Using ^{137}Cs and Modelling (WATEM, TillEM, DirTillEM) to Estimate Tillage and Water Erosion within a Hummocky Podzolic Landscape in Atlantic Canada

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Background

Total soil erosion is the result of all soil erosion agents – wind, water and tillage. In Canada, the risk of soil erosion (in particular by tillage and water erosion) is expected to be greatest in regions where highly erosive cropping and tillage systems are used on highly erodible landscapes – such as the potato growing regions of northwestern New Brunswick. However, no previous studies have looked at the combined impacts of tillage and water erosion on soil and crop health in Atlantic Canada.

Estimates of the extent of past soil erosion and redistribution can be made using cesium-137 (^{137}Cs, half-life 30.2 years), an environmental radionuclide that is present in the environment primarily as a result of atmospheric testing of nuclear weapons during the 20th century. This “bomb derived” ^{137}Cs came in contact with the soil through atmospheric deposition (usually in association with precipitation), and is strongly and rapidly adsorbed onto exchange sites within the fine earth fraction of mineral soils. Once adsorbed to the soil, ^{137}Cs is essentially non-exchangeable, and biological and chemical processes move little of the adsorbed ^{137}Cs through the soil profile. Since ^{137}Cs remains concentrated in the surface soil, and its deposition at the local scale is assumed to be uniform, the subsequent redistribution of ^{137}Cs throughout the landscape allows for the estimation of the location, extent, redistribution and rate of total soil loss from all erosion processes for a time period of approximately 40 years.

Objectives: The objective of this project was to estimate the relative contributions of tillage and water erosion within intensive potato production in the eastern Canadian province of New Brunswick. By comparing the ^{137}Cs estimates of total soil erosion to estimates generated by tillage and water erosion models, it is possible to evaluate the relative contributions of the different erosion processes across the landscape.

Materials and Methods

- Depth incremental soil samples were collected at one of the two Agriculture and Agri-Food Canada benchmark sites located near the town of Grand Falls, New Brunswick.
  - Site 20NB (46º54’N, 67º47’W) is 3.5 ha in size, under conventional up and down slope cultivation, and has a slope ranging from 2 to 17 % (Fig. 1).
- Soil samples were collected across the landscape using two grid patterns (Figs. 1 to 3):
  - 25 x 25 m over the entire field
  - 12.5 x 12.5 m at the top (most convex part) of the field.
- A proportional model was used to convert the ^{137}Cs radioactivity inventory at each grid point into a soil loss rate:

$$A^* = \frac{\rho_C D_C (Cs_0 - Cs_i)}{YCs_0}$$

  - where, A* (kg m^{-2} yr^{-1}) is the average annual soil loss rate (positive for soil loss, negative for soil gain), Dc (m) is the depth of soil in which the ^{137}Cs is distributed, ρc (kg m^{-3}) is the bulk density, Y (yr) is the time period, Cs_i (Bq m^{-2}) is the measured ^{137}Cs inventory of the sample, and Cs_0 (Bq m^{-2}) is the baseline ^{137}Cs radioactivity inventory (2547 Bq m^{-2}, n = 12, CV = 13%).

- Water and tillage erosion were estimated using two established models:
  - **WATEM_W**: the water erosion component of the Water and Tillage Erosion Model (Van Oost et al., 2000) is a three dimensional model, based on RUSLE, that incorporates routing algorithms to simulate both convergent and divergent water flows across the landscape.
  - **TillEM**: the Tillage Erosion Model (Lobb et al, 1999; Li et al. 2007) estimates point-tillage erosion rates using a continuity equation (assumes that tillage operations occur in opposing directions equally as often):

$$E_{Ti} = -\frac{\partial M}{\partial t} = -\frac{\partial T_M}{\partial s} = -\left(\beta\frac{\partial \theta}{\partial s} + \gamma\frac{\partial \phi}{\partial s}\right)$$

  - where, E_{Ti} is the estimated tillage erosion rate, positive for soil loss and negative for soil gain (kg m^{-2} yr^{-1}), M is the mass of soil per unit area (kg m^{-2}) above a specified base elevation, t is time (yr), θ is slope gradient (m m^{-1} %$^{-1}$), ϕ is slope curvature (m m^{-1} (% m^{-1})$^{-1}$), and s is the distance in any specified horizontal direction (m). β (kg m^{-1} %$^{-1}$ yr^{-1}) and γ (kg m^{-1} (% m^{-1})$^{-1}$ yr^{-1}) are the erosivity coefficients derived from previous tillage translocation field experiments. They describe the additional tillage translocation resulting from slope gradient and slope curvature, respectively.

