Influence of the time and rate of liquid-manure application on yield and nitrogen utilization of silage corn in south coastal British Columbia

B. J. Zebarth[1], J. W. Paul[1], O. Schmidt[2], and R. McDougall[3]

[1]Pacific Agriculture Research Centre (Agassiz), Agriculture and Agri-Food Canada P.O. Box 1000, Agassiz, British Columbia, Canada V0M 1A0; [2]Dairy Producers' Conservation Group, 1767 Angus Campbell Rd., Abbotsford, British Columbia, Canada V3G 2M3; and [3]Hog Producers' Sustainable Farming Group, Abbotsford, British Columbia, Canada. *Contribution No. 528, received 21 August 1995, accepted 15 January 1996.*

Zebarth, B. J., Paul, J. W., Schmidt, O. and McDougall, R. 1996. **Influence of the time and rate of liquid-manure application on yield and nitrogen utilization of silage corn in south coastal British Columbia**. Can. J. Soil Sci. **76**: 153–164. Manure-N availability must be known in order to design application practices that maximize the nutrient value of the manure while minimizing adverse environmental impacts. This study determined the effect of time and rate of liquid manure application on silage corn yield and N utilization, and residual soil nitrate at harvest, in south coastal British Columbia. Liquid dairy or liquid hog manure was applied at target rates of 0, 175, 350 or 525 kg N ha^{-1}, with or without addition of 100 kg N ha^{-1} as inorganic fertilizer, at two sites in each of 2 yr. Time of liquid-dairy-manure application was also tested at two sites in each of 2 yr with N-application treatments of: 600 kg N ha^{-1} as manure applied in spring; 600 kg N ha^{-1} as manure applied in fall; 300 kg N ha^{-1} as manure applied in each of spring and fall; 200 kg N ha^{-1} applied as inorganic fertilizer in spring; 300 kg N ha^{-1} as manure plus 100 kg N ha^{-1} as inorganic fertilizer applied in spring; and a control that received no applied N. Fall-applied manure did not increase corn yield or N uptake in the following growing season. At all sites, maximum yield was attained using manure only. Selection of proper spring application rates for manure and inorganic fertilizer were found to be equally important in minimizing residual soil nitrate at harvest. Apparent recovery of applied N in the crop ranged from 0 to 33% for manure and from 18 to 93% for inorganic fertilizer.

Key words: N recovery, manure management

Zebarth, B. J., Paul, J. W., Schmidt, O. et McDougall, R. 1996. **Influence de l'époque et du taux d'épandage de lisier sur le rendement du maïs ensilage et sur l'utilisation de l'azote par la culture dans le sud-ouest de la Colombie-Britannique**. Can. J. Soil Sci. **76**: 153–164. Il est essentiel de déterminer la biodisponibilité de l'azote de fumure, si l'on veut mettre au point des pratiques d'épandage qui maximisent la valeur nutritive du fumier, tout en atténuant le plus possible ses effets nuisibles sur l'environnement. Nos travaux réalisés avaient pour objet de déterminer les effets de l'époque et du taux d'épandage du lisier sur le rendement du maïs ensilage, sur son utilisation de l'azote et sur la teneur résiduelle du sol en nitrates au moment de la récolte, dans le sud-ouest de la Colombie-Britannique. Du lisier d'exploitation laitière ou du lisier de porcherie était épandu à 2 emplacements pendant 2 ans aux doses calculées de 0, 175, 350 ou 525 kg N ha^{-1}, avec ou sans complément de 100 k N ha^{-1} en fumure minérale. Simultanément, l'époque d'épandage du lisier d'exploitation laitière était étudiée à 2 emplacements pendant 2 ans. On comparait les traitements suivants: 600 kg N ha^{-1} sous forme de lisier 1) en épandage de printemps ou 2) en épandage d'automne, 3) 200 kg ha^{-1} en fumure minérale au printemps et en automne, 4) 300 kg ha^{-1} sous forme de lisier, plus 100 kg ha^{-1} sous forme d'engrais minéral au printemps et 5) témoin, aucun apport de N. L'épandage du lisier en automne n'apportait aucun accroissement du rendement du maïs ni de l'exportation de N par la culture dans la saison de croissance suivante. À tous les emplacements, le rendement le plus élevé était obtenu avec le traitement au lisier sans complément minéral. Le choix judicieux de la dose d'épandage de printemps, tant pour le lisier que pour l'engrais chimique, se révélait déterminant pour diminuer le plus possible les concentrations en nitrate du sol à la récolte. Le taux de récupération apparente du N de fumure par la culture allait de 0 à 33% dans le cas du lisier et de 18 à 93% dans celui de l'engrais minéral.

Mots clés: Récupération de N, système d'élimination du fumier

For manure management to be environmentally and economically sound, it is necessary to know the availability of the manure N for crop utilization. It is difficult to predict the amount and time of manure-N availability for plant growth because N in manure is in both organic and inorganic forms (Beauchamp and Paul 1989). Manure N applied in excess of that required can contribute to nitrate contamination of groundwater.

Proper manure management is particularly important in south coastal British Columbia because livestock densities are high and lead to high N-loading rates to agricultural land. Based on 1991 census data, Brisbin (1996) estimated that manure-N production from all livestock in the lower Fraser Valley was equivalent to 237 kg N ha^{-1} of land in agricultural production (including land in annual- and perennial-crop production and improved and unimproved pasture). A large proportion of the dairy manure is applied to land in silage-corn (*Zea mays* L.) production. A system for making N-management recommendations for corn that take manure into account is generally lacking.

A number of studies have estimated manure-N availability for corn in different climatic regions. Paul et al. (1990)

found reports of apparent recovery of the manure total N in corn ranging from 5 to 28% for liquid dairy cattle manure and from 14 to 95% for inorganic fertilizer. Beauchamp (1983) and Safley et al. (1986) estimated manure-N availability based on crop yield response. Xie and MacKenzie (1986) estimated manure-N availability relative to inorganic fertilizer with respect to residual soil nitrate at harvest. In one study, Khan (1986) determined the N availability in liquid hog manure for silage-corn production under south coastal British Columbia conditions.

The purpose of the study was to determine the influence of the rate and time of liquid-manure application on silage-corn yield and N uptake and on soil inorganic N at harvest. Separate experiments were conducted to test the effects of rate and time of manure application.

MATERIALS AND METHODS

Rate of Manure Application

Experiments were conducted at two locations, identified as the Graham and Alderglen sites, in 1992 and 1993. The experimental sites were located on farms, and all were cropped to corn in the previous year, except for the Graham 1993 site, which followed a spring ploughdown of forage grass after harvest of the first cut. At Alderglen, fall rye (*Secale cereale* L.) was planted following the previous corn harvest, harvested in spring, and ploughed down prior to planting in both years. All sites had a history of manure use. The 1992 and 1993 Alderglen sites were located within the same field, whereas the 1992 and 1993 Graham sites were located in two separate fields on the same farm. The Graham sites were located on a sandy soil of the Sumas soil series, classified as a Rego Gleysol (Luttmerding 1980), with a water table at approximately 1-m depth. The Alderglen sites were located on a sloping field of the Elk soil series, classified as a Rego Humic Gleysol (Luttmerding 1980). Soil properties at the experimental sites are summarized in Table 1.

