Wind Erosion Risk as an indicator of soil quality

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Introduction

Wind erosion is a natural process that removes topsoil from cultivated agricultural lands. And since topsoil is rich in organic matter, these losses contribute to a break down of soil structure, to lower soil fertility levels and to an overall decline in soil quality. As the quality of the soil diminishes, either crop yields decline or additional inputs, most commonly fertilizers, are required to maintain yields. In either case long term economic sustainability of the system is adversely affected. Moreover, wind eroded sediments can also have a detrimental effect on air quality. Dust clouds can limit visibility creating dangerous driving conditions, and drainage ditches and irrigation canals can become clogged with wind blown sediments from adjacent fields.

While wind erosion is a concern in many areas of Canada from the sandy soils along the Fraser River in British Columbia to the coastal areas of the Atlantic Provinces, it is on the arid Prairies where large tracts of agricultural land lie unprotected from the wind that the risk is by far the most significant. In fact in the absence of soil conservation practices over two thirds of the prairie region would be at significant risk to wind erosion, a fact vividly borne out during the dust bowl of the 1930's (Table 1). Since the 1930's, however, the risk has been substantially reduced. Many of the most susceptible lands have been seeded to perennial forages, and modern residue management techniques have further reduced the risk to the point where less than 10 % of area is considered to have a significant risk and only about 2 % has a severe risk.

The wind erosion risk indicator is a measure of the change in the wind erosion risk, and, as the name implies, can be viewed as an indicator or indirect measure of a change in soil quality. Since wind erosion is a soil degradation process that results in decreased soil quality, all other factors being equal, a declining erosion risk is considered positive in terms of soil quality.

Methods

The indicator analysis is based on 1:1 million scale Soil-Landscapes of Canada maps for each of the Prairie Provinces. These maps provide a spatial inventory of the soil and landscape characteristic of the region. Pertinent climate data such as wind speed and precipitation along with land use and management information such as crops grown and tillage practices were linked to the Soil-Landscape maps to provide a integrated land resource data base.

The conceptual procedure for estimating wind erosion risk involves first estimating the inherent erosion risk on bare unprotected soil, and then reducing that value according to the amount of residue and its effectiveness in controlling erosion. Since residues can be related to prevailing land use and management practices, changes in those parameters are used to calculate changes in wind erosion risk. Wind erosion rates for bare unprotected soil were calculated using the following equation:

$$E = KC(V^2 - SW^2)^{1.5}$$

where E = erosion rate
K = surface roughness and aggregation factor
C = factor representing soil resistance to movement by wind
V = drag velocity of the wind at the soil surface
S = soil moisture shear resistance
W = surface soil moisture content (volumetric)

Table 1. Inherent (bare soil) wind erosion risk of cultivated land of the Prairie Provinces

Wind Erosion Risk Class	Cultivated land (%)			
	Alberta	Saskatchewan	Manitoba	Prairies
Negligible	7	4	8	6
Low	38	22	38	29
Moderate	24	34	19	29
High	27	33	30	30
Severe	4	7	5	6

The effectiveness of land use and management practices in reducing erosion risk is directly related to the amount of residue or cover present during the April-May period when wind erosion risk is highest. Initial residues, or the residues at harvest, were calculated by multiplying the ten-year average crop yields adjusted for soil zone and soil texture by a crop conversion factor based on crop-specific ratios of straw to grain yield. To calculate residue levels for the April-May period, initial residues were reduced according to cropping system, type and frequency of tillage and an overwinter decomposition factor (Table 2).

The actual erosion risk was calculated for the years 1981, 1991 and 1996 using estimates of crop type, extent of fallow, and tillage practices from the Census of Agriculture for each year. This was supplemented by a questionnaire sent to farmers, extension specialists, and soil conservationists. Linking the Census data to the Soil-Landscape maps provides an estimate of change in cropping systems and tillage practices that have occurred on specific soil types, which, using an erosion model, can in turn be used to estimate the effect of these changes on wind erosion risk.

