# The impacts of land use on the risk of soil erosion on agricultural land in Canada

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## Abstract
Using established erosion models and national databases, A Soil Erosion Risk Indicator (SoilERI) was developed under the National Agri-Environmental Health Analysis and Reporting Program (NAHARP) in Canada to assess the risk of soil erosion in agricultural land from the combined effects of tillage, water and wind erosion processes. The indicator was build upon the Soil Landscape of Canada (SLC) polygon and was then aggregated to the province and national scale. It reflects the characteristics of the climate, soil and topography and responds to changes in land use over the 25-year period between 1981 and 2006. The results showed that the risk of soil erosion on Canadian cropland has steadily declined with time since the 1980s, largely due to the adoption of the conservation tillage, particularly no-till systems. However, there are still areas in every province with risks of unsustainable soil erosion. The risk of soil erosion was greatest under potato and sugar beet production and corn and soybean produced with conventional tillage. Serious erosion occurs on an important portion of cropland in southern Ontario and in Atlantic Canada. The information obtained in this study could help the decision makers to better target the hot spot of soil erosion in different scales and to design the best management practices for a given region.

## Key Words
Soil erosion risk indicator (SoilERI), land use, agricultural land, Canada.

## Introduction
Soil erosion is a major threat to agricultural sustainability in Canada. The loss of soil from current and past management is a major cause of low crop productivity and inefficient use of cropping inputs and can also have significant off-farm adverse impacts on the environment. Soil erosion occurs through three main processes: wind, water and tillage erosion. The combined effects of wind, water and tillage erosion pose a more serious threat than individual erosion processes. Management of the combined effects of wind, water and tillage erosion is required to maintain soil health. The risks of each component erosion processes and, therefore, the combined soil erosion are determined by the characteristics of the climate, soil and topography conditions and the land use.  In a large scale, the characteristics of the climate, soil and topography conditions are relatively stable while the land use in agricultural land can change rapidly with time. This includes the change of crop types (e.g., from annual crop to forage) and tillage systems (e.g., from conventional tillage to no-till), both may cause the change of soil erosion risk with time. A Soil Erosion Risk Indicator (SoilERI) was developed under the NAHARP in Canada to assess the risk of soil erosion from the combined effects of all three forms of erosion processes. The SoilERI was designed to reflect the effects of land use change on the risk of soil erosion and is aimed at providing science-based agri-environmental information that can guide policy and program design (Lefebvre *et al.* 2005).

## Methods
Soil erosion was calculated on the scale of Soil Landscapes of Canada (SLC) polygon (Figure 1). Each SLC polygon is characterized by one or more representative landforms, and each landform is characterized by hillslope segments (upper, mid and lower slopes and depression). Water, wind and tillage erosion rates were calculated for each segment. Other input data were obtained from established national databases or national surveys (Figure 1).

### *Individual erosion processes*
Tillage erosion was calculated as the product tillage erosivity and landscape erodibility (Lobb *et al*. 2006):

$$A_{Ti} = ET \bullet EI \qquad (1)$$

where $A_{Ti}$ is the rate of soil loss (Mg/ha/y), ET is tillage erosivity (Mg/m/%), and EI is landscape erodibility (% m/ha). ET was assigned to crops for given agricultural regions based on field experiments of tillage translocation studies carried out in various crop productions common in Canada. EL was calculated as a function of slope gradient and slope length.

Water erosion was determined using the Universal Soil Loss Equation (USLE):

$$A_{Wt} = R \cdot K \cdot LS \cdot C \cdot P \quad (2)$$

where $A_{Wt}$ is the average annual water erosion rate, R is the climate factor, K is the soil erodibility factor, LS is the topography factor, C is the crop management factor and P is the supporting practice factor. However, adjustments have been applied to these factors based on intensive test runs of the Revised USLE version 2 program (RUSLE2) using data of the US counties along the US-Canada border (Li *et al.* 2008). The adjustment was made to capture the important advancements in water erosion science (e.g., the interactions between individual factors).