Two adjacent trials were conducted at each site, one using liquid dairy manure and one using liquid hog manure. All trials in both years used a split-plot arrangement of treatments in a completely randomized block design, with two replications. Main plots received one of four target rates of liquid manure, 0, 175, 350 or 525 kg total N ha^{-1}, based on the manure analyses performed by a commercial laboratory (Table 2). The manure-application target rates were chosen to represent 0.5, 1.0 and 1.5 times the maximum recommended rate of manure application for silage corn on soils with low (< 4%) **organic matter** (**OM)** content (British Columbia Ministry of Agriculture, Fisheries and Food 1993).

Manure was obtained from concrete liquid-manure storage pits on farms close to the field sites. The manure was well agitated prior to sampling, and a single 1-L sample was taken from each pit and analyzed for total N content within 24 h. In 1992, manure analyses were performed no more than 3 d prior to application, and actual application rates were likely close (within 10%) to the target rates. In 1993, manure application was delayed up to 2 wk following manure analyses, as a result of poor weather conditions. Additional manure samples were taken on the day of application to verify the amount of N applied. The values of the samples obtained on the day of application were somewhat lower than the values measured previously. In all but one case, actual and target application rates in 1993 differed by no more than 20%.

The manure was surface applied to 36 m × 5.25 m plots, using a vacuum-tank liquid-manure spreader, and incorporated

Table 1. Soil pH (1:1 soil/water), organic matter content (combustion at 450ºC), total N content (dry-ash method), sand and clay contents (pipette method), and soil bulk density at the experimental sites[z]

Site	Year	Depth (cm)	Soil pH	Organic matter content (%)	Sand content (%)	Clay content (%)	Soil bulk density (g cm^{-3})
				Rate of manure application			
Alderglen	1993	0–15	5.3 (0.06)	10.5 (1.96)	1.9 (0.4)	17.8 (4.8)	0.97 (0.048)
		15–30	5.5 (0.12)	9.4 (2.21)	1.7 (0.5)	17.3 (4.9)	0.96 (0.005)
		30–60	5.5 (0.07)	4.2 (1.29)	1.2 (0.6)	8.6 (4.3)	1.16 (0.234)
Graham	1992	0–15	5.4 (0.13)	2.6 (0.40)	28.1 (13.5)	12.2 (2.8)	1.56 (0.043)
		15–30	5.8 (0.16)	2.3 (0.26)	23.7 (7.2)	12.4 (3.9)	1.55 (0.079)
		30–60	6.0 (0.24)	1.6 (0.16)	35.1 (17.9)	9.8 (7.9)	1.43 (0.059)
	1993	0–15	5.3 (0.16)	3.5 (0.20)	55.5 (2.9)	9.6 (0.9)	1.44 (0.070)
		15–30	5.3 (0.16)	2.1 (0.17)	56.8 (6.5)	9.2 (1.8)	1.46 (0.190)
		30–60	5.7 (0.20)	1.4 (0.27)	36.2 (19.2)	15.2 (4.1)	1.62 (0.057)
				Time of manure application			
Sumas	1993	0–15	4.5 (0.07)	3.0 (0.11)	82.2 (3.9)	6.8 (3.6)	1.36 (0.058)
		15–30	4.6 (0.03)	2.6 (0.13)	83.6 (4.8)	6.6 (3.3)	1.37 (0.056)
		30–60	4.9 (0.07)	1.2 (0.32)	72.3 (6.0)	3.4 (0.4)	1.51 (0.083)
		60–90	5.1 (0.08)	0.9 (0.07)	89.6 (2.0)	7.1 (4.5)	NA
Agassiz	1993	0–15	5.0 (0.13)	8.0 (0.33)	9.9 (2.4)	18.7 (2.0)	1.13 (0.074)
		15–30	5.0 (0.08)	7.2 (0.41)	9.1 (2.1)	17.3 (1.5)	1.13 (0.073)
		30–60	4.9 (0.05)	3.2 (0.54)	20.8 (9.7)	14.0 (2.4)	1.23 (0.098)
		60–90	4.9 (0.10)	1.9 (0.52)	3.6 (2.2)	10.5 (1.8)	NA

[z]Values are means (± 1 SE) of four determinations.
NA, not available.

Table 2. Description of chemical parameters of manures used in the rate- and time-of-application experiments, on a wet-weight basis

	Total N (mg kg^{-1})	Ammonium-N (mg kg^{-1})	Total P (mg kg^{-1})	Total K (mg kg^{-1})	Moisture content (%)
Rate of manure application					
Alderglen 1992					
Dairy	2600	1300	600	2500	92.7
Swine	3200	2700	1300	1000	98.7
Alderglen 1993					
Dairy	3900	2900	1300	1300	97.4
Swine	3500	2000	900	2600	92.6
Graham 1992					
Dairy	2000	800	500	2600	94.6
Swine	4700	4300	700	2000	98.6
Graham 1993					
Dairy	3100	1100	900	3000	92.9
Swine	2600	1900	200	1100	99.5
Time of manure application					
Sumas 1992					
Fall 1991	3100	1500	1100	5,100	88.3
Spring 1992	4100	1600	2300	5,200	87.9
Sumas 1993					
Fall 1992	4100	1600	1900	4,400	87.9
Spring 1993	3800	1700	900	3,600	90.1
Agassiz 1992					
Fall 1991	3500	1000	NA	NA	91.4
Spring 1992	3600	1600	3000	3,700	89.5
Agassiz 1993					
Fall 1992	2500	1200	1200	3,100	92.2
Spring 1993	2600	1100	700	2,500	92.8

NA, not available.

by ploughing within 24 h. Manure was applied on 14 April 1992 and 18 May 1993 at the Graham sites and on 15 May 1992 and 14 May 1993 at the Alderglen sites.

Subplots received 0 or 100 kg N ha^{-1} as inorganic fertilizer. Fertilizer (40-0-0-5.5S in 1992 and 34-0-0 in 1993) was hand broadcast on 15 May 1992 and 19 May 1993 at the Graham sites and on 19 May 1992 and 25 May 1993 at the Alderglen sites.

Silage corn was planted at the Graham sites on 20 May 1992 (Pioneer hybrid 3925) and 25 May 1993 (Pioneer hybrid 3925); at the Alderglen sites, on 20 May 1992 (Dekalb hybrid 24) and 26 May 1993 (Pioneer hybrid 3957). The row spacing was 76 cm at each site. One harvest area in each plot, 2 rows by 6 m, was thinned to 76 000 and 70 000 plants ha^{-1} at the Graham sites in 1992 and 1993, respectively, and to 70 000 and 65 600 plants ha^{-1} at the Alderglen sites in 1992 and 1993, respectively. Plants in the harvest areas were harvested by hand on 14 September 1992 and 5 October 1993 for the Graham sites and on 16 September 1992 and 8 October 1993 for the Alderglen sites. Total silage yield was determined. Ten representative corn plants from each plot were chopped, and a 700-g subsample was used to determine **dry matter** (**DM**) and total N content.

Total N content of plant materials was determined in 1992 by a standard Kjeldahl digestion, followed by determination of ammonium-N concentration in the digest, using an auto-analyzer. Total N concentration was determined in 1993 by a dry-ash method, using a Leco FP-428 N determinator. Cross-calibration of the two methods was performed, and all 1992 values were corrected to make them consistent with the 1993 values.

