The Effects of Wind and Water Erosion on the Sustainability of Prairie Soils.

M. Black

PFRA, 603 CIBC Tower, 1800 Hamilton Street, Regina, Sk. S4P 4L2

Key Words: Soil Sustainability, Soil Erosion, USLE, WEQ, SimPLE.

Abstract

The impact of erosion on soil sustainability is difficult to evaluate. A modelling system was developed which attempts to address this issue at a scale of 1:1m for policy analysis and program targeting. The system combines erosion estimates from the Universal Soil Loss Equation and the Wind Erosion Equation and passes the results through the SimPLE model to evaluate the effects on wheat yields. Final results are displayed using a GIS.

Application of the modelling system to evaluate the long term sustainability of Prairie soils under rotations and tillage practices employed in 1996 is discussed. Results indicate that annual cropland in many polygons of the Brown Soil Zone of Saskatchewan could reach an uneconomic yield threshold within 100 years. Soils in the Black and Gray Soil Zones may be aggrading. Conservation tillage systems could significantly enhance the sustainability of Prairie soils.

Introduction and Objectives

Soil erosion can severely reduce crop yields and cause environmental degradation, ultimately erosion may reduce soil sustainability. Recent studies (Wall et al. 1995; Shelton et al. 2000) have estimated erosion from Prairie soils and related the results to an erosion tolerance (T) which was used as an indicator of soil sustainability.

T has been employed in the USA as a soil conservation planning tool based on estimated rates of soil formation (Johnson 1987). However, soil formation is a complex interaction of physical, chemical and biological processes (Hall et al. 1985). Some characteristics of soils develop rapidly and others more slowly such that the rate of soil development is dependant on many factors including soil moisture conditions, crop growth, and tillage. Crop yield trend over time is likely a more pragmatic indicator to evaluate the effects of erosion on soil sustainability.

The objective of this study was to evaluate the long term effects of erosion on the sustainability of Prairie soils as indicated by trends in wheat yields.

Materials and Methods

There are few data on actual levels of erosion and their effects on Prairie soils (PFRA 2000). Consequently, the Universal Soil Loss Equation or USLE (Wischmeier and Smith 1978) was employed to estimate water erosion. The equation uses soil, landscape, crop management, rainfall and soil conservation parameters to provide a long term average estimate of water erosion.

Wind erosion was estimated using the Wind Erosion Equation (Woodruff and Siddoway 1965). The equation uses soil erodibility, surface roughness, climate, fieldwidth and crop cover factors to estimate the long term average wind erosion from the field in question. Both the USLE and the Wind Erosion Equation (WEQ) are field scale models and results cannot simply be extrapolated across complex landforms.

The SimPLE model (Greer et al. 1993) was employed to evaluate the effects of erosion on wheat yields. SimPLE needs few input parameters, they are: solum depth, % clay, % silt, soil organic matter carbon, conductivity of the C horizon, infiltration and aggregation indices, N and P fertilizer applied, growing season precipitation, non growing-season precipitation, mean growing season temperature, and rate of erosion. Yield estimates derived by the model are dominated by growing season precipitation and strongly influenced by plant nutrient availability as supplied by decomposition of soil organic matter and through application of fertilizer. Results of SimPLE validation for wheat yields under Prairie conditions are comparable or superior to similar models (Greer et al. 1993).

Values of input parameters for the three models were obtained from many sources. Soils and landscape data were taken from the Soil Landscapes of Canada (SLC) database (CLBRR, 1996). The SLC polygons were used as a basemap for this project, they are at a scale of 1: 1 million. Further soils information was provided from the Agri-Environmental Indicator Project database.

Soil aggregation data for the wind erosion estimates was taken from Canadian research literature. This was necessary since generally accepted values of dry soil aggregation are not applicable for the Prairies (Black and Chanasyk 1989). Climatic parameters for the USLE and WEQ were taken from the CanHELP (PFRA 1994) user files. Climatic information for SimPLE was taken from Environment Canada weather tapes (1947-1996). Both sets of weather data were assigned to individual SLC polygons using ArcView.

