TILLAGE EROSION IN THE TOPOGRAPHICALLY, COMPLEX LANDSCAPES OF THE CANADIAN PRAIRIES

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ABSTRACT

In topographically complex landscapes, tillage erosion causes the progressive downslope movement of soil. Tillage practices which, in time, cause more soil to be translocated downslope than upslope result in the loss of soil from upper slope landscape positions and the accumulation of soil in lower slope positions. This paper examines the significance of tillage erosion and the impacts agriculture and the environment.

Keywords: Soil erosion, Tillage erosion

INTRODUCTION

In topographically complex landscapes, tillage erosion causes the progressive downslope movement of soil. Tillage practices which, in time, cause more soil to be translocated downslope than upslope result in the loss of soil from upper slope landscape positions and the accumulation of soil in lower slope positions.

Tillage erosion is described in terms of tillage erosivity and landscape erodibility. Large, aggressive tillage implements, operated at excessive depths and speeds are more erosive, with more passes resulting in more erosion. Landscapes that are very topographically complex (short, steep, diverging slopes) are more susceptible to tillage erosion.

Visual evidence of tillage erosion includes: loss of organic rich topsoil and exposure of subsoil at the summit of ridges and knolls; and undercutting of field boundaries, such as fencelines and terraces, on the down-slope side and burial on the up-slope side.

SIGNIFICANCE OF TILLAGE EROSION

The maximum rate of soil loss by tillage erosion observed within topographically complex landscapes is typically between 15 and 150 t ha^{-1} yr^{-1} (Lobb et al., 1995; Lobb and Kachanoski, 1999a). Such rates are several times what is considered sustainable for crop production. Tillage erosion has been found to account for the majority of soil loss observed on convex slope positions. Estimates made using resident ^{137}Cs indicate that between 70 and 100% of soil lost on these slope positions is the direct result of tillage erosion (Lobb et al., 1995; Lobb and Kachanoski, 1999a).

Using the tillage translocation data of Lobb et al. (1995, 1999), the Tillage Erosion Risk Indicator (TERI) model (Lobb, 1997), 1996 agriculture census data, and landscape data from the National Soil Data Base, King et al. (2000) concluded that approximately 50% of the cropland in the prairies was subjected to unsustainable levels of tillage erosion (Table 1). A similar assessment was made for water erosion by Shelton et al. (2000) and it was found that only approximately 12% of the cropland was subjected to unsustainable levels of water erosion. Within any given piece of cropland, water erosion results in soil losses from approximately 50% of the area (back and foot slopes) and tillage erosion results in soil losses from approximately 25% (shoulder slopes and crests). These studies found that the risk of water erosion and the risk of tillage erosion have decreased between 1981 and 1996. This decrease is due to the adoption of conservation tillage practices. The analyses by King et al. (2000) and by Shelton et al. (2000) were based on the assumption that the area in conservation tillage in 1981 was negligible. The adoption of conservation tillage since 1996 is believed to be minimal; consequently, soil degradation by tillage erosion in the prairies remains widespread.

AGRICULTURAL AND ENVIRONMENTAL IMPLICATIONS

Severity and extent of tillage erosion. Tillage erosion occurs to some degree in all topographically complex cultivated landscapes. Although tillage erosion research has focused on "hilly" landscapes, tillage erosion can also be significant on "flat" landscapes. The Red River Valley, a flat landscape, is topographically complex even though its relief can be less than 2 m in 1,000 m. On such a flat landscape, tillage implements with widths in excess of 20 meters are commonly found. Surface drainage enhances the topographic complexity of these landscapes. The infilling and required regular cleaning of these drains is the consequence of tillage erosion. Tillage erosion can be severe on simple hillslopes that are dissected with terraces, buffer strips, etc. Field boundaries dissect slopes, resulting in soil loss by tillage erosion at the upper slope of each boundary and soil accumulation at the lower slope. The total soil loss on a slope increases by a factor equal to the number of dissections.