Soil samples were taken from each plot at the time of harvest, at depth increments of 0–15, 15–30 and 30–60 cm, for determination of the concentration of extractable nitrate- and ammonium-N. A 20-g subsample of moist soil was extracted with 2 M KCl, using a 1:5 soil/extractant ratio and 1-h shaking time. The concentrations of nitrate- and ammonium-N in the extract were determined spectrophotometrically by flow-injection analysis. Ammonium-N was determined using a pH indicator, after diffusion of ammonia through a Teflon™ membrane. Nitrate-N was determined from a diazo-based colour reaction with nitrite, after passing the sample through a cadmium column, which reduced the nitrate to nitrite. Extractable nitrate- and ammonium-N were converted to a kilogram-per-hectare basis, using the bulk-density values presented in Table 1.

Preliminary statistical analyses were performed to determine whether data from the adjacent trials using either liquid hog or liquid dairy manure could be pooled. These were performed using the **general linear model** (**GLM**) procedure of the SAS Institute, Inc. (1985), using the following model statement:

$$DV = TYPE\ REP(TYPE)\ RATE\ RATE \times TYPE$$

where DV is the dependent variable; TYPE is the manure type (either liquid dairy or liquid hog); REP is replication; and RATE is rate of manure application. The effect TYPE was tested against REP(TYPE), and the interaction RATE × TYPE was tested against the residual error. Data from the two trials were pooled (i.e., treated as four replicates of one source of manure) for dependent variables for which both TYPE and RATE × TYPE were not statistically significant ($P < 0.05$). Data were pooled for yield and N uptake at all sites and for soil nitrate-N at Graham in 1992 and Alderglen in 1993.

Statistical analyses for pooled and unpooled data were performed using the GLM procedure of the SAS Institute, Inc. (1985) appropriate for a split-plot design with two replications for unpooled data and with four replications for pooled data. Statistical analyses were done on the basis of the target application rates to allow data to be pooled.

Apparent N recoveries from manure and fertilizer were calculated as the increase in crop N uptake over the control, divided by the total N applied as manure or fertilizer. An average apparent manure-N recovery was calculated at each site as the slope of a linear regression of apparent manure-N recovery against target manure application rate.

Time of Manure Application

One experiment was conducted at each of two locations, identified as the Sumas and Agassiz sites, in 1992 and 1993. The 1993 plots were located adjacent to the 1992 plots at both sites. The Sumas site was located on a coarse-textured soil of the Sumas soil series, classified as a Rego Gleysol (Luttmerding 1980), which had a water table maintained within 60 cm of the soil surface from June through September. The Agassiz site was located on a well-drained, medium-textured soil of the Monroe series, classified as an Eluviated Eutric Brunisol (Luttmerding 1980). The soil properties at the experimental sites are presented in Table 1.

A randomized complete-block design, with six treatments and four replications, was used for the experiment at each site in each year. The treatments were control (C), which received no manure or fertilizer N; fall application of 600 kg total N ha^{-1} as liquid dairy manure (FM600); spring application of 600 kg total N ha^{-1} as liquid dairy manure (SM600); fall application of 300 kg total N ha^{-1} plus spring application of 300 kg total N ha^{-1} as liquid dairy manure (FM300+SM300); spring application of 200 kg N ha^{-1} as inorganic N fertilizer (SF200); and spring application of 300 kg total N ha^{-1} as liquid dairy manure plus spring application of 100 kg N ha^{-1} as inorganic N fertilizer (SM300+SF100). Manure and fertilizer rates were chosen to provide a similar quantity of plant-available N, based on the assumption that plant availability of manure total N is approximately one-third that of fertilizer N (Paul and Beauchamp 1993).

Liquid dairy manure was surface applied to plots 9 m × 30 m and 6 m × 30 m at the Sumas and Agassiz sites, respectively, using a vacuum-tank liquid-manure spreader, and incorporated within 24 h by ploughing or discing. The manure was applied on 2 October 1991, 21 April 1992, 28 September 1992, and 21 April 1993 at the Sumas site and on 3 October 1991, 7 April 1992, 30 September 1992, and 6 April 1993 at the Agassiz site. The chemical analyses of the manures applied are given in Table 2. Inorganic-fertilizer N (34-0-0) was surface applied using a precision plot spreader on 14 May 1992 and 11 May 1993 at the Sumas site and on 5 May 1992 and 6 May 1993 at the Agassiz site. Phosphorus and K were applied in excess of the requirement predicted by a soil test, to reduce the possibility of crop response to nutrients other than N in the manure. Silage corn, i.e., hybrids Pioneer 3901 (at Sumas) and Funks 4066 (at Agassiz), was planted at a row spacing of 76 cm on 13 May 1992 and 11 May 1993 at Sumas and on 6 May 1992 and 6 May 1993 at Agassiz. One harvest area, 1.5 × 6 m, in each plot was thinned to 64 000 plants ha^{-1} at Sumas in both years and to 68 000 plants ha^{-1} at Agassiz in both years. The corn was harvested from this area by hand on 9 September 1992 and 14 September 1993 at Sumas and on 17 September 1992 and 13 September 1993 at Agassiz. Total silage yield was determined. Ten representative corn plants from each plot were chopped, and a 700-g subsample was used for determination of DM content and total N concentration. Total N concentration was determined by a dry-ash method, using a Leco FP-428 N determinator.

Soil samples were taken from each plot at the time of harvest, at depth increments of 0–15, 15–30, 30–60 and 60–90 cm, for determination of the concentrations of extractable nitrate- and ammonium-N, as described previously.

Climate information was collected from the climate station at Agassiz.

Apparent fertilizer- and manure-N recovery in the crop was calculated as described previously. Apparent net mineralization was calculated from the control treatment at each site as the sum of the increase in soil inorganic N from early April (prior to manure application) to harvest and the crop N uptake. Apparent recovery of manure N in the crop plus soil was calculated as the sum of the increase in soil inorganic N from early April to harvest and the crop N uptake, minus the apparent net mineralization calculated from the control treatment, all divided by the total N applied as manure.

RESULTS

Climatic Conditions

Growing conditions were favourable for corn production in 1992. From May to September, air temperature at Agassiz was approximately 1°C higher than the long-term average; total precipitation was slightly above normal (Fig. 1); and weather conditions were generally sunny. Conditions in 1993 were somewhat poorer for corn growth than in 1992, with slightly cooler temperatures and very wet conditions from May to July. The wet weather in spring and early summer of 1993 resulted in slow early growth.