There is insufficient Prairie data to allow the estimation of different cropping factors for minimum tillage and zero tillage for the USLE. Therefore comparisons could only be made between conventional and conservation tillage systems. Crop rotation information was provided by PFRA field staff across the Prairies, crop distribution data was obtained from the 1996 Agricultural Census (Statistics Canada 1977) and assigned to individual SLC polygons using ArcView. Crop management information was taken from the 1997 PFRA Crop Residue and Seeding Survey. The PFRA survey was only conducted in Saskatchewan, so it was assumed that the ratio of conventional to conservation till seeding systems by soil zone was similar for the adjacent provinces. Erosion from these two seeding systems was modelled for dominant and sub-dominant soils, and was area-weighted to result in one wind and one water erosion estimate for each SLC polygon.

Estimates of wind and water erosion were aggregated and used as input to the SimPLE model. The effects of erosion on wheat yields under soil management conditions pertaining in 1996 were modelled over a 50 year timespan (1996 to 2045). For the purposes of this study it was assumed that the technology (tillage systems, plant genetics, fertilizer etc.) used to grow the crop would not change during the 50 year period. SimPLE model runs used actual weather data for 1947-1996 to incorporate the interacting effects of weather variability together with the cumulative effect of erosion on wheat yields.

Yield trends as impacted by erosion have been reported to follow a Mitscherlich-Spillman form (de Jong 1988). Preliminary analysis of wheat yield response to erosion modelled by SimPLE revealed that in fact most soils displayed an almost linear relationship during the modelled period. Accordingly, linear regression was used to evaluate the yield trend relationship.

An index of wheat yield sustainability was developed to evaluate the sustainability of Prairie soils. The general form of the index is as follows:

$$\text{Wheat Yield Sustainability} = \frac{\text{Yield Intercept}}{\text{Yield Slope}} \qquad \text{Equation 1}$$

It was assumed that land would be taken out of annual crop production when long term average wheat yields decline to 15 bu/ac.

Results

The effect of erosion on the wheat yield sustainability index is mapped in Figure 1. The analysis assumes that farming practices remain unchanged from 1996. To the extent that long term trends in wheat yields can reflect soil quality this map is considered to indicate trends in soil sustainability.

The most obvious feature in Figure 1 is the large area of annual cropland in the Boreal Transition and the Parkland ecoregions on which wheat yields are estimated to increase over the next 50 years despite wind and water erosion (dot pattern in Figure 1). The model results suggest typical soils in these areas are, on the whole, being farmed sustainably. Nevertheless erosion with attendant environmental degradation may still be a concern in these areas since the scale of the modelling does not discriminate small pockets of erodible soils or inferior soil management practices.

Also of particular interest in Figure 1 are the areas delineated in dark shading. Erosion is estimated to cause a significant decline in wheat yields in these areas to the extent that **if agricultural practices do not change** annual cropping will be uneconomic within 40 years. These areas are mainly located in the Brown Soil Zone of Saskatchewan.

Areas with an economically viable life expectancy for wheat production of between 40 and 100 years are in lighter shading in Figure 1. These areas are interspersed with the dark shading in the Brown Soil Zone of Saskatchewan leading to the interpretation that ultimately annual crop production may be significantly curtailed in this area if changes to cropping systems are not made.