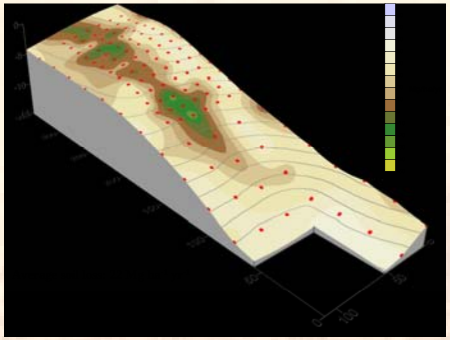

Fig. 1. The ^{137}Cs estimated total soil erosion at 20NB (note, soil accumulation in the trough down the middle of the field).

Fig. 2. Collecting depth incremental soil samples.

Fig. 3. Soil core to 45 cm.

Results

- The pattern of ^{137}Cs estimated soil erosion was not strongly correlated with either TillEM (r = 0.35***, Fig. 4) or WATEM_W (r = 0.41***, Fig. 5) estimated soil erosion patterns.
- A new tillage erosion model (DirTillEM) was developed to account for the apparent effect of tillage direction, lateral tillage translocation, and field boundaries on soil redistribution at this field site.
  - DirTillEM determines the net translocated mass of soil (T_M^N) for each point in the landscape by calculating the soil translocated into (T_M^{in}) and out of (T_M^{out}) that point using the four nearest grid-cells:

$$T^N_{M(i)} = \sum_{i=1}^{4} T^{in}_{M(i)} - \sum_{i=1}^{4} T^{out}_{M(i)} = \sum_{i=1}^{4}(\alpha_i + \beta\theta_i^{in} + \gamma\phi_i^{in}) - \sum_{i=1}^{4}(\alpha_i + \beta\theta_i^{out} + \gamma\phi_i^{out})$$

- The pattern of ^{137}Cs estimated soil erosion were correlated best with DirTillEM (r = 0.58***, Fig. 6) and when DirTillEM and WATEM_W were combined (0.62***, Fig. 7).

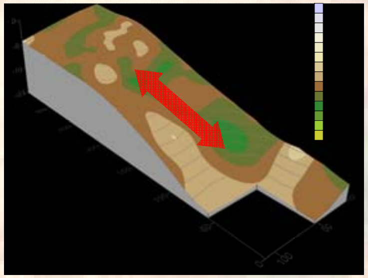

Fig. 4. Tillage Erosion (TillEM) – alternating tillage directions: r = 0.35* vs. ^{137}Cs estimates.**

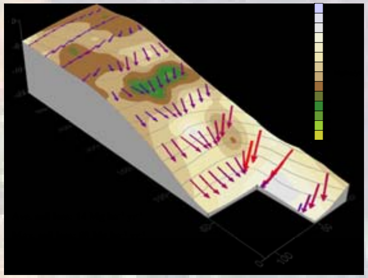

Fig. 5. Water Erosion – WATEM_W: r = 0.41* vs. ^{137}Cs estimates.**

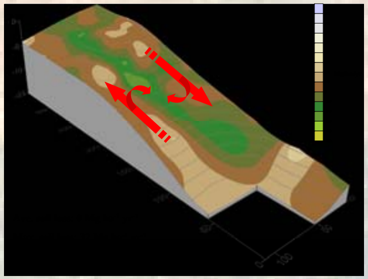

Fig. 6. Directional Tillage Erosion (DirTillEM) – mouldboard plough 1 direction w/ furrow turned in, remaining potato and grain operations alternating directions: r = 0.58* vs. ^{137}Cs estimates.**

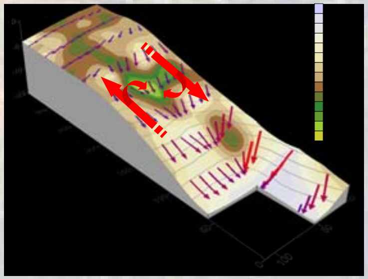

Fig. 7. WATEM_W and DirTillEM combined: r = 0.62* vs. ^{137}Cs estimates.**

Conclusions

Our results suggest that both tillage and water erosion are major erosive agents at this field site, but that tillage erosion is the dominant soil redistribution process. Tillage direction, lateral translocation and field boundaries were significant factors and must be considered in future modelling efforts. Additional analyses will be undertaken to determine if relationships exist between crop yield, soil properties, topography and overall soil redistribution. Current inventories of ^{137}Cs will also be compared to those previously taken at 20NB in 1990 and 1996 to compare soil redistribution over a shorter timescale (ca. 10 – 15 years). It is clear that both residue management for water erosion control and soil movement from tillage erosion must be considered when designing soil conservation strategies for potato production systems in Atlantic Canada.

Special Thanks to Local Collaborators:
- The Centre of Excellence in Agriculture and Biotechnological Sciences (CESAB)
- The Eastern Canada Soil and Water Conservation Centre (ECSWCC)
- New Brunswick Agriculture, Fisheries and Aquaculture

McGill
University of Manitoba
Agriculture and Agri-Food Canada / Agriculture et Agroalimentaire Canada
NSERC CRSNG