Rate of Manure Application Experiments

Corn DM yield responded to N addition at both sites in both years (Table 3; Fig. 2). At the Graham site in 1992 and at the

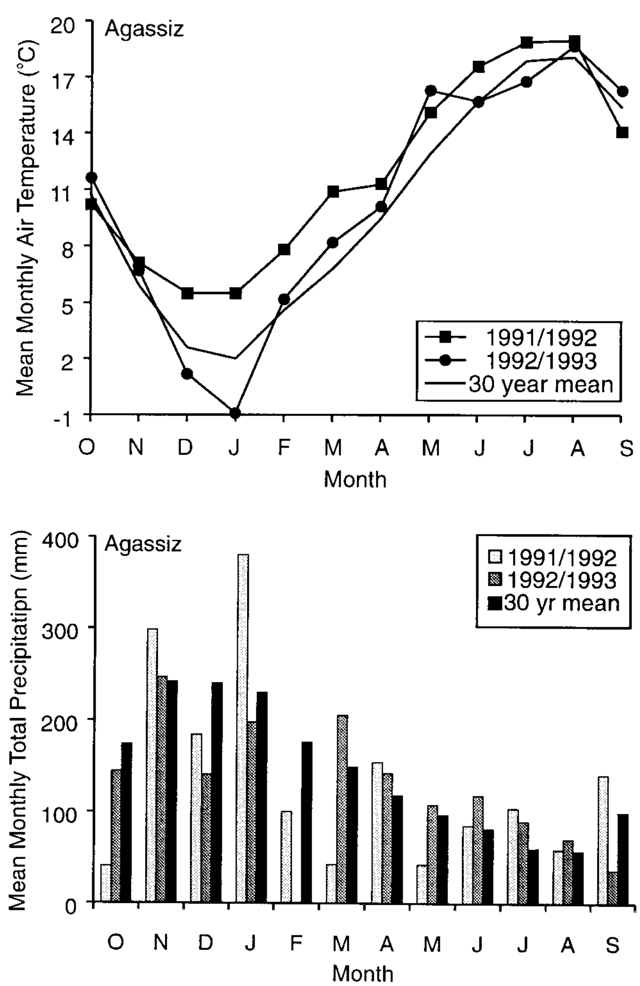

Fig. 1. Air temperature and total precipitation at Agassiz during the study period.

Table 3. Statistical significance of treatment effects on crop yield and N uptake for rate-of-manure application experiments in 2 yr[z]

		DM yield ($t\ ha^{-1}$)		N uptake ($kg\ N\ ha^{-1} \times 10^3$)	
Source	df	Graham	Alderglen	Graham	Alderglen
1992					
Main plots					
Block	3	0.10	0.17	0.88	1.16
Manure rate (M)	3	11.33*	3.50	5.03*	5.82*
Linear (L)	1	25.38*	8.87*	15.04*	14.48*
Quadratic (Q)	1	8.59*	1.04	0.00	2.27
Error	9	1.38	1.36	0.572	0.981
Subplots					
Fertilizer (F)	1	6.75*	3.23*	17.21*	9.18*
F × M	3	1.49	2.45*	3.28	2.13
F × L	1	2.99*	6.86*	9.84*	2.27
F × Q	1	0.79	0.50	0.00	3.89
Error	12	7.19	0.632	1.64	1.38
1993					
Main plots					
Block	3	0.32	4.74*	0.05	1.09
Manure rate (M)	3	8.69	6.16*	5.53*	4.51*
Linear (L)	1	24.11*	7.73*	15.60*	12.02*
Quadratic (Q)	1	0.05	9.78*	0.01	0.95
Error	9	3.56	1.03	1.08	0.479
Subplots					
Fertilizer (F)	1	0.11	0.64	0.19	2.58*
F × M	3	1.74	3.91*	0.59	1.36*
F × L	1	4.68	8.94*	0.74	3.42*
F × Q	1	0.38	2.73	0.40	0.02
Error	12	1.71	0.783	0.306	0.153

[z]Values are mean squares.
* Significant at $P < 0.05$.

Alderglen site in both years, there was a significant interaction between the DM yield response to manure (dairy or hog) rate and the addition of 100 kg N ha^{-1} as fertilizer. At the Graham site in 1992, yield was more responsive to increasing rate of manure application when no fertilizer N was applied than with the addition of fertilizer, whereas, at the Alderglen site in both years, increasing rate of manure application increased yield only in the absence of fertilizer. At the Graham site in 1993, only the linear response to manure rate was significant, because yield increased slightly with increasing rate of manure application, especially at the highest rate.

Corn DM yield and N uptake were more responsive to manure- and fertilizer-N addition at the Graham site in 1992, where corn was grown after a previous corn crop, than at the Graham site in 1993, where corn was grown after a forage-grass ploughdown (Fig. 2).

In all four experiments, application of 175 or 350 kg N ha^{-1} as manure resulted in DM yields of no less than 90 or 92%, respectively, of the maximum yield measured at each site (Fig. 2). When compared with application of 100 kg N ha^{-1} as inorganic fertilizer alone, additional manure application resulted in little or no yield increase, except at the Graham site in 1992.

There was a significant interaction between the linear response of crop N uptake to the rate of manure (dairy or hog) application and the addition of fertilizer N at both the Graham site in 1992 and the Alderglen site in 1993 (Table 3). In both cases, crop N uptake was more responsive to the rate of manure application where no fertilizer was applied (Fig. 2). Crop N uptake responded linearly to the rate of manure application at both the Alderglen 1992 and the Graham 1993 sites but increased with the addition of fertilizer N only at the former site.

Crop yield and N uptake were generally lower in 1993 than in 1992 at the Graham site, presumably as a result of a cool wet spring and early summer reducing early growth in 1993 (Fig. 1). However, yield and crop N uptake were generally similar in both years at the better drained Alderglen site.

Soil nitrate-N to 60-cm depth at harvest responded linearly to the rate of manure application in all cases except that of dairy manure at the Graham site in 1993, where soil nitrate-N showed no response to rate of manure application (Table 4; Fig. 3). Rate of manure application interacted with the addition of fertilizer N for the pooled dairy and hog manure at Alderglen in 1993 and for hog manure at Graham in 1993. Soil nitrate was more responsive to manure rate when fertilizer had been applied. Rate of manure application also interacted with the addition of fertilizer N for hog manure at Alderglen in 1992; however, the response was the reverse of that in the previous two cases, possibly as a result of high variability in the soil nitrate results.

Soil nitrate-N at harvest was generally lower at Graham than at Alderglen, although there was substantial nitrate-N at Graham in 1993 where hog manure was used (Fig. 3). Soil nitrate-N to 60-cm depth ranged from 22 to 93 kg N ha^{-1} or 68 to 342 kg N ha^{-1} when 175 or 350 kg N ha^{-1}, respectively, was applied as manure, regardless of manure source. In comparison, application of 100 kg N ha^{-1} as fertilizer resulted in a range of 18 to 162 kg N ha^{-1} soil nitrate-N to 60-cm depth.

Apparent manure-N recovery in the crop ranged from approximately 14 to 20% of the total N applied at the four sites (Table 5). Recovery was greatest at the Graham site in 1992; lowest, at the Graham site in 1993, where the corn followed a grass ploughdown. In comparison, apparent fertilizer-N recovery in the crop ranged from 18 to 93%. Apparent fertilizer-N recovery followed a pattern similar to that of manure-N recovery and was highest at the Graham site in 1992; lowest, at the Graham site in 1993. Apparent recovery of manure N averaged 27% of fertilizer-N recovery for the three sites that had corn in the previous year.