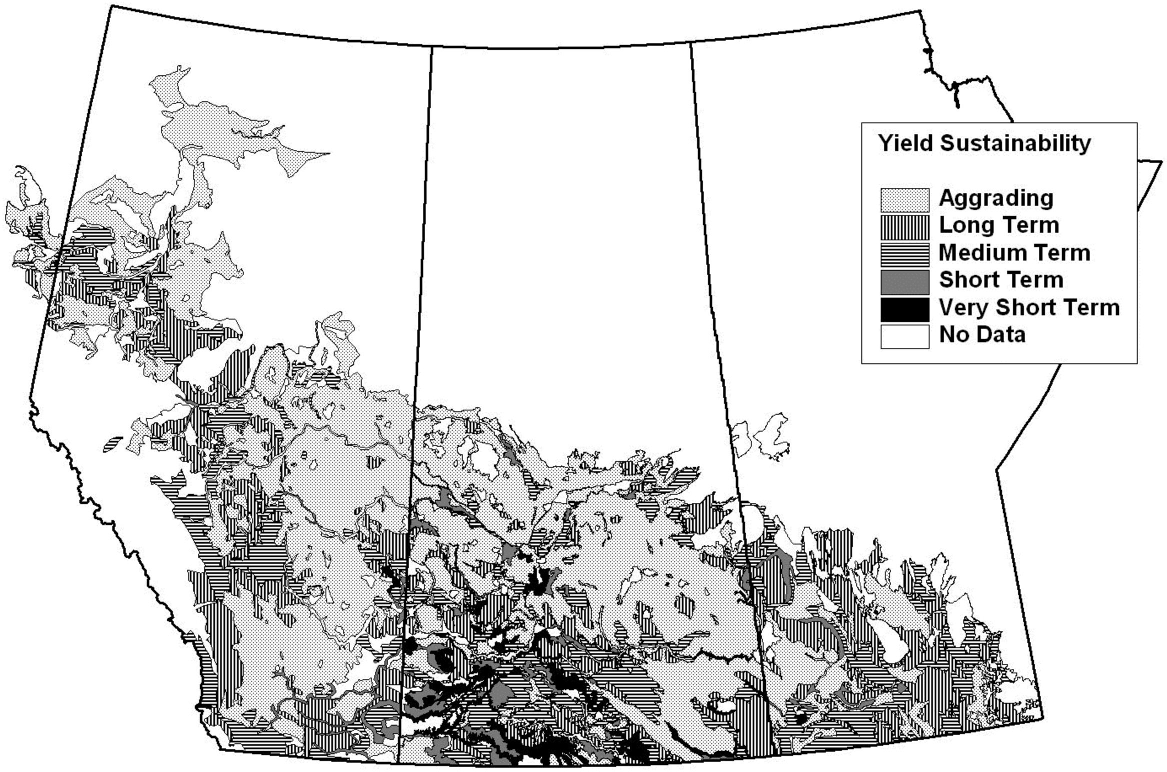

Figure 1. Wheat yield sustainability Vs erosion; time to <15 bu/ac with 1996 practices.

Areas in Figure 1 with horizontal lines indicate polygons where wheat yields will drop to 15 bu/ac between 100 and 500 years hence if farming practices do not change. Polygons with vertical lines are modelled to have a slow yield decline as a result of wind and water erosion, but at a rate which is no immediate threat to the sustainability of the soil resource.

These results are very similar to those of a study by Pettapiece et al. (1998) who evaluated changes in soil quality in Alberta resulting from erosion. Pettapiece et al. (1998) concluded, that in general, soil quality is being maintained in subhumid Boreal Transition and the Parkland ecoregions, but is declining in the semi-arid Grasslands.

It is unlikely that many producers in areas which are modelled to lose crop yields due to erosion are noticing an obvious trend of declining yields. Crop yields from year to year are most strongly influenced by the availability of soil moisture which fluctuates widely. Also, improved varieties, better moisture management, increasing fertilizer use, improved timeliness resulting from the adoption of larger equipment, improved harvesting technology etc. all serve to mask the impacts of erosion on crop yields. Indeed crop yields have generally been improving since the 1960's (Flaten and Hedlin 1988).
Further analysis was conducted to evaluate the effect of a complete conversion to conservation tillage practices. The results, shown in Figure 2, suggest that such a conversion would have a

large and extremely positive impact on the maintenance of wheat yields over areas which are currently degrading. Producers who have been practicing zero tillage and continuous cropping for a number of years have reported discernable changes to soil physical properties together with yields at least comparable to conventional tillage practices. This analysis seems to confirm that further adoption of these practices could stabilize or improve yields over most of the Prairies.

