Estimation of Canadian Manure and Fertilizer Nitrogen Application Rates for Crops at the Soil Polygon Level Using the CANB v2.0 Model

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Abstract

In response to national environmental and climate change modeling projects such as agri-environmental indicators, greenhouse gases, carbon sequestration and policy scenarios, fertilizer N and manure nitrogen N application rates were estimated for individual crops at the Soil Landscapes of Canada (SLC) polygon scale (1:1 million). This database provides an estimate of the actual amount of N applied per crop and per hectare, based on provincial fertilization recommendations, manure production levels of each type of livestock and reported amounts of fertilizer sold. The database is being incorporated into ongoing programs related to Kyoto accounting of greenhouse gas emissions, environmental performance and policy formulation at Agriculture and Agri-Food Canada.

A standardized Canadian Agricultural Nitrogen Budget (CANB v2.0) model was developed to calculate the agri-environmental indicators Residual Soil Nitrogen (RSN) and Indicator of Risk of Water Contamination by Nitrogen (IROWC-N). CANB is a national-level model that operates on 3500 SLC polygons using generalized soil, landscape, climate, and Census of Agriculture socioeconomic data. It is designed to provide a regional update on the soil N balance for each of the census years of 1981, 1986, 1991, 1996, 2001 and into the future. The database and model have the capability to calculate a number of different components of the nutrient balance, including the inputs of fertilizer N, manure N, biological N and atmospheric N and N the removals of N in the harvested proportion of the crop and via nitrogenous gas emissions.

This paper describes the procedures to estimate fertilizer N and manure N inputs for each crop within each polygon. It includes: (i) the compilation of soil-specific N application rates from provincial extension guidelines, (ii) the calculation of total manure N production from animal numbers and excretion rates, (iii) the calculation of available manure N after storage and handling

losses, and (iv) the recommended and adjusted nitrogen application rates. Adjustments were made to account for the amount of inorganic N in the manure applied to the various crops. The adjusted nitrogen rate data was also reconciled with the provincial fertilizer sales data.

Introduction

Nitrogen (N) recommendation rates provided by agronomists and soil and fertilizer consultants vary by soils and crops across Canada. The fertilizer industry provides annual reports of fertilizer N sales at the provincial level. If producers are applying the recommended rates on all crops, the provincial sales figures should match the total of fertilizer N recommendations. However, when manure N is also applied to crops in some of the polygons, the amount of fertilizer N required to match crop requirements is reduced. Other N inputs into the system include nitrogen fixation by leguminous crops and atmospheric deposition.

National environmental programs such as the National Agri-Environmental Health and Reporting Program (NAHARP), the National Carbon and Greenhouse gas Accounting and Verification System (NCGAVS), and the assessment of policy scenarios have all identified the need for estimates of fertilizer N and manure N application rates for individual crops at the Soil Landscapes of Canada (SLC) polygon scale. The N database should provide an estimate of the actual amount of N applied per crop and per hectare from both fertilizer N and manure N. Data available to construct such a database include fertilizer recommendation rates by crop and soil type, the number of each type of livestock by SLC polygon, manure N excretion rates by livestock type, the area of each crop type by SLC polygon and annual fertilizer sales by province.

The objective of this paper is to describe in detail the procedures developed in the Canadian Agricultural Nitrogen Budget (CANB v2.0) to allow us to: (1) link soil-specific N application rates from provincial extension guidelines to SLC polygons, (2) calculate total manure N production and available manure N after considering the N losses from storage and handling, (3) calculate total recommended fertilizer N applications and adjust them to annual N sales and (4) estimate actual fertilizer N and manure N application rates for each crop at the SLC polygon scale.

Data and calculation methods

Databases

The national Census of Agriculture database, collected every five years on every farm in Canada by Statistics Canada (Statistics Canada, 2004), provides crop areas and number of each type of livestock at varying spatial scales. Agriculture and Agri-Food Canada (AAFC), in collaboration with Statistics Canada, has 'reconfigured' the Census database to the Soil Landscapes of Canada (SLC v3.0) and related eco-stratification spatial hierarchies. Annual crop yield estimates at the Census Division level were obtained from Statistics Canada (2004), and allocated to SLC polygons through an intersection of the two boundary files. Soil types at the Great-Group level of classification (Canada Soil Survey Committee, Sub-committee on Soil classification, 1978) were extracted from the Canada Soil Information System (CanSIS), Soil Landscapes of Canada, version 3.0 (Agriculture and Agri-Food Canada, 2004) based on the dominant soil component