Time of Manure Application

The time of liquid-dairy-manure application had a significant effect on corn DM yield and N uptake at both sites in both years (Table 6; Fig. 4). There was no significant difference between the control and fall application of 600 kg N ha^{-1} as manure in crop DM yield or crop N uptake at either site in either year. The two contrasts that compared the treatments that had all N applied in spring (i.e., SM600, SF200 and SM300+SF100) were not significant for DM yield or N uptake at either site in either year. The treatments that received all N application in spring had increased DM yield at Sumas in 1992, had increased N uptake at Sumas in both years, and had similar DM yield and N uptake in both years at Agassiz, compared with the split fall and spring manure application. The control and FM600 treatments had lower

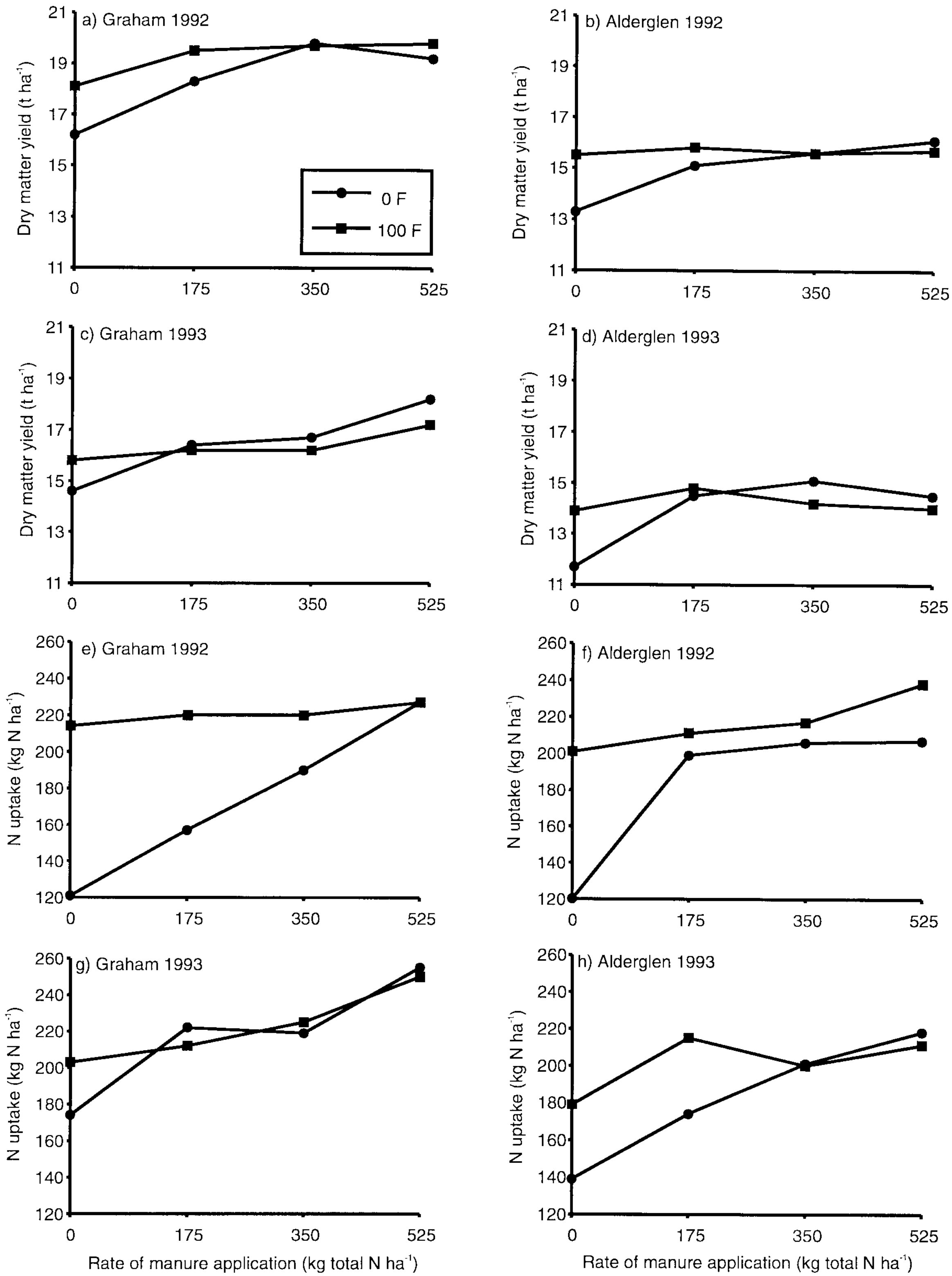

Fig. 2. Crop yield and N uptake as influenced by rate of manure application and addition of fertilizer at two sites in 2 yr (0 F and 100 F are 0 and 100 kg N ha^{-1} as inorganic fertilizer, respectively).

Table 4. Statistical significance of treatment effects on soil nitrate–N to 60-cm depth at harvest for rate-of-manure-application experiments at the Graham and Alderglen sites in 2 yr

		Dairy plus hog (kg N ha^{-1} × 10^3)			Dairy (kg N ha^{-1} × 10^3)		Hog (kg N ha^{-1} × 10^3)	
Source	df	Graham 1992	Alderglen 1993	df	Alderglen 1992	Graham 1993	Alderglen 1992	Graham 1993
Main plots								
Block	3	7.28	4.09	1	4.01	4.11	19.43*	5.69
Manure rate (M)	3	15.97	39.11*	3	13.83	4.17	110.97*	38.16*
Linear (L)	1	35.09*	116.67*	1	37.15*	10.03	315.94*	100.41*
Quadratic (Q)	1	2.97	1.24	1	4.16	2.46	4.38	14.03
Error	9	4.71	2.07	3	1.81	2.94	1.41	2.44
Subplots								
Fertilizer (F)	1	0.99*	64.71*	1	66.74*	0.434	14.20*	23.91*
F × M	3	0.23	6.07*	3	0.80	0.116	4.50	4.41*
F × L	1	0.01	17.21*	1	0.78	0.034	11.50*	9.23*
F × Q	1	0.05	0.61	1	1.61	0.066	0.00	3.93
Error	12	0.20	0.51	4	4.26	0.097	1.19	0.56

[z]Values are mean square.
* Significant at $P < 0.05$.

DM yield and N uptake than all other treatments combined at both sites in both years.

Application of 600 kg N ha^{-1} as manure in the previous fall did not increase soil nitrate-N to 90-cm depth at harvest over that in the control treatment at either site in either year (Table 6; Fig. 4). Soil nitrate-N values at harvest for spring application of 600 kg N ha^{-1} as manure or 200 kg N ha^{-1} as fertilizer were similar at both sites in 1992. In 1993, however, spring manure application resulted in higher soil nitrate-N than spring fertilizer application at Sumas, whereas the reverse was true at Agassiz. Application of all N in the spring increased soil nitrate-N at harvest at both sites in 1992 but had no effect at both sites in 1993, compared with the split fall and spring manure application. Soil nitrate-N at harvest for the control and fall manure-application treatments was lower than the average for all other treatments where N was applied in spring at both sites in both years.

Soil nitrate-N to 90-cm depth at harvest for the split spring and fall manure-application treatment was effectively the same as a spring-only application of 300 kg N ha^{-1} and ranged from 42 to 143 kg N ha^{-1}. In comparison, soil nitrate-N at harvest ranged from 48 to 188 kg N ha^{-1} and from 38 to 173 kg N ha^{-1} following spring application of 600 kg N ha^{-1} as manure and 200 kg N ha^{-1} as inorganic fertilizer, respectively.