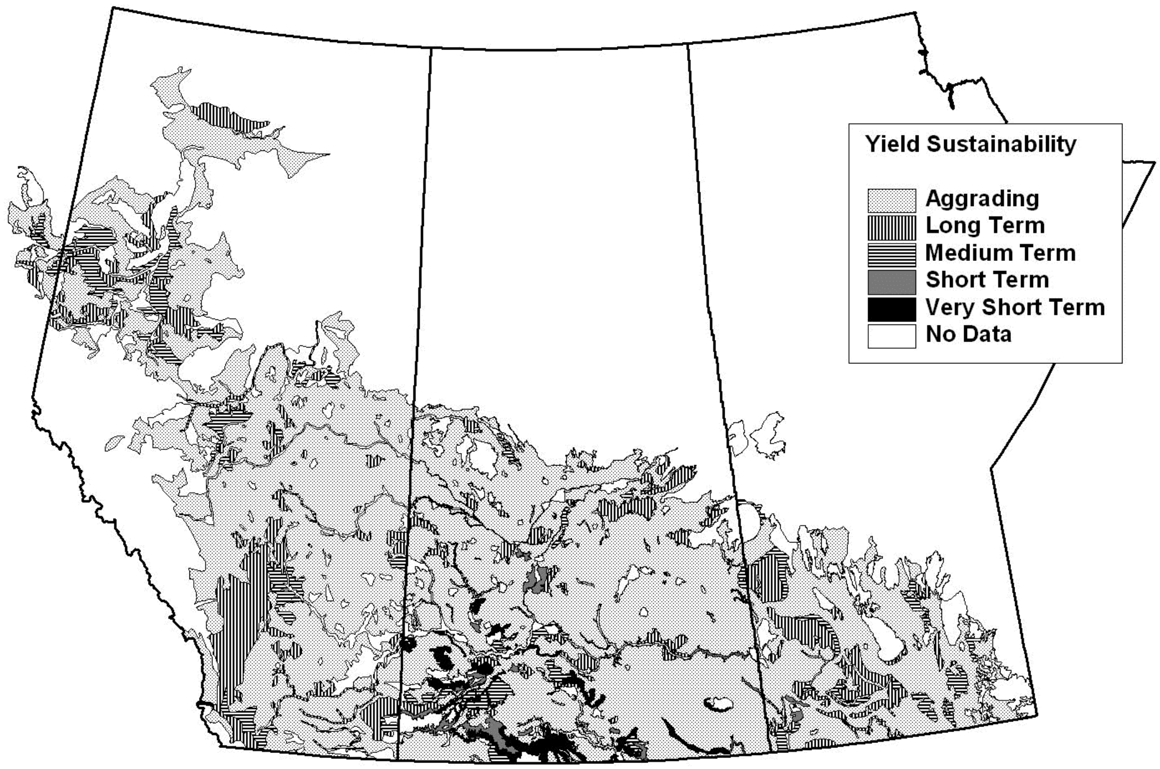

Figure 2. Wheat yield sustainability Vs erosion; time to <15 bu/ac with conservation tillage practices.

The methodology has several shortcomings, such as not accounting for snowmelt, gully, or tillage erosion, which, taken in aggregate, would tend to make the results conservative. Also, the erosion models used are field scale models, consequently the results of this analysis are considered only to apply to undefined areas within a polygon which are represented by the model input data and by the processes simulated by the USLE and the WEQ. Lastly, this analysis does not include the potential impact of climate change on soil sustainability.

Conclusions

Wheat yields as modelled in SimPLE may be increasing in large areas of the Black and Gray Soil Zones. This would imply that soil sustainability is being improved. In contrast, wheat yields in more arid areas may decline to a threshold of 15 bu/ac quite rapidly due to erosion if management does not change. Much of the Brown Soil Zone of Saskatchewan in particular was modelled to suffer large yield declines within 100 years leading to the conclusion that current annual cropping practices may not be sustainable.

The adoption of conservation till practices would have large benefits in maintaining yields and soil sustainability over much of the Canadian Prairies.

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