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Residual soil nitrogen in soil landscapes of Canada as affected by land use practices and agricultural policy scenarios

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Abstract

Agri-environmental indicators are being developed in Canada to assess and report on the environmental sustainability of agricultural production activities. Concerns about water quality have led to the development of an indicator called residual soil nitrogen (*RSN*), which reflects annual nitrogen left in the soil profile after crops are harvested. The Canadian agricultural nitrogen budget (CANB) is used to integrate this indicator with the economic Canadian regional agriculture model (CRAM) to assess the implications of national and regional agricultural policy scenarios. CANB has built-in scaling-up and scenario-analysis capabilities, so that its outputs can be generated and mapped at the soil landscapes of Canada (scale 1:1 million) level, as well at provincial and national scales. Using census of agriculture data for 1981 and 1996, the CANB model predicted *RSN* levels across Canada for 2008. The impacts of CRAM policy scenarios in the year 2008, which include changes in crop areas, animal numbers, fertilization and animal feeding practices, each with a low, medium and high level of adoption, are evaluated in terms of changes in *RSN* compared to a 2008 'business as usual' scenario. National average *RSN* values are projected to increase from 21.8 kg N/ha in 1981 to 36.5 kg N/ha in the 2008 'business as usual' scenario. Between 1996 and 2008, the proportion of farmland containing greater than 40 kg of excess N/ha increased from 18% to 34% in response to increased fertilizer use, increased manure application and increases in the area of legume crops. Changes in land use practices, such as decreasing the summerfallow area or switching some annual cropland to perennial forages and forestry, appear to have a minimal effect on *RSN* levels as compared to the 'business as usual' scenario. However, policy scenarios that improve nitrogen fertilization and animal feeding practices were found to significantly decrease *RSN* levels and thereby reduce the risk of nitrate contamination of the environment.

Keywords: Residual soil nitrogen; Census of agriculture; Agricultural policy scenarios; Nitrogen modeling; Scaling up; Soil landscapes of Canada

Introduction

Potential contamination of ground and surface water by nitrogen is a growing concern in Canada, and there is a need to assist the public, the farming community and policy-makers to gain more insight into the risk posed by nitrogen to human health and environmental quality (Vitousek et al., 1997). Moreover, there is a need to evaluate and quantify the effectiveness of agricultural policies and beneficial management practices (BMPs) that are put in place to reduce excessive soil nitrogen levels resulting from crop production and animal husbandry activities (Power et al., 2001; Shirazi et al., 2001; Spalding et al., 2001; Zhang et al., 1996). Site measurements are generally inadequate to assess the impacts of a wide range of agricultural policies and management practices that are implemented at agro-ecosystem, provincial and national scales. For this reason, computer simulation models are often used to predict the impacts of changes in soil- and crop-management practices on the fate of inorganic nitrogen in the environment. For example, nitrogen models that have been used in agricultural sustainability studies include those that are site- and field-oriented (Probert et al., 1998; Hartkamp et al., 1999),

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management and/or policy-oriented (Svendsen et al., 1995; Delgado et al., 2002; Haberl et al., 2003) and regionally oriented (Chung et al., 2001 van Ittersum et al., 2004). Policy scenarios and/or legislative measures have been evaluated in Europe by simulating nitrogen in agro-ecosystems (Kersebaum, 1995; Børgesen et al., 2001). In the USA, Williams and Kissell (1991) developed a simple nitrogen leaching index that was intended to inform the public and policy-makers of the potential for ground water contamination at the national level.

In Canada, two nitrogen indicators are being developed to assess the environmental sustainability of agricultural production activities: (i) residual soil nitrogen (*RSN*), which is an estimate of the quantity of mineral nitrogen remaining in the soil after harvest and (ii) indicator of risk of water contamination by nitrogen (IROWCN), which links *RSN* to soil types and climatic conditions to assess the likelihood of nitrogen moving out of the agricultural system (MacDonald, 2000a, b). The Canadian agricultural nitrogen budget (CANB) model is being developed to calculate these indicators and link them with various agricultural policy scenarios.