The quantity of ammonium-N in the soil to 90-cm depth at harvest averaged 34 and 17 kg N ha^{-1} at the Sumas and Agassiz sites, respectively, in 1992 and 71 and 42 kg N ha^{-1} at the Sumas and Agassiz sites, respectively, in 1993 and was not influenced by the treatments.

Apparent net mineralization was calculated as being 158 and 111 kg N ha^{-1} at Agassiz and 96 and 152 kg N ha^{-1} at Sumas in 1992 and 1993, respectively. This is equivalent to apparent net mineralization rates of 0.94 and 0.66 kg N ha^{-1} d^{-1} at Agassiz and 0.59 and 0.96 kg N ha^{-1} d^{-1} at Sumas in 1992 and 1993, respectively.

Apparent fertilizer-N recovery in the crop was almost twice as high at Sumas (84%) as at Agassiz (44%) (Table 7). Similarly, apparent manure-N recovery in the crop was almost twice as high at Sumas (27%) as at Agassiz (14%) for spring-applied manure. Recovery of fall-applied manure in the crop was very low at both sites. Manure-N recovery averaged 44 and 32% of fertilizer-N recovery following spring application of 300 and 600 kg N ha^{-1}, respectively.

There was negligible apparent recovery of N from fall-applied manure in the crop plus soil (Table 7). Apparent manure-N recovery in the crop plus soil was generally higher in 1992 than in 1993, particularly at Sumas. When averaged across all sites, apparent manure-N recovery in the crop plus soil was 33 and 32% following spring application of 300 and 600 kg total N ha^{-1}.

DISCUSSION

Fall-applied manure did not benefit crop yield or N uptake in the following growing season. Similarly, fall-applied manure had no effect on the quantity of soil inorganic N at harvest in the following year, and there was negligible apparent N recovery from the fall-applied manure in the crop plus soil. This suggests that most or all of the plant-available N from the fall-applied manure was lost during the fall and winter following application in south coastal British Columbia. This loss occurs both as nitrate leaching and as denitrification (Paul and Zebarth 1993).

Studies conducted in other regions have shown a beneficial effect of fall-applied manure on corn yield in the following year. Phillips et al. (1981) compared three rates of liquid dairy manure applied to silage corn in Ontario. The manure was applied in the fall, winter, or spring or in a combination of one half in the fall and one half in the spring, but the time of manure application had no significant effect on crop yield or N uptake. Safley et al. (1986) found that there was either a small or no increase in silage-corn yield in North Carolina when liquid dairy manure was applied in spring, compared with a fall application.

In south coastal British Columbia, it is acceptable to apply some manure to corn land in the fall if a fall cover crop is planted (British Columbia Ministry of Agriculture, Fisheries and Food 1993). Fall cover crops, planted after

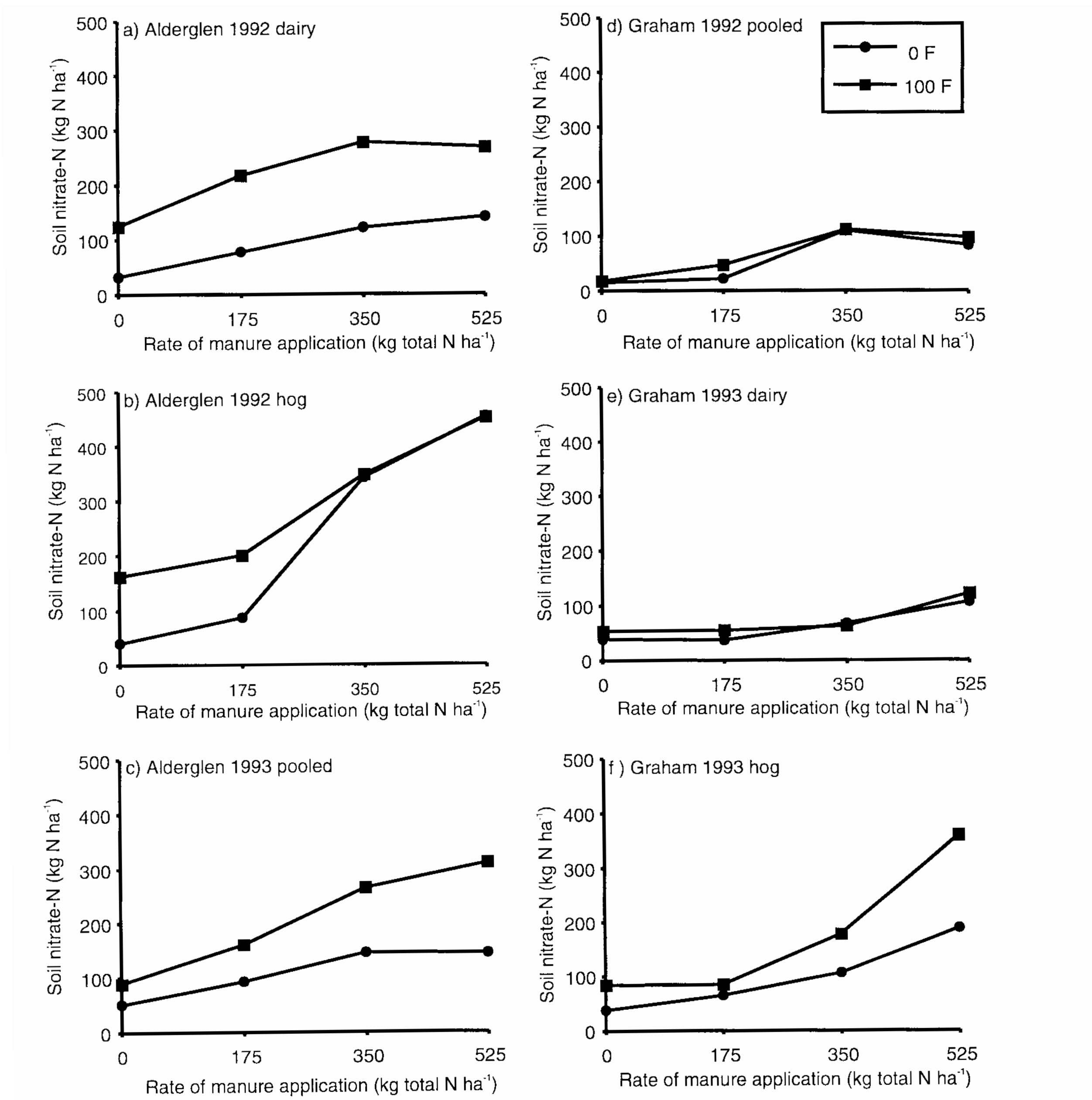

Fig. 3. Soil nitrate-N to 60-cm depth at harvest, as influenced by rate of manure application and addition of fertilizer at two sites in 2 yr (0 F and 100 F are 0 and 100 kg N ha^{-1} as inorganic fertilizer, respectively).

corn harvest, do not have sufficient time for significant N uptake in most years and rarely have N uptake of greater than 30 kg N ha^{-1} (Bittman and Hunt 1994). Because of the amount of nitrate remaining in the soil following harvest in most experiments in this study, a fall cover crop has the potential to take up only a relatively small fraction of this soil nitrate and would have a very limited potential to reduce nitrate leaching associated with additional manure application in the fall. As a result, fall application of manure cannot be recommended for silage-corn production in south coastal British Columbia.