Table 2. Spring residue levels as a proportion of harvest residues by Ecoregion (soil zone) crop sequence and tillage practice.

Ecoregion (soil zone)	**Cropping sequence**	**Tillage system**	**Tillage operation**	**Remaining residue (%) (April-May)**
Mixed Grassland and Moist Mixed Grassland (Brown-Dark Brown)	Crop-->Crop	Conventional	s-cultivator	50
			s-disc	
			s-harrow (2x)	
		Conservation	s-air seeder	76
			s-harrow	
		Direct seeding	s-air seeder	81
	Crop-->Fallow		none	90
	Crop-->Fallow-->Crop	Conventional	f-cultivator (4x)	11
			s-cultivator	
			s-disc	
			s-harrow	
		Conservation Direct seeding	f-cultivator(2x)	22
			s-air seeder	
			s-harrow	
			s-air seeder	36
Parkland and Boreal Transition (Black, Dark Gray)	Crop-->Fallow	Conventional	f-cultivator	45
			s-cultivator	
			s-hoedrill	
			s-harrow (3x)	
		Conservation	s-cultivator	60
			s-air seeder	
			s-harrow	
		Direct seeding	s-air seeder	81
	Crop-->Fallow		none	90
	Crop-->Fallow-->Crop	Conventional	f-cultivator (6x)	6
			s-cultivator	
			s-hoedrill	
			s-harrow (2x)	
		Conservation	f-cultivator (2x)	20
			s-air seeder	
			s-harrow	
		Direct seeding	s-air seeder	32

Results and Discussion

Estimates of the relative risk of wind erosion on bare unprotected soil across the prairies show that about 70% of the cultivated land is at moderate to severe risk (Table 1). Most soils in the highest risk class are sandy, while those in moderate risk class is generally sandy loam, although some clayey soils in the more southern regions are also considered at moderate risk. Otherwise within the region the risk generally decreases from south to north, a reflection of

lower wind speeds, cooler temperatures and higher precipitation in the north. It is important to keep in mind that the above assessment pertains to bare unprotected soil. And while it is in a sense theoretical, it emphasizes the potential erosion risk if protective measures are not adopted and maintained.

Under present day land use and management practices, the potential erosion risk is of coarse dramatically less than that on bare unprotected soils. Many of the most susceptible soils have been planted to perennial forages, and modern farming practices in the prairies are now such that less than 10 % of the cultivated area, or about 2 million hectares, is considered at high or severe risk to wind erosion (Table 3). As shown in Figure 1 most of the susceptible areas occur in the Brown and Dark Brown soil zones of southern Alberta and Saskatchewan.

Table 3. Risk of wind erosion on Prairies, 1981 to 1996

	Percent of cultivated land (million ha)		
Risk Class	**1981**	**1991**	**1996**
Negligible	40.6 (13.2)	55.1 (18.0)	63.5 (20.1)
Low	22.2 (7.2)	16.0 (5.2)	12.8 (4.2)
Moderate	22.1 (7.2)	21.5 (7.0)	17.4 (5.7)
High	13.1 (4.3)	6.2 (2.0)	5.2 (1.7)
Severe	2.0 (0.6)	1.2 (0.4)	1.1 (0.4)

Analysis of the trend in wind erosion risk in the prairies from 1981 to 1996 show that the risk has declined by about 30 %, with about two thirds of the decline occurring between 1981 and 1991. Overall about 75% of the reduction can be attributed to a change in tillage, while the remainder is due largely to a change in cropping practices, or more specifically less summerfallow (Table 4).