Wind erosion was calculated based on the Wind Erosion Equation (WEQ):

$$A_{Wd} = f(I,K,C,L,V) \quad (3)$$

where $A_{Wd}$ is the average annual wind erosion rate, I is the soil erodibility index, K is the soil ridge roughness factor, C is the climate factor related to wind speed, air temperature and rainfall, L is the unsheltered distance across a field and V is the vegetative cover factor (Woodruff and Siddoway, 1965).

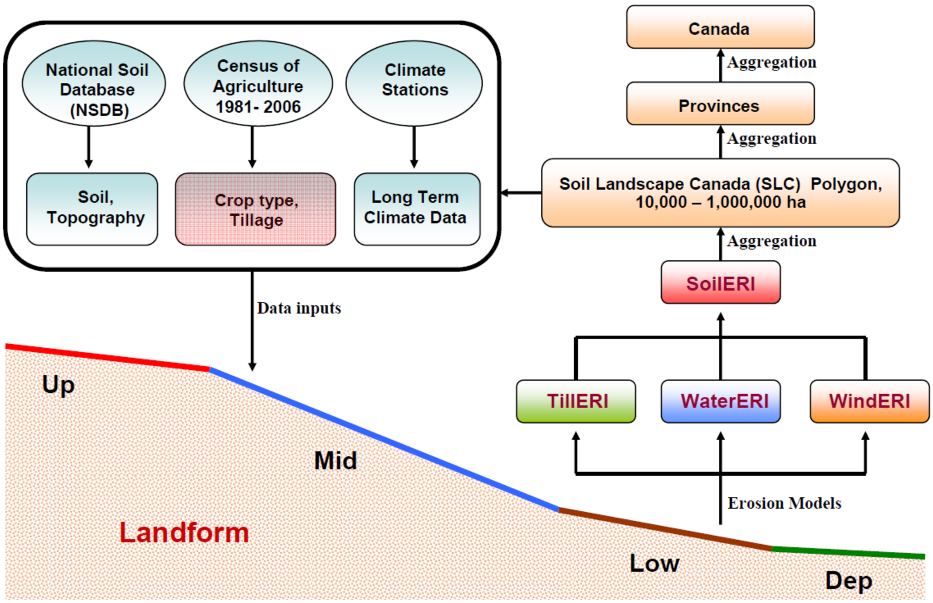


**Figure 1. The framework of the Soil Erosion Risk Indicator (SoilERI).**

*The integrated Soil Erosion (SoilERI)*

The integrated soil erosion was calculated as the sum of tillage, water and wind erosion for each landscape segments (Figure 1). The interactions (non-additive effect) between different erosion processes were not considered.

$$A_{Soil} = A_{Ti} + A_{Wt} + A_{Wd} \quad (4)$$

The soil erosion rates for individual segments were aggregated to the SLC polygon, province and national levels (Figure 1). The soil erosion rates were calculated for six years (1981, 1986, 1991, 1996, 2001 and 2006) corresponding to the Census of Agriculture in Canada and were grouped into six risk classes: negligible (< 3 Mg/ha/yr), very low (3 - 6 Mg/ha/yr), low (6 - 11 Mg/ha/yr), moderate (11 - 22 Mg/ha/yr), high (22 - 33 Mg/ha/yr) and very high (> 33 Mg/ha/yr). Areas in the very low risk class are considered capable of sustaining long-term crop production and maintaining agri-environmental health, under current conditions. The other four classes represent the risk of unsustainable conditions that call for soil conservation practices to support crop production over the long term and to reduce risk to water quality.

## Results

The risk of soil erosion on Canadian cropland has steadily declined between 1981 and 2006 (Figure 2). The majority of this change occurred between 1991 and 2006. In 2006, 80% of cropland area was in the very low risk class (Figure 3). This is a considerable improvement over 1981 when only 47% was in this risk class. The cropland area in the higher risk classes each decreased by about one half during this time period, reaching a cumulative total of 20% in 2006. The integrated erosion risk indicator results paint a picture that is less positive than the results from the individual component indicators for water, wind and tillage erosion, but better reflects the actual risk of soil degradation by erosion. The improvement in soil erosion risk reflects reduction in all forms of soil erosion, however, the reduction in tillage erosion risk exceeded that of wind and water erosion.