The overall objective is to evaluate, at a regional level, the impact of various land use practices and proposed agricultural policies (scenarios) on the residual soil nitrogen level after harvest. The specific objectives are to: (i) integrate the CANB model with the economic Canadian regional agricultural model (CRAM) (Horner et al., 1992), (ii) simulate spatial and temporal variations in *RSN* under past, current and projected land use practices and policy scenarios; and (iii) identify limitations of the model and the input databases.

Methods

Canada covers about 992 M ha, of which about 7.4% (68 M ha) is farmland. The wide variation in climatic conditions, soil types and landscapes results in a similarly wide variety of crop and animal management practices, many of which are quite regional in nature. Calculation of the *RSN* indicator is based on 'regional' biophysical and farm management information that portrays environmental conditions on the landscape at a given point in time. The soil landscapes of Canada (SLC) (Ecological Stratification Working Group, 1995), prepared for use at a scale of 1:1 million, partitions agricultural land in Canada into approximately 3000 discrete areas (polygons) based on similarities in soil and landscape characteristics. These SLC polygons form the basic spatial framework for all calculations. The SLC polygons are nested within ecodistricts, ecoregions and ecozones, which allows the possibility of scaling-up to larger areas. The national census of agriculture (Statistics Canada, 1992) provides farm management data for every 5th year since 1981.

The CANB model, which operates at the SLC scale, is an annual budget model that compares inputs and outputs of nitrogen. Furthermore, it contains a routine for scaling up results from SLCs to ecoregion, provincial and national levels. The integration of the CANB model with other models, programs and databases is depicted in Fig. 1.

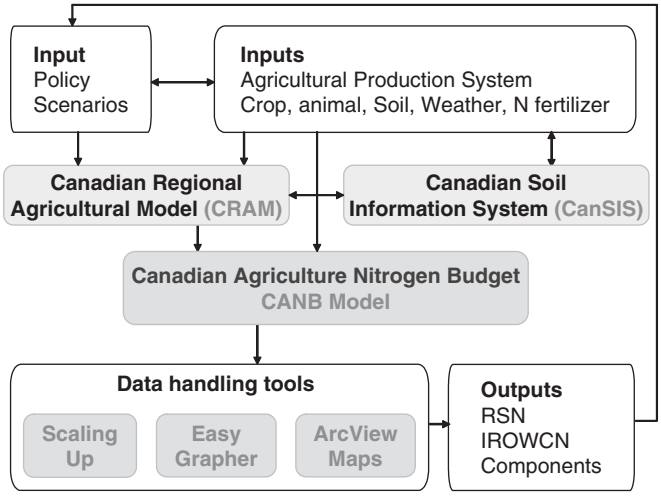

Fig. 1. Data flow associated with the integrated modeling using both the Canadian regional agricultural model (CRAM) and the Canadian agricultural nitrogen budget model (CANB).

Input databases

Census data

The census of agriculture data are allocated to the SLC polygons through an area-weighting process in order to provide crop areas and livestock types and numbers for each polygon. The census database contains nine animal types, 17 crop types in the prairie provinces and 14 crop types in British Columbia and the eastern provinces (Table 1).

For all provinces except Newfoundland, soil polygons with a farmland area less than 5% of the total SLC area are excluded from further analyses. In Newfoundland, this was not feasible as agricultural land is sparse and fragmented. If polygons with less than 5% farmland area were eliminated from this analysis, then only 43% of the farmland in Newfoundland would have been included. As a result, only polygons with less than 10 ha of farmland are excluded in the province of Newfoundland.

Rate parameters

Various animal and crop parameters are used as input to the CANB model. These are: (i) nitrogen excretion rates for different animal types (Culley and Barnett, 1984), (ii) provincial nitrogen recommendation rates for crops, (iii) provincial nitrogen fixation rates and nitrogen credits from legume crops, (iv) nitrogen uptake rates (humid areas), and (v) nitrogen from crop residues in the semi-arid prairie provinces (average soil nitrogen test values).

Agricultural policy scenarios

For policy scenario analyses, a 2008 'business as usual' baseline was developed based on the 1996 and 2001 census data, assuming that changes in agricultural land use and