Tillage erosion occurs under any form of tillage. Consequently, it is possible that unsustainable levels of tillage erosion may exist even when conservation tillage systems are used. The chisel plough and secondary tillage implements such as the tandem disc can be equally as erosive as the mouldboard plough (Lobb et al. 1995, 1999). Even though the mouldboard plough buries more crop residue it was found to result in less net translocation of soil. As long as tillage is used, there is the potential for the severity and aerial extent of this erosion to increase. ***Impacts on soil-landscape variability.*** Tillage translocation and tillage erosion have contrasting effects on the spatial variability of soil. Tillage erosion increases the variability of soil properties within landscapes. As tillage erosion progresses, the properties of the subsoil are expressed on convex areas. In some cases, it is possible to see 'halos' in hilly landscapes where the white/yellow soil material from the C horizon is exposed on the hilltops, the black/brown soil material from the A horizon is exposed at the base of the hills, and the red/brown soil material from the B horizon is exposed on the sides of the hills. Tillage translocation reduces variability by spreading soil over great distances. Soil can be mixed over a length in excess of 3 m per sequence of tillage (Lobb et al., 1995); in fact, McLeod et al. (2000) has shown that a single pass of a cultivator sweep operated at 15 cm depth and 5 km hr^{-1} can translocate soil as much as 4 m. Sibbesen (1986) demonstrated the significance of the dispersion of soil and its constituents and developed a model to predict the dispersion for long-term small-plot research. The contrasting effects of tillage on spatial variability of soils was recognised by Kachanoski et al. (1985).

Impact of tillage erosion on crop production. Yield losses of 40-50 % have been associated with severely eroded convex landscape positions (Lobb et al., 1995). Assuming that the average annual yield loss on convex slopes is one-half of this value, that this yield loss results from tillage erosion, and that convex slope positions account for about 25 % of the landscape of a region, tillage erosion can be expected to cause about a 5 % annual loss in crop production. Such losses represent tens of millions of dollars in intensive agricultural regions. The increased soil variability caused by tillage erosion results in less efficient use of production inputs and, therefore, increased production costs. Less efficient use of nutrients and pesticides results in increased risk of environmental contamination. Soil losses associated with tillage erosion may be the major cause for the need to manage soil-landscapes variably, i.e. precision farming.

Impacts on wind and water erosion. Tillage erosion can increase soil erosion by wind and water by exposing subsoil that is highly erodible to wind and water. Tillage erosion acts as a delivery mechanism for water erosion, transporting soil to areas of concentrated overland water flow, i.e. rills and convergent landforms. This delivery process has been examined by Lobb and Kachanoski (1999a). Tillage erosion may be more significant than inter-rill erosion as a delivery mechanism for rill erosion.

Impacts on other biophysical processes. Tillage erosion has potential significant impacts on biophysical processes other than crop production and erosion by wind and water. The loss of topsoil that occurs on the upper slope landscape positions and the consequential changes in soil properties affect the hydrology of the landscape. Typically, the infiltration capacity of these eroded soils is reduced resulting in increased overland water flow to lowerslope positions. Furthermore, these eroded soils typically have a reduced water holding capacity. Changes in soil moisture conditions affect changes in soil temperature. In the process of redistributing soil within the landscape, tillage erosion depletes nutrients such as carbon and nitrogen on convex slope positions and accumulates and buries nutrients on concave slope positions. These combined changes can be expected to have significant impacts on biophysical processes such as the production and emission of the greenhouse gasses.

Estimation of soil erosion . Changes in the concentration of soil constituents, such as organic matter and resident ^{137}Cs, are commonly used as indicators of soil erosion. However, a decrease in concentration can occur at a specific point in the landscape without a change in soil mass at that point. The concentration of a constituent in the soil translocated into a point by tillage is not necessarily the same as that translocated out from that point. As a consequence of tillage translocation, changes in concentration reflect soil losses at that point and the surrounding area. This phenomenon, its impact on the estimation of soil erosion using ^{137}Cs and improved methods to estimate soil erosion have been described by Lobb et al. (1995), Lobb and Kachanoski (1999b).

Soil erosion modelling. Soil erosion models that do not include the process of tillage erosion do not adequately represent erosion on cultivated land with complex topography. Schumacher et al. (1999) have demonstrated the combined use of water and tillage erosion models. In comparison to wind and water erosion models, tillage erosion models are more universal because the erosive agent is not related to climate.

Soil conservation planning and policy. Preventative and corrective soil loss measures that do not include the reduction of tillage erosion will not be effective in controlling soil loss on convex upper slope positions of cultivated landscapes. Given that it is these areas that are most severely eroded, it would be negligent to ignore tillage erosion. A fully integrated approach to soil conservation is required. Several soil conservation practices are identified below.

For the most part, agricultural soil conservation policies and programs have had two primary objectives, to reduce soil losses within farm fields and to reduce sediment delivery from farm fields. Many soil conservation policy and programs, such as the National Soil Conservation Program, have been based on the presumption that the process responsible for off-site sediment delivery (wind and water erosion) is the same erosion process that is responsible for losses in crop productivity; therefore, practices that reduce sediment delivery to acceptable levels should result in sustainable levels of soil erosion within fields. However, where tillage erosion operates within a landscape, unsustainable levels of soil erosion may exist within a field even though acceptable levels of wind and water erosion are achieved.

