*	0.52*a*	3.11*a*
	112	2.70*b*	0.18*a*	3.70*b*	1.53*a*	0.60*a*	3.38*a*
Janvier sandy clay loam	0	2.29*ab*	0.09*a*	4.16*a*	1.79*a*	0.11*a*	3.67*a*
	28	1.82*a*	0.09*a*	2.80*b*	1.70*a*	0.12*a*	2.74*a*
	56	2.33*b*	0.12*b*	3.21*b*	1.28*a*	0.12*a*	2.74*a*
	112	2.67*b*	0.14*b*	4.09*a*	1.46*a*	0.11*a*	3.09*a*
St. Jude loamy sand	0	1.81*a*	0.06*a*	3.54*a*	1.41*a*	0.14*a*	2.53*a*
	28	2.07*a*	0.07*a*	4.09*a*	1.36*a*	0.34*a*	3.56*b*
	56	2.32*a*	0.08*ab*	4.49*a*	1.37*a*	0.11*a*	3.05*ab*
	112	3.29*b*	0.10*b*	4.55*a*	1.70*a*	0.10*a*	3.87*b*

a,b For each soil, means in the same column followed by the same letter are not significantly different according to Tukey's honestly significant difference procedure at the 5% level.

112 tonnes/ha (459 kg N/ha) manure produced significantly higher yields than when no manure had been applied. No significant differences were observed between yields obtained with the non-treated control or on plots treated with the chemical fertilizer or manure at a rate of up to 56 tonnes/ha (145 kg N/ha) (Table 5). Apparently, there were sufficient reserves of plant nutrients from previous fertilizations (Table 6) to give yields on the non-treated control plots comparable to those obtained with the chemical fertilizer. Higher yields obtained with the application of 112 tonnes/ha manure could be attributed to the additional amounts of nutrients applied or to the moisture contained in the liquid manure. Because very wet conditions prevailed in May 1983 followed by a dry spell during the summer, mean corn yield was 752 kg/ha lower in 1983 than in 1982. Chemical fertilizer and application of 28 tonnes/ha (164 kg N/ha) manure resulted in yields similar to those in plots with no fertilization (Table 5). The highest yield was obtained with 112 tonnes/ha (405 kg N/ha) manure. This can partly be ascribed to the significant amounts of residual nutrients observed in the soils having received substantial amounts of manure. In fact, after 1 yr of corn cultivation, those plots to which the highest rate of manure had been applied were richer in P, Ca and

Table 5. Silage corn yields from hog manure and chemical fertilizer treated Kamouraska silty clay soil

	Dry matter yields (tonnes/ha)		
Applied nutrient	1982	1983	1982 + 1983
Chemical fertilizer	7.13*abc*	5.05*ab*	12.18*ac*
Manure (tonnes/ha)			
0	4.36*a*	3.93*a*	8.29*b*
28	5.88*ab*	5.83*abc*	11.71*c*
56	7.14*abc*	7.26*bc*	14.40*acd*
112	9.39*c*	8.07*c*	17.46*d*

a-d Means in the same column followed by the same letter are not significantly different according to Tukey's honestly significant difference procedure at the 5% level.

Mg than plots treated with the chemical fertilizer (Table 6). Corn cultivation for 1 yr on Kamouraska silty clay soil significantly reduced the percentage of water-stable aggregate (Table 7), Martel and MacKenzie (1980) showed that in those Quebec soils which are used for continuous row-cropping, there is an important loss in organic matter, associated with a decrease in structural stability and soil productivity, even when the availability of nutrients is improved by greater use of fertilizer. Manure application at rates as high as 112 tonnes/ha did not, after 1 yr, improve aggregate stability in water nor soil organic matter content (Tables 6 and 7), but a long-term effect needs more investigation. Since the contents of N, P, K, Ca and Mg in whole plants were similar with all treatments, it can be concluded that silage corn composition was not affected by hog manure applications (Table 8). High doses of manure did not affect corn Cu, Fe, Mn and Zn contents as compared to the chemical fertilizer treatment (Table 9). Sutton et al. (1983) did not observe an increase of Cu concentration in corn tissue when liquid manure from pigs fed on a diet containing high level of $CuSO_4$ was applied at rates of up to 270 tonnes/ha over a 4-yr period.

Nutrient uptake by corn plants increased when larger amounts of nutrients were available from applied hog manure (Table 10). The apparent N recovery (Miller and MacKenzie 1978) by the corn plant, from plots treated with chemical fertilizer and

Table 6. Soil composition (0- to 15-cm layer) of plots cultivated with corn for one year, before manure application in spring 1983

Applied nutrient	pH	Organic matter (%)	kg/ha P	kg/ha K	kg/ha Ca	kg/ha Mg
Chemical fertilizer	6.8	5.91*a*	109*a*	283*a*	6138*a*	407*a*
Manure (tonnes/ha)						
0	6.6	4.65*a*	81*b*	211*bc*	5201*b*	340*b*
28	7.0	4.04*a*	102*a*	206*b*	6384*a*	322*b*
56	6.8	4.38*a*	102*a*	223*c*	5506*b*	331*b*
112	6.8	5.31*a*	141*c*	272*a*	7060*c*	456*c*
1982†	7.2	4.70	99	161	5376	353

a-c Means in the same column followed by the same letter are not significantly different according to Tukey's honestly significant difference procedure at the 5% level.
†Soil analysis in spring 1982 before the beginning of trials.