described within each polygon. Nitrogen excretion rates for different animal types were obtained from the American Society of Agricultural Engineers (ASAE, 2003), now American Society of Agricultural and Biological Engineers (ASABE) and modified to account for slightly different animal husbandry practices in Canada (Agriculture and Agri-Food Canada 2004). Provincial recommended N application rates for non-leguminous crops, N fixation rates for legume crops and N concentration in harvested yield (N_{uprt}) were collected from provincial agronomic practices bulletins (see Yang et al., 2006 for detail). Annual N sales data at the provincial level were compiled from various sources by AAFC (http://www.agr.gc.ca/spb/fiap-dpraa/publications/canfert/canfert_e.php), and were allocated to SLC polygons on the basis of proportion of provincial share of fertilizer expenses as determined from the Census. Estimates of horticultural uses of fertilizer N were subtracted from the SLC values (MacDonald and Thomsen, 2005). The proportion of manure N deposited on pastures was estimated through an expert opinion survey by researchers at the University of Guelph (Marinier et al. 2005) and N losses through storage and management of the remainder of the manure were estimated by MacDonald and Thomsen (2005).

The CANB model

A standardized Canadian Agricultural Nitrogen Budget (CANB v2.0) model was used to calculate manure and fertilizer N application rates (Yang et al., 2006). The CANB v2.0 model was a new version of CANB which was initially developed to calculate the agri-environmental indicators: Residual Soil Nitrogen (RSN) (Drury et al., 2005) and Indicator of Risk of Water Contamination by Nitrogen (IROWC-N) (De Jong et al., 2005). CANB is a national-level model that operates on 3500 SLC polygons using generalized soil, landscape, climate, and Census of Agriculture socioeconomic data. It is designed to provide a regional update on soil N balance for each of the census years of 1981, 1986, 1991, 1996, 2001 and into the future. The database and model provide the capability to calculate a number of different components of the nutrient balance, including the inputs of fertilizer N, manure N, biological N and atmospheric N and the removals of N in the harvested proportion of the crop and via nitrogenous gas emissions. A conceptual diagram of CANB model is shown in Fig. 1.