Over the past number of years, the use of tillage in the prairies has declined significantly to the point where in 1996 almost half of the area was managed under some type of reduced tillage regime, with about 15 % being under a no-till or direct seeding regime (Table 5). In addition, it is interesting to note that the decline in tillage, and in particular the use of direct seeding, is significantly greater in Saskatchewan than elsewhere on the prairies, a fact that can be attributed, at least in part, to the efforts of organizations such as the Saskatchewan Soil Conservation Association who have aggressively promoted direct seeding as a practical and effective method of soil conservation, and in particular wind erosion control. Overall the reduction in tillage across the prairies over the past 15 years or so has resulted in a 20 to 25 % decline in the wind erosion risk.

Table 4. Change in the wind erosion risk in Prairie Provinces, 1981 to 1996.

		1981 to 1991			**1991 to 1996**		
		Change (%) in erosion risk due to:			**Change (%) in erosion risk due to:**		
	Cultivated land (million ha)	**Cropping System [1]**	**Tillage Practice [2]**	**Total**	**Cropping System**	**Tillage Practice**	**Total**
Soil Zone							
Brown	6.7	- 4.1	- 15.3	**- 19.4**	- 2.5	- 4.3	**- 6.8**
Dark Brown	7.1	- 3.9	- 21.8	**- 25.7**	- 4.4	- 12.4	**- 16.8**
Black	12.3	- 4.8	- 15.2	**- 20.0**	- 3.0	- 14.9	**- 17.9**
Dark Gray/Gray	6.4	- 4.8	- 8.5	**- 13.3**	- 9.0	- 10.3	**- 19.3**
Province							
Alberta	10.6	- 2.1	- 16.2	**- 18.3**	- 4.4	- 10.7	**- 15.1**
Saskatchewan	18.6	- 4.4	- 16.9	**- 21.3**	- 4.2	- 9.2	**- 13.4**
Manitoba	3.3	- 9.5	- 15.9	**- 25.4**	+ 2.7	- 4.6	**- 1.6**
Prairies	32.5	- 4.3	- 16.6	**- 20.9**	- 3.7	- 9.2	**- 12.9**

[1] related to the types of crops grown and amount of summerfallow
[2] related to the adoption of reduced tillage systems

Table 5. Tillage practices on the Prairies, 1991 to 1996.

	Cultivated land (million ha)	Cropland (% of total area seeded)						Summerfallow					
		Conventional tillage		Conservation tillage		Direct Seeding		Conventional tillage		Conservation tillage		Zero Tillage	
		1991	1996	1991	1996	1991	1996	1991	1996	1991	1996	1991	1996
Soil Zone													
Brown	6.7	58	49	28	29	14	23	53	57	42	31	5	12
Dark Brown	7.1	59	40	29	35	13	26	57	55	39	37	4	9
Black	12.3	69	54	27	33	5	13	63	50	34	43	3	7
Gray	6.4	80	65	19	28	2	8	70	52	28	42	3	7
Province													
Alberta	10.6	74	59	23	32	3	10	58	51	37	38	5	11
Saskatchewan	18.6	64	45	26	33	10	22	57	55	39	37	4	9
Manitoba	3.3	67	63	28	28	5	9	73	61	24	34	3	6
Prairies	**32.5**	**68**	**53**	**25**	**32**	**7**	**16**	**58**	**54**	**38**	**37**	**4**	**9**

Changes in cropping practices including the type of crops grown and the frequency of summerfallow can also have a significant and, in some cases, a dramatic effect on wind erosion. According to census data, the change in cropping systems on the prairies from 1981 to1996 was comprised of about a 10 % decrease in summerfallow and a compensating increase in oilseeds, pulse crops and forages, with cereals remaining relatively stable (Table 6).