Large quantities of inorganic N were released from the soil OM by mineralization, as indicated by the high estimates of apparent net mineralization. These estimates are conservative because they do not consider denitrification and leaching losses during the growing season. It is interesting to note that, averaged over the 2 yr, apparent net mineralization was similar for the two sites, despite the much lower soil organic contents at the Sumas site. This emphasizes the importance of management history in determining soil mineralization potential.

High soil mineralization would also be expected at the Graham site in 1993 because of the spring ploughdown of a

Table 5. Apparent N recovery in silage corn of fertilizer and manure N applied

Site	Regression equation[x]	r^2	Apparent manure-N recovery[z] (%)	Apparent fertilizer-N recovery[y] (%)
Graham 1992	$y = 121 + 0.201x$	1.00	20.1	93.3
Graham 1993[w]	$y = 182 + 0.137x$	0.87	13.7	17.9
Alderglen 1992	$y = 143 + 0.153x$	0.67	15.3	56.4
Alderglen 1993[w]	$y = 143 + 0.151x$	0.98	15.1	45.7

[z]Based on slope of crop N recovery as a function of manure total N applied.
[y]Based on increased recovery of N in crop, compared with control treatment, as a proportion of fertilizer N applied.
[x] *y* Apparent recovery of manure total N in the crop; *x* Total N applied as manure.
[w]Apparent N recovery may be underestimated because actual manure application rates were less than the target rates.

forage crop prior to corn planting. This increased mineralization would be expected to reduce the requirement for additional manure- or fertilizer-N application to meet the crop N requirement. This was reflected in the greater response of crop yield and N uptake to manure and fertilizer addition in 1992 than in 1993.

The crop N response varied considerably among sites and years. The results suggest that crop N requirement is sensitive to the soil properties, climatic conditions, and past management practices, although the variation in response may be due in part to differences in the corn hybrids and plant densities used. Similarly, the quantity of soil nitrate-N remaining in the root zone after harvest, in response to the spring manure management, also varied considerably among sites. The nitrate remaining in the soil profile at harvest has been suggested as a useful index of the potential for

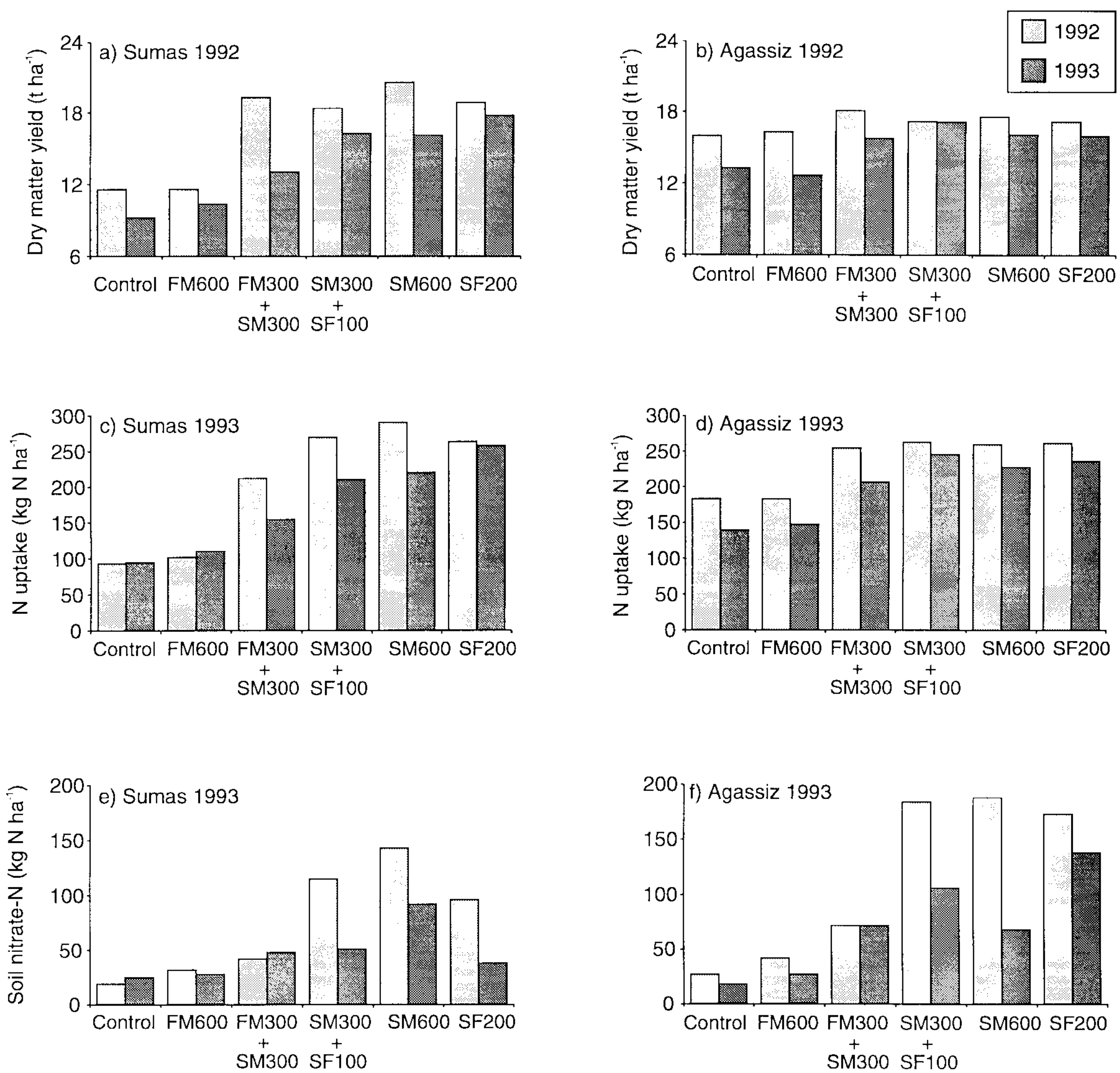

Fig. 4. Influence of time of manure application on crop yield, N uptake and soil nitrate-N to 90-cm depth at harvest at two sites in 2 yr (treatments: F, fall; S, spring; M, manure; F, inorganic fertilizer; value is application rate in kg N ha^{-1}).

Table 6. Statistical significance of treatment effects for the time-of-manure-application experiments in 2 yr[z]

		DM yield (t ha^{-1})		N uptake (kg N ha^{-1} × 10^3)		Soil nitrate-N[y] (kg N ha^{-1} × 10^3)	
Source	df	Sumas	Agassiz	Sumas	Agassiz	Sumas	Agassiz
			1992				
Blocks	1	1.00	2.047*	0.294	0.866	0.76	0.23
Treatment	5	65.90*	2.470*	30.590*	6.345*	10.08*	22.61*
SM600 vs. SF200	1	5.48	0.354	1.403	0.012	4.45	0.42
SM600, SF200 vs. SM300+SF100	1	4.53	0.057	0.161	0.009	0.05	0.03
SM600, SF200, SM300+SF100 vs. FM300+SM300	1	0.00	1.863	11.951*	0.128	17.12*	35.91*
C vs. FM600	1	0.00	0.209	0.166	0.000	0.33	0.46
C, FM600 vs. rest	1	319.48*	9.867*	139.268*	31.578*	28.46*	76.21*
Error	15	1.90	0.596	0.659	0.309	1.23	3.57
			1993				
Blocks	1	4.05	2.27	0.615	0.906	0.50	0.92
Treatment	5	48.82*	12.61*	16.964*	8.618*	2.40	8.39*
SM600 vs. SF200	1	5.40	0.02	2.845*	0.131	5.88*	9.91*
SM600, SF200 vs. SM300+SF100	1	1.28	3.27	2.259	0.516	0.51	0.04
SM600, SF200, SM300+SF100 vs. FM300+SM300	1	40.46*	1.31	16.852*	2.685*	0.47	3.12
C vs. FM600	1	2.80	0.76	0.514	0.140	0.01	0.18
C, FM600 vs. rest	1	194.19*	57.68*	62.353*	39.620*	5.14*	28.69*
Error	15	2.50	1.43	0.583	0.302	1.10	1.10

[z]Values are mean squares.
[y]To 90-cm depth.
* Significant at $P < 0.05$.