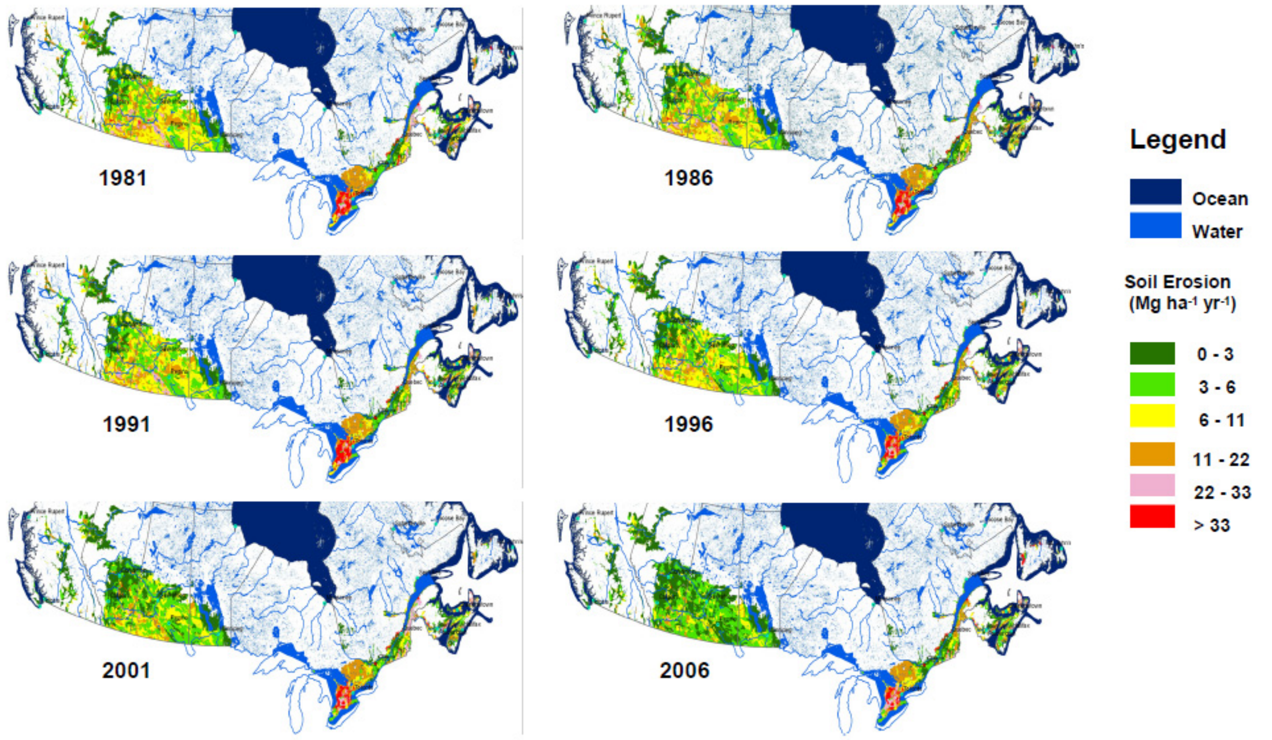


**Figure 2. Soil erosion risk classes on agricultural landscapes in Canada from 1981 to 2006.**

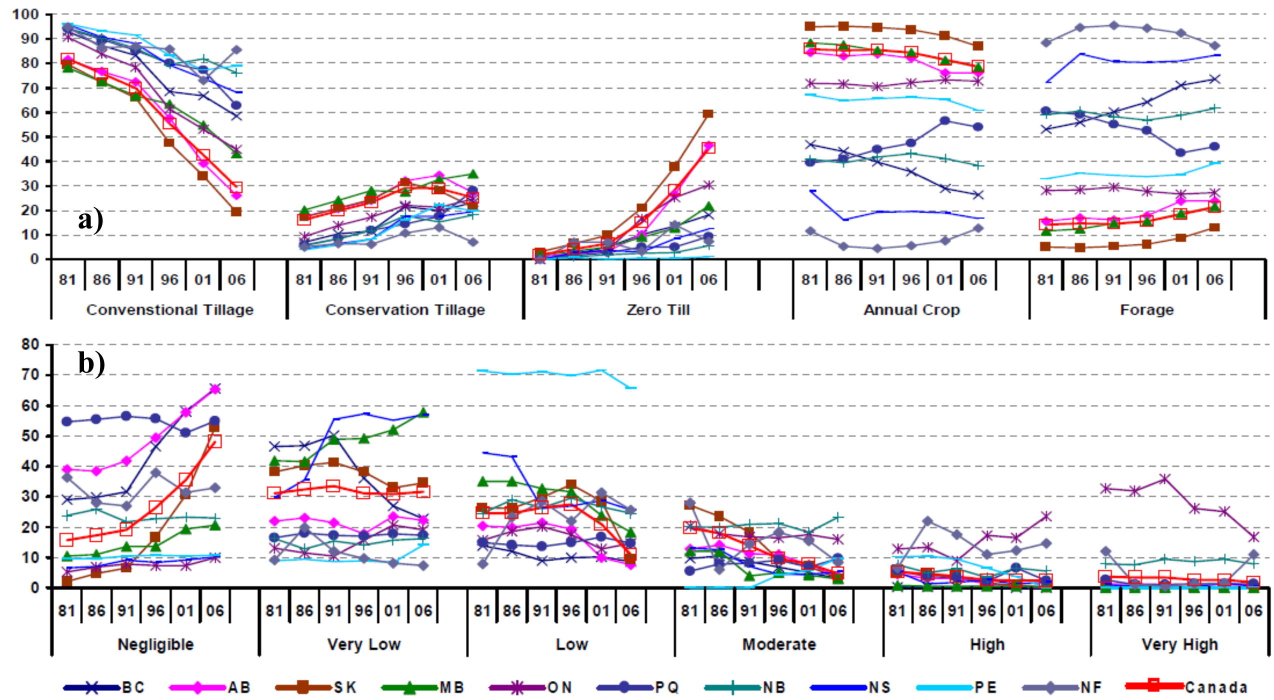


**Figure 3. Shares (%) of cropland in Canada in: a) different tillage systems and major crop types; and b) different soil erosion risk classes**

The decrease in all forms of erosion in Canada is largely due to the widespread adoption of conservation tillage, particularly no-till systems (Figure 3). Changes in share and mix of crops grown were less of a contributing factor. Crops requiring more intensive tillage, making them more erosive, such as corn, potatoes and beans, increased in area from 6% of cropland in 1981 to 13% in 2006. This uptrend was offset by the decrease in summer fallow, from 24% in 1981 to 9% in 2006, and by the increase in high residue crops requiring very little tillage such as alfalfa and hay, from 14% in 1981 to 21% in 2006. Although most crops have seen a reduction in tillage intensity, the adoption of direct-seeding (no-till) in cereals has had the greatest influence on soil erosion, owing to the large share of cropland devoted to cereals.

Of the cropping systems across Canada, the risk of soil erosion was greatest under potato and sugar beet production where there is very intensive tillage and little opportunity to reduce the intensity through conservation tillage practices (data not shown). The cropping system with the next greatest risk of erosion is corn and soybean produced with conventional tillage, although there is a huge opportunity to reduce this erosion risk with conservation tillage. Of the soil landscapes across Canada, the risk of soil erosion is greatest on those with maximum slopes of 10% or more, especially those located in eastern Canada where climate produces a high inherent risk of water erosion. The most serious erosion concern occurs where the cropping systems with high erosion risks are practiced on soil landscapes with high erosion risks. This happens for an important portion of cropland in southern Ontario and in Atlantic Canada (Figure 2). However, there are areas in every province with risks of unsustainable soil erosion.

Detailed information such as the patterns and relative contributions of individual erosion processes could be used to delineate the hot spots of soil erosion in a given region, based on which to design the best management practices to reduce the risk of soil erosion.

## Conclusions

Overall, the risk of soil erosion on Canadian cropland has steadily declined with time since the 1980s, largely due to the adoption of the conservation tillage, particularly no-till systems. However, there is still a large acreage of agricultural land in Canada with risks of unsustainable soil erosion. The detailed information could help the decision makers to better target the hot spot and, therefore, design the best management practices for a given region.

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