Table 6. Change (%) in cropping practices on the Prairies, 1981 to 1996

	Cultivated Land (million ha)	Fallow	Cereal	Oilseed	Pulse	Forage
Soil Zone						
Brown	6.7	**- 7.8**	**-2.5**	**24.1**	**+ 1.4**	**+ 1.4**
Dark Brown	7.1	**- 14.2**			**+ 3.6**	**+ 1.5**
Black	12.3	**- 10.1**			**+ 2.2**	**+ 3.0**
Dark Gray/Gray	6.4	**- 9.4**			**+ 2.2**	**+ 7.8**
Province						
Alberta	10.6	**- 7.6**	**- 3.9**	**18.2**	**+ 1.1**	**+ 5.1**
Saskatchewan	18.6	**- 12.9**	**+ 0.6**		**+ 3.2**	**+ 2.2**
Manitoba	3.3	**- 5.3**	**+ 1.9**		**+ 1.4**	**+ 4.3**
Prairies	32.5	**-10.4**	**-0.7**	**+ 6.5**	**+ 2.3**	**+ 3.3**

It is interesting to note that the reduction in summerfallow is slightly greater in Saskatchewan than in Manitoba and Alberta. And while this no doubt reflects the proportionally greater use of summerfallow in Saskatchewan, it is also likely related to the greater use of direct seeding, as one of the side-benefits of direct seeding is a reduced reliance on summerfallow due to improved moisture use efficiency. The area of forage crops also increased slightly between 1981 and 1996, with the greatest increase occurring in the Dark Gray and Gray soil zones where climate conditions favour forages compared to annual crops. A notable exception, however, was the shift from annual crops to perennial forage in some of the highly erodible sandy areas of southern Saskatchewan and Alberta prior to 1991. This shift, which reduced the erosion risk in those areas by as much as 20 to 25%, was presumably in response, at least in part, to government programs such as the Permanent Cover Program which paid producers to convert marginal erosion-prone annual crop land into pasture or permanent forage. Overall the change in cropping systems from 1981 to 1996 resulted in about a 5 to 10 % decrease in the wind erosion risk.

It is generally agreed that the recent trend toward reduced tillage and less summmerfallow on the prairies is due to a several factors in addition to the obvious soil conservation benefits, including reduced labour, energy and machinery costs, increased moisture use efficiency, higher yields, and better weed control. These benefits, coupled with the fact that only about half to the area is currently under a reduced tillage regime, would suggest that the current trend is likely to continue. And if true, particularly in the Brown and Dark Brown soil zones where the wind erosion risk is highest, then the wind erosion risk will decline further. Nonetheless it must be kept in mind that over past 15 years climate conditions have been abnormally favourable throughout a large part of the Brown and Dark Brown soil zone and that a return to more normal or perhaps even abnormally dry conditions could see a return to shorter rotations and more summerfallow. Economic conditions that favour the production of low residue oilseeds and pulse crops in place of cereals, or a significant increase in herbicide-resistant weeds could also slow or perhaps even reverse the trend.

In the Black and Gray soil zones, further significant reductions in wind erosion risk are less likely. The area of summerfallow there is already minimal, accounting for only about 10 % of the total cropland, and while summerfallow declined significantly from 1981 to 1991, there was only a minimal decline from 1991 to 1996 suggesting that further declines are unlikely. In fact in Black soil zone in Manitoba, summerfallow actually increased slightly from 1991 to 1996. Moreover, because of the generally low inherent wind erosion risk, long rotations and high crop yields in this region, residues levels are often sufficient to control erosion even with conventional tillage. Consequently, with the exception of a few sandy erosion-prone soils, the trend toward reduced tillage, while generally enhancing crop residue levels, may not necessarily much effect the wind erosion risk.

Conclusions

1. Over two thirds of cultivated land in the prairie region is at significant risk to wind erosion without the use of soil conservation practices, although under current management only about 5 to 10 % is at significant risk. Nonetheless, this still represents and area of over 2 million hectares.

2. Implementation of reduced tillage technologies coupled with a significant decline in the use of summerfallow in the prairie region from 1981 to 1996 has resulted in about a 30 % decline in the wind erosion risk.

3. In 1981 over 15 % (5 million ha) of the cultivated land in the prairie region was considered at high to severe risk to wind erosion, whereas by 1996 it had been reduced to slightly over 5% or about 2 million ha. Improvements were greatest where sandy, highly erodible lands were converted from annual crops to perennial forages.