Table 7. Variation in aggregate stability in water, for plots cultivated with corn and having received different rates of liquid hog manure for 1 yr

Applied nutrient	% aggregation: Before manure application and planting	% aggregation: At harvest	% aggregation: Average loss in aggregation
Chemical fertilizer	60±8.5*a*	44±9.9*a*	16
Manure (tonnes/ha)			
0	63±9.4*a*	42±5.0*a*	21
28	52±8.6*a*	46±9.8*a*	6
56	63±3.9*a*	40±6.6*a*	23
112	54±4.0*a*	51±10.6*a*	3

a Means in the same column followed by the same letter are not significantly different according to Tukey's honestly significant difference procedure at the 5% level.

Table 8. N, P, K, Ca and Mg contents of silage corn grown on Kamouraska silty clay soil having received hog manure for 2 yr

	% in whole plant									
	1982					1983				
Applied nutrient	N	P	K	Ca	Mg	N	P	K	Ca	Mg
Chemical fertilizer	1.40*a*	0.26*a*	0.93*a*	0.30*a*	0.21*a*	1.52*a*	0.17*a*	0.97*ab*	0.36*a*	0.20*a*
Manure (tonnes/ha)										
1	1.33*a*	0.26*a*	0.92*a*	0.29*a*	0.18*a*	1.28*a*	0.16*a*	0.80*a*	0.30*a*	0.17*a*
28	1.34*a*	0.25*a*	0.84*a*	0.33*a*	0.18*a*	1.48*a*	0.17*a*	0.83*a*	0.32*a*	0.19*a*
56	1.46*a*	0.23*a*	0.89*a*	0.30*a*	0.18*a*	1.54*a*	0.16*a*	0.93*ab*	0.32*a*	0.18*a*
112	1.57*a*	0.24*a*	0.82*a*	0.28*a*	0.19*a*	1.54*a*	0.17*a*	1.08*b*	0.29*a*	0.18*a*

ab Means in the same column followed by the same letter are not significantly different according to Tukey's honestly significant difference procedure at the 5% level.

Table 9. Silage corn Cu, Fe, Mn and Zn from Kamouraska silty clay soil after having received hog manure for 2 yr

Applied nutrient	µg/g in whole plant in 1983			
	Cu	Fe	Mn	Zn
Chemical ferilizer	2.07*a*	232*a*	24.0*a*	22.2*a*
Manure (tonnes/ha)				
0	3.57*a*	431*a*	19.9*a*	30.0*a*
28	2.32*a*	242*a*	17.7*a*	23.3*a*
56	2.94*a*	202*a*	23.9*a*	22.3*a*
112	3.77*a*	189*a*	22.4*a*	24.9*a*

a Means in the same column followed by the same letter are not significantly different according to Tukey's honestly significant difference procedure at the 5% level.

with 28, 56 and 112 tonnes/ha manure was 28, 63, 32 and 19%, respectively, in 1982 and 17, 22, 25 and 18%, respectively, in 1983. The low N recovery from the plots to which the largest quantities of manure were applied in 1982 are probably the result of a higher loss by volatilization of ammonia at a soil pH of 7.2 (Table 6) (Hoff et al. 1981), and the use of N in excess of crop requirements (459 kg N/ha).

During the 2-yr field study, the application of 112 tonnes/ha of liquid hog manure to Kamouraska silty clay significantly increased silage corn dry matter yield as com-

Table 10. Nutrient removal by silage corn grown on a Kamouraska silty clay

Applied nutrient	Rate of N application	N uptake	Rate of P application	P uptake	Rate of K application	K uptake
	$kg \cdot ha^{-1} \cdot yr^{-1}$					
			1982			
Chemical fertilizer	150	99.8	65.5	18.5	125	66.3
Manure (tonnes/ha)						
0	0	58.0	0	11.3	0	40.1
28	33	78.8	3.4	14.7	11	49.4
56	145	104.2	21.6	16.4	49	63.5
112	459	147.4	117.8	22.5	122	77.0
			1983			
Chemical fertilizer	150	76.7	65.5	8.6	125	49
Manure (tonnes/ha)						
0	0	50.3	0	6.3	0	31.4
28	164	86.3	49.9	9.9	43	48.4
56	244	111.8	55.5	11.6	62	67.5
112	405	124.3	66.7	13.7	100	87.2

pared to a chemical fertilizer and did not lead to phytotoxicity problems.

Apparent N recovery by corn from low rates of manure was higher than for the inorganic fertilizer and at the highest rate of manure application N recovery was similar to that in the case of the fertilizer in 1983 and was lower in 1982. Long-term application of high rates of liquid hog manure to Quebec soils needs further investigation to determine if manure will adversely affect soil and plant growth.

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