SOIL CONSERVATION PRACTICES

The most effective way to arrest tillage erosion and its adverse impacts is to eliminate tillage; however, it is not always possible to do so. Where tillage is necessary, there are several practices that can be used to reduce tillage erosion:

Reduce tillage frequency and intensity. All unnecessary tillage operations should be eliminated from a tillage system. Tillage should be done when soil conditions are suitable to avoid correctional tillage. The depth and speed at which a tillage implement is operated affect its intensity and, therefore, its erosivity. Tillage implements should be operated at minimum recommended depths and speeds.

Reduce tillage speed and depth variability. Operators should try to maintain a constant tillage depth and tillage speed, even in topographically complex landscapes. To maintain constant operating depth and speed in such landscapes requires more power from a tractor than would be recommended for a specific tillage implement by an equipment manufacturer/dealer. Implements are rated for required horsepower assuming that they will be operated on level ground. Operation in excess of recommended depth and speed results in greater translocation variability, and, consequently, results in greater tillage erosion.

Reduce the size of tillage implements. The larger the implement is relative to landform size, the more rapid the landscape is levelled. Tillage implements that are very long and/or very wide should be avoided on landscapes that are highly erodible to tillage.

Use less erosive tillage patterns. Where possible, tillage should be conducted along the contour of the landscape. This will reduce the variation in tillage depth and speed and, consequently, reduce tillage erosion. Where tillage is conducted on the contour, a reversible or rollover mouldboard plough can be used to throw the furrow upslope on every tillage pass, leaving a back-furrow on the uppermost slope position. Moving soil upslope with the mouldboard plough offsets the progressive downslope movement of soil by other implements in the tillage system (Mech and Free, 1942). Reversible and rollover ploughs are not commonly used. Farmers who use these one-way ploughs typically throw the furrow downslope to leave a smoother surface for subsequent field operations and to reduce draught requirements. However, this is not always the case; farmers who have recognised that tillage causes their topsoil to accumulate at the bottom of slopes regularly, if not always, throw the furrow upslope. Some farmers have been observed to take a more aggressive approach; ploughing on an angle to the contour to throw the furrow directly up the slope. However, ploughing on an angle to the contour will reduce the effectiveness of plough ridges in controlling overland water flow and water erosion. Ploughing on an angle to the contour may be necessary on steep slopes. Mech and Free (1942) noted that difficulties may be experienced turning furrows upslope while contour tillage if slope gradients exceed 17%.

Restore severely degraded land. Where it is feasible, areas that are severely degraded by tillage erosion should be restored by returning the topsoil that has accumulated in slope concavities. This should be followed by the implementation of practices to reduce tillage erosion. The Innovative Farmers Association of Ontario (Aspinall, 1997) and the Chinook Area Research Association (CARA,1996) have evaluated this restoration practice and have found it to be an effective method of regaining lost crop production potential. In Europe in the 1940s, Lowdermilk (1953) observed the common practice of hauling topsoil from the base of slopes back to the top "to compensate for the downslope movement of soil under the action of ploughing".

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Table 1. Risk of tillage erosion on Canadian cropland† in 1981 and 1996

Province§	Cropland¶ (10^6 ha)	Proportion of cropland (%) in various risk classes									
		Tolerable‡		Low‡		Moderate‡		High‡		Severe‡	
		1981	1996	1981	1996	1981	1996	1981	1996	1981	199
B.C.	0.5	30	50	42	36	28	14	<1	0	0	0
Alberta	10.6	47	62	24	19	26	19	3	0	0	0
Saskatchewan	18.	29	35	14	19	52	46	5	0	0	0
Manitoba	4.9	22	44	53	38	24	18	1	0	0	0
Ontario	3.4	33	41	21	35	43	24	3	<1	0	0
Quebec	1.6	68	75	21	16	11	9	0	0	0	0
New Brunswick	0.	33	38	26	32	32	21	3	8	6	1
Nova Scotia	0.1	40	66	52	28	8	6	0	0	0	0
P.E.I.	0.1	50	50	29	30	10	10	11	10	0	0
Canada	40.1	35	46	23	23	38	31	4	<1	<1	0

† includes seeded and summer fallow (tilled but not seeded); ‡ Tolerable (sustainable) < 6 t ha^{-1} yr^{-1}; Low = 6-11 t ha^{-1} yr^{-1}; Moderate = 11-22 t ha^{-1} yr^{-1}; High = 22-33 t ha^{-1} yr^{-1}; Severe > 33 t ha^{-1} yr^{-1}; § Newfoundland excluded based on the small area of cropland; ¶ average values for 1981 and 1996

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