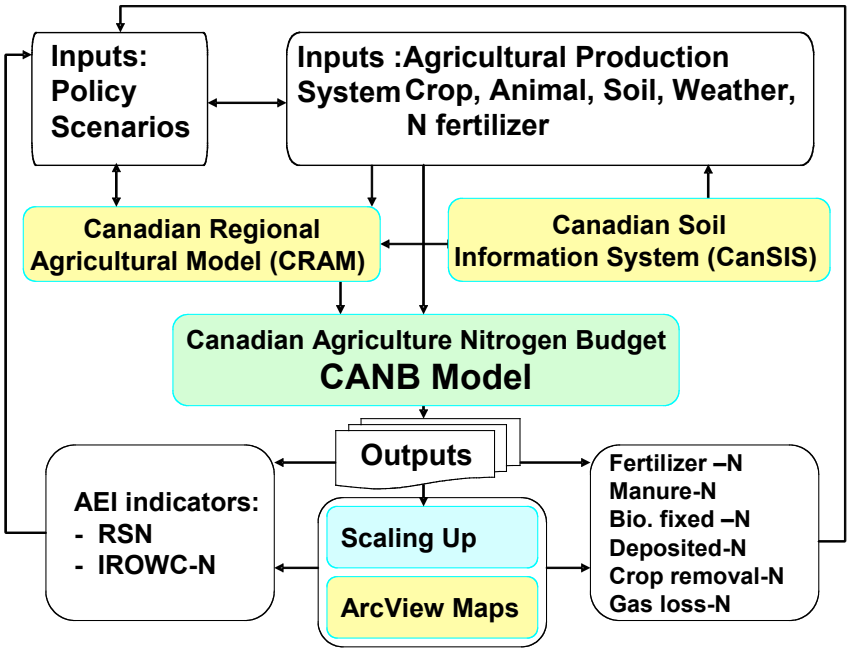

Fig. 1. Flow chart of the CANB v2.0 model

Calculations

N recommendation

Nitrogen recommendation rates were prepared by crop and soil types based on information contained in provincial agricultural practices guides and from expert opinion (Table 1). Fertilization guidelines were obtained from BC Ministry of Agriculture, Food and Fisheries (2005), Alberta Agriculture, Food and Rural Development (2004), Saskatchewan Agriculture (1988), Manitoba Agriculture, Food and Rural Initiatives (2001), Ontario Ministry of Agriculture and Food (2003), Quebec Ministry of Agriculture (CRAAQ, 2003) and New Brunswick Agriculture, Fisheries and Aquaculture (2001). In Alberta and Saskatchewan recommended rates are provided for the major soil Great Groups such as Brown, Dark Brown and Black Chernozems, while in Manitoba, Quebec and New Brunswick recommendations are provided only by crop. In Ontario some distinction is made on the basis of Crop Heat Units (especially for corn), while in British Columbia some distinctions are made for the dry interior and for organic soils. In most cases a range of application rates is provided for each case. In the process of establishing recommended rates by soil type (i.e. Great Group), ranges and multiple recommendations were averaged, regional differences (e.g. by Crop Heat Units) were interpreted with reference to a soil map and missing values were interpolated from the nearest appropriate value.

The N recommendation rates were allocated to SLCs based on the soil type (Great Group) of the dominant components within the polygon, and the rates were assumed to apply as a guide for both manure N and fertilizer N.

Table 1 N recommendation rates (kg N ha^{-1}) by Great Group soil type and census crop type.

SOIL GREAT GROUP	Wheat	Cereal	Corn	Canola	Forage	Potato	Pasture
BROWN CHERNOZEM	35	36	N/A	34	29	N/A	34
BLACK CHERNOZEM	73	72	77	72	46	71	67
GRAY BROWN LUVISOL	70	35	175	100	75	130	50
HUMO-FERRIC PODZOL	70	48	137	100	55	134	49
HUMIC GLEYSOL	80	63	111	95	60	95	50
MELANIC BRUNISOL	70	35	130	100	75	130	50

The 'potential' N application for a given SLC and crop was calculated by multiplying the N recommendation rate by the area of the particular crop. No fertilizer was recommended for either legume crops (pulses, soybeans, hays and alfalfa) or for unimproved pasture. The total potential manure N was calculated by allocating the total manure N in the polygon to individual crops based on the relevant recommendation rates. Manure N was also allocated to legumes and unimproved pasture. The amounts of fertilizer N and manure N for a given SLC were denoted by *FNrcmd* (*i,j*) and *MNrcmd* (*i,j*), where i and j are SLC and crop type respectively. Summation of *FNrcmd* and *MNrcmd* for all crops in each SLC provides total fertilizer N and manure N for the SLC, as below

$$TotMNrcmd(i) = \sum_{j} MNrcmd(i, j) \quad (1)$$

$$TotFNrcmd(i) = \sum_{j} FNrcmd(i, j) \ (j \neq \text{leguminous crops and unimproved pasture}) \quad (2)$$

where *TotMNrcmd*(*i*) and *TotFNrcmd*(*i*) are the total manure and fertilizer N recommended for the *i*th SLC across all crop types.

Fertilizer N applied

Annual fertilizer N sales data (*Nsold*) are compiled by AAFC from a variety of sources and are available at the provincial scale (Korol, 2002). Nitrogen fertilizer sales data were allocated to individual SLCs based on the polygon's proportion of the Census variable "total expenses on fertilizer and lime" (Eq.3).

$$Nsold(i) = Nsold(p) \times \frac{N\$(i)}{N\$(p)} \quad (3)$$

where *N$*(*i*) is the net N $ expense in each SLC, and
N$(*p*) is the total net N $ expense in each province (p) (MacDonald and Thomsen, 2005).

SLC values were then adjusted by subtracting estimates of fertilizer and lime expenses contributed by the horticultural industry, as compiled through custom micro-processing of Census data (MacDonald and Thomsen, 2005). Since the provincial sales data and the Census variable "total expenses on fertilizer and lime" both include costs for all fertilizer components (nitrogen, phosporus, potassium and lime), the Nsold value for each SLC was further refined to

represent only the nitrogen portion through the use of common fertilizer formulations and the price ratios amongst the components (MacDonald and Thomsen, 2005).

Fertilizer N applied (*FNapplied*(*i,j*)) on each crop was estimated by multiplying the recommended rate by the ratio of total fertilizer sold to total fertilizer recommended in the SLC.

$$FNapplied(i,j) = FNrcmd(i,j) \times \frac{Nsold(i)}{TotFNrcmd(i)} \quad (4)$$

where *i* is SLC and *j* is crop type.