Table 7. Apparent N recovery during the growing season by silage corn from inorganic fertilizer or liquid dairy manure in 2 yr at two sites and apparent N recovery from manure in the crop plus soil

	Agassiz			Sumas		
N source	1992	1993	Mean	1992	1993	Mean
Apparent N recovery in crop (%)						
Fertilizer	39.5	48.6	44.0	85.5	81.7	83.6
Manure						
FM600	0.0	1.4	0.7	1.5	2.7	2.1
FM300+SM300[z]	24.0	22.6	23.2	39.6	20.0	29.8
SM600	12.8	14.9	13.8	33.0	21.0	27.0
Apparent N recovery in crop plus soil (%)						
Manure						
FM600	–3.6	2.8	–0.4	2.1	0.3	1.2
FM300+SM300[z]	35.8	35.4	35.6	43.7	18.2	31.0
SM600	33.2	22.0	27.6	42.5	28.5	35.5

[z]Apparent recovery calculated based on spring application of manure only. Recovery of fall-applied manure was negligible; therefore, this treatment is effectively equivalent to spring application of 300 kg N ha^{-1}, or one–half the rate of the SM600 treatment.

nitrate leaching over the fall and winter under conditions in south coastal British Columbia (Kowalenko 1991; Zebarth et al. 1995). As a result, N recommendations for manure and (or) fertilizer management in south coastal British Columbia must take this among-year variation into account if the recommendations are to be successful in predicting crop N requirements and to minimize the potential for nitrate leaching.

Except for Sumas in 1992, only minimal increases in crop yield were observed at any site for manure-application rates greater than 350 kg N ha^{-1}. It appears that the maximum N rate that can be applied as either dairy or hog manure to silage corn, as described by British Columbia Ministry of Agriculture, Fisheries and Food (1993), will supply most of the N requirement of a silage-corn crop in this region under current management conditions. Corn is grown primarily as a source of energy for dairy cattle, and the increased N concentration associated with the application of manure or fertilizer N beyond the rate required to obtain maximum crop yield would be of limited practical benefit.

Apparent N recoveries in this study are similar to those reported elsewhere. Paul et al. (1990) reported a range of apparent N recoveries in silage corn of 5–28% for liquid cattle manure and 14–95% for fertilizer. In this study, apparent N recovery ranged from 0 to 33% for liquid dairy and swine manure and from 18 to 93% for fertilizer.

Estimates of manure-N availability as compared to fertilizer-N made in previous studies include 27–44% (Jokela 1992), 12–63% (Motavalli et al. 1989), 33–60% (Beauchamp 1983), 25–100% (Xie and MacKenzie 1986), and 30–140% (Safley et al. 1986). In comparison, the ratio of manure to fertilizer apparent-N recovery ranged from 22 to 76% in this study. The sites where crop yield was more responsive to N addition had higher apparent recoveries of manure and fertilizer N but showed little effect on the ratio of manure-N to fertilizer-N recovery. There appeared to be greater availability of the hog than of the dairy manure N, as indicated by generally higher soil nitrate concentrations at harvest. This may be attributed to the generally higher proportion of ammonium-N in hog manure.

The manure- and fertilizer-N application rates in the time of manure application experiments were based on the assumption that the N in the manure was approximately one-third as plant available as N from inorganic fertilizer. The 32% average recovery of the manure N in the crop plus soil when 600 kg N ha^{-1} was applied in the spring suggests that the assumption was valid. Therefore, in this study, spring application of 600 kg N ha^{-1} as manure can be considered as having provided a similar level of plant-available N as 200 kg ha^{-1} of inorganic fertilizer.

Application of similar quantities of plant-available N as manure, inorganic fertilizer, or a combination of the two had no effect on crop yield and only small effects on crop N uptake. Where the source of N did have a significant effect on the quantity of nitrate remaining in the soil profile at harvest, the effect was not consistent among sites and was presumably a function of differing soil N processes at the different sites. Thus, meeting the crop N requirement using manure alone did not increase the risk of nitrate leaching over the fall and winter in the short term.

Similarly, Jokela (1992) found that the quantity of soil nitrate-N to 150-cm depth in the fall following manure application was less than or similar to the quantity of nitrate-N following application of an agronomically similar rate of inorganic fertilizer. Beauchamp (1986) found application of 600 kg N ha^{-1} as manure resulted in no greater fall soil nitrate than application of 150 kg N ha^{-1} as urea, and Beauchamp (1983) found no greater residual soil nitrate at harvest when liquid dairy cattle manure was applied at twice the rate of urea N. Xie and MacKenzie (1986) found that 1–5 kg of manure N resulted in the same increase in residual soil N at harvest as 1 kg of urea N. Phillips et al. (1981) found no greater nitrate in tile-drain effluent from silage corn receiving 897 kg N ha^{-1} as liquid dairy manure than from 134 kg N ha^{-1} applied as inorganic fertilizer. In contrast, Roth and Fox (1990) found that when the economic-optimum fertilizer-N rate was applied to grain corn, residual soil nitrate to 120-cm depth averaged 74 kg N ha^{-1} on non-manured sites, compared with 94 kg N ha^{-1} on responsive manured sites. Roth and Fox (1990) also reported that soil nitrate-N to 120-cm depth at harvest at the economic-optimum-N application rate for grain corn was greater in a manured system (135 kg N ha^{-1}) than in a non-manured system (115 kg N ha^{-1}) in a long-term study.

Using the approach of Zebarth et al. (1995), it can be estimated that soil nitrate at harvest should not exceed approximately 100 kg N ha^{-1}, to maintain groundwater nitrate concentrations below the Canadian Drinking Water Guideline of 10 mg L^{-1} in south coastal British Columbia. Soil nitrate at harvest was generally below this level for manure application rates of 175–350 kg N ha^{-1}, which resulted in yields that were no less than 90% of the maximum yield measured at each site. Given that these manure application rates are typical of what is currently applied to corn fields in this region, the results suggest that it may be possible to supply all of the N to corn in south coastal British Columbia as manure on a long-term basis without excess loading of N to groundwater. Such long-term management may, however, result in over-application of P (Simard et al. 1995).

Most farms that produce silage corn in the lower Fraser Valley have a supply of hog or dairy manure. Because the N requirement of corn can be met equally well by either manure or fertilizer application, it is logical that the crop N requirement be met by the spring application of manure, supplemented as necessary with fertilizer N.

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