Manure N applied

The total amount of manure N produced by each animal type *k* in each SLC, (*MNtotal*(*i,k*)), was calculated by multiplying animal numbers by the appropriate manure excretion rate and N content. The fraction of manure N which was directly deposited on pasture, (*MNpast*(*i,k*)), was calculated by multiplying the total amount of manure N from each livestock type by the appropriate pasture distribution percentage, as estimated through an expert opinion survey by Marinier et al. (2004). Table 2 presents manure N excretion rates and percent distribution of manure deposited on pasture by province and livestock type.

Table 2 Manure N excretion rate by livestock type and percentage of manure N added to pastures across provinces.

Animal types	N excrete rate	BC	AB	SK	MB	ON	PQ	NB	NS	PE	NF	CAN
	kg N head^{-1} yr^{-1}	distribution of manure management practices (%)										
Broi lers	0.36	0	0	1	0	0	0	0	2	0	0	0
Laying hen	0.55	0	0	6	0	0	0	0	0	0	0	0
Pullets	0.36	0	0	6	0	0	0	0	0	0	0	0
Pturkey	1.54	0	18	23	6	1	2	1	2	0	1	1
Calfe	25.33	41	26	28	41	19	29	29	29	23	26	26
Steers	56.29	41	26	28	41	19	29	29	29	23	26	26
Herfer	52.19	3	0	15	29	10	11	13	6	23	13	13
Beef cow	78.81	41	26	28	41	19	29	29	29	23	26	26
Milk cow	121.97	3	0	15	29	10	11	13	6	23	13	13
Bulls	90.07	41	26	28	41	19	29	29	29	23	26	26
Bpars	9.93	1	0	1	0	0	0	0	0	1	0	0
Hogs	8.53	1	0	1	0	0	0	0	0	1	0	0
Weaners	3.48	0	0	0	0	0	0	0	0	0	0	0
Sows	9.60	0	0	0	0	0	0	0	0	0	0	0
Sheeps	6.95	47	58	35	44	36	25	23	15	29	23	23
Goats	10.51	44	44	35	44	35	15	22	29	22	22	22
Horse	49.28	29	52	35	35	33	29	27	29	23	27	27
Boars, deer	25.05	29	52	35	35	33	29	27	29	23	27	27

[Z] N excrete rates were from ASAE (2003), and modified by Statistics Canada (2004)
[Y] Distribution of manure (%) to pasture were from Marinier et al. (2004)

Assuming all manure not on pasture is stored and spread, then manure N stored (*MNstored*(*i,k*)) equals the sum of total manure N from all livestock types minus the sum of all manure N on pasture. Manure N available to crops (*MNavail*(*i,k*)) is considered to be a function of the amount of manure stored minus N losses through management (i.e. N losses as gas and unavailable as soil organic N), and was calculated by multiplying manure N stored by % N available as ammonium N estimates for each type of livestock manure (Table 3) (MacDonald and Thomsen, 2005). The amount of manure applied on each crop in each polygon (*MNapplied*(*i,j*) was calculated according to the ratio of N recommended for the crop to the total N recommended in the polygon (Eq. 5). A manure N calculation is shown in Fig. 2

$$MNapplied(i,j) = MNcrops(i) \times \frac{MNrcmd(i,j)}{TotMNrcmd(i)} \quad (5)$$

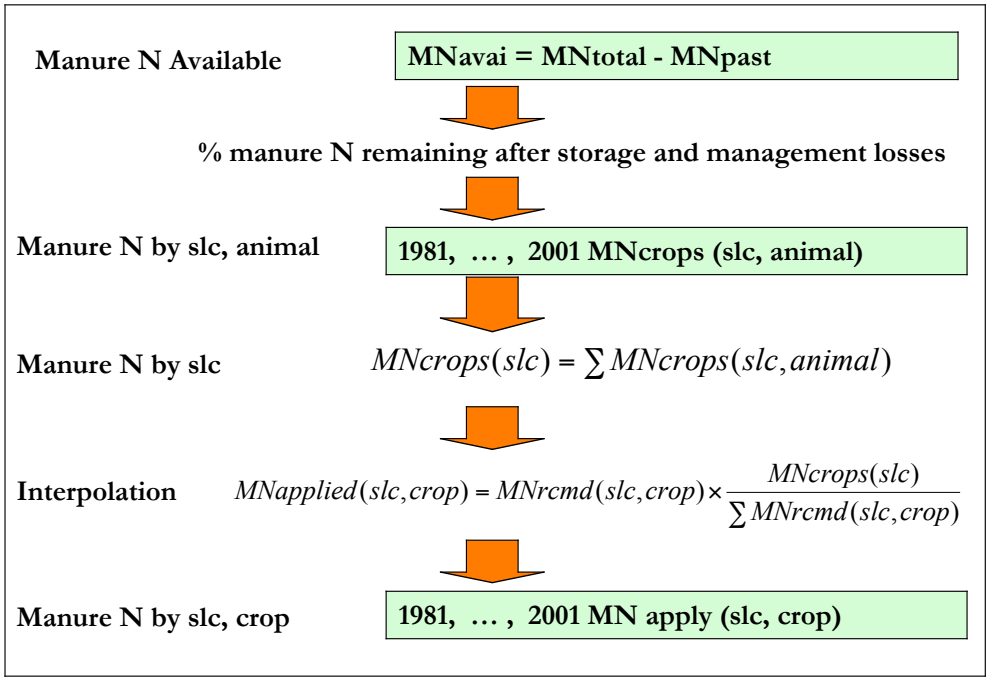

Fig. 2 Manure N calculation and allocation to crops

Table 3 Percent of available manure N added to the soil after storage and management losses are considered[Z].

Province	Poultry	Cattle	Pig	Others
BC	24	14	21	14
AB	28	17	26	17
SK	27	16	25	16
MB	30	18	27	18
ON	28	17	25	17
PQ	28	17	26	17
NB	26	15	24	15
NS	25	14	23	14
PE	25	14	23	14
NF	21	11	19	11

[Z] Table 3 data were from MacDonald and Thomsen (2005)

Total N applied

Total N applied to each crop equals the sum of the manure N applied plus the fertilizer N applied (Eq. 6).

$$TNapplied(i, j) = MNapplied(i, j) + FNapplied(i, j) \quad (6)$$

Results and discussions

The calculations as outlined above provides an estimate of actual N application rates (kg N ha^{-1}) from both manure and fertilizer for each crop, at the SLC scale, for each Census year from 1981 to 2001. The results, scaled up to soil type, provincial and national scales are presented below.

Examples of estimated N application rates (kg N ha^{-1}) by soil type (Great Group) are given in Table 4. Compared with Table 1, Table 4 shows that the average N application rates, including both fertilizer N and manure N, are quite close to the N recommendation rates. In general the actual application rates are less than the recommended rates, except for pasture.

Total manure N and fertilizer N applied at the national scale (1981 to 2001) are listed in Table 5. Total N application increased gradually from a national average of 20 kg N ha^{-1} in 1981 to 35 kg N ha^{-1} in 2001. During this time period, the increases were mostly attributed to fertilizer N, with a slight increase in the amount of manure-N applied.

With respect to national manure N in 2001 (Table 5), 11% was allocated to improved pasture, 24% was allocated to unimproved pasture and 65% was stored and spread on field crops. The 65% which was applied to crops was partioned as follows: 21% was lost due to ammonia volatilization and denitrification, 32% was organic N which was not available to crops in the year of application and 12%, was available to crops as inorganic N.

Total manure N before losses and fertilizer N on provincial averages per hectare in 1981, 1991 and 2001 are given in Fig. 3. Low manure N is reported for the Prairies, while Quebec, Nova Scotia and Newfoundland show the highest values. The high averages of fertilizer N application occur in Prince Edward Island, Manitoba, Ontario, Quebec and New Brunswick. Fertilizer N per hectare farmland increased with time in most of provinces except British Columbia, Ontario and Nova Scotia.

Table 4 Calculated average N application rates (Manure N plus Fertilizer N) by soil type and crop (kg N ha^{-1})

SOIL GREAT GROUP	Wheat	Cereal	Corn	Canola	Forage	Potato	Pasture
BROWN CHERNOZEM	36	37	N/A	33	19	N/A	9
BLACK CHERNOZEM	63	63	23	62	34	34	24
GRAY BROWN LUVISOL	48	28	137	12	27	86	65
HUMO-FERRIC PODZOL	50	56	97	8	14	89	63
HUMIC GLEYSOL	75	67	100	12	18	57	80
MELANIC BRUNISOL	54	30	100	13	27	70	53

Table 5 Total N application from manure N and fertilizer N in pastures and crops from 1981 to 2001

Year	MN total[z]	MN unpast	MN Impast	MN stored			FN applied	TN applied	Farm Area	TN Per ha
				MN losses	MN organic	MN applied				
	Mt N	Mt N	Mt N	Mt N	Mt N	Mt N	Mt N	Mt N	M ha	kg N ha^{-1}
1981	928	209	100	211	297	113	835	1256	62	20
1986	866	199	82	201	277	107	1255	1643	62	27
1991	915	218	87	206	293	111	1196	1612	62	26
1996	1035	257	103	221	331	122	1448	1931	62	31
2001	1080	255	119	230	346	130	1682	2186	62	35

[z] MN total = total manure N, MN unpast = total manure N to unimproved pasture, MN impast = total manure N to improved pasture, MN stored = total manure N stored to crops, MN losses = total manure N losses from storage and management, MN organic = tot manure N in organic form in current year, MN applied = total manure N applied to crops as ammonium N after losses. FN applied = total fertilizer N applied to crops adjusted by N sold, TN applied = MN applied + FN applied, Farm area = total farmland area (croplands + unpast + impast + summerfallow), and TN per ha = averages of TN applied per hectare farm area.

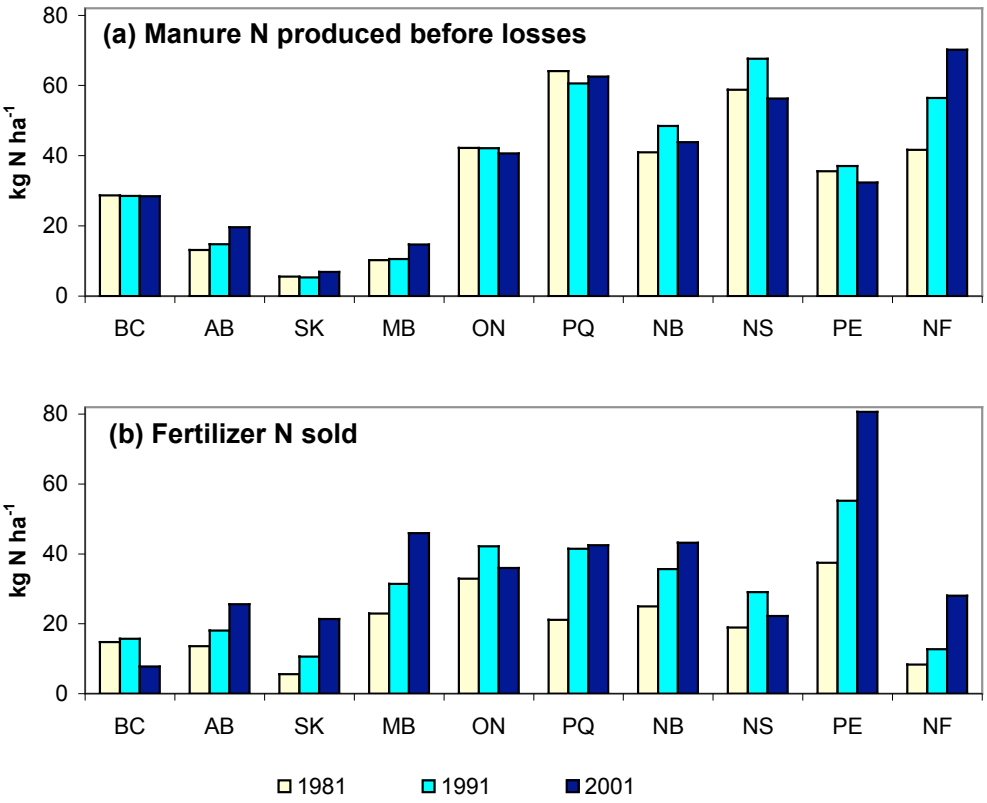

Fig. 3. Averages of manure N produced before losses (a) and fertilizer N sold (b) per farmland hectare in 1981, 1991 and 2001

Conclusions

This paper describes the methods which were used to develop a database of fertilizer N and manure N application rates for individual crops at the scale of the 1:1 million Soil Landscapes of Canada (SLC) polygons. The database provides an estimate of the actual amount of N applied per crop and per hectare, based on provincial fertilization recommendations, the number and manure production levels of each type of livestock and reported amounts of fertilizer sold. The estimated N rates are sensitive to both N recommendation rates and are adjusted based on the manure inputs and losses. The database was used in the CANB model to calculate fertilizer N and manure N application rates at the provincial and national scale. After further verification, the database will be incorporated into ongoing programs related to environmental monitoring and policy scenario assessment.

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