Soil Nutrient Redistribution by Wind Erosion

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Problem

It is generally believed that soil erosion is the greatest single factor causing loss of soil productivity. However, the exact nature of these losses in terms of the concentrations of nutrients removed in windblown sediment compared to the sediment's parent soil has not been adequately quantified.

Literature Review

Wind erosion is one of the main forms of soil degradation on the semi-arid Canadian prairies[5]. Although the transport capacity of wind is much less than that of water, water erosion is restricted to sloping land while wind erosion can remove the fine nutrient-rich particles from the soil's entire surface. Movement of plant-available nutrients due to wind erosion is of special concern because it may affect long-term soil productivity. There is also the potential for nutrient-rich windblown material to deposit in roadside ditches, drainage ditches or irrigation canals with repercussions for water quality and aquatic weed growth. Generally, windblown sediment is more fertile than the surface material of the parent soil[6,7]. Due to sorting by wind, the surface soil texture becomes coarser and organic matter declines. These changes occur slowly, requiring years to clearly reveal their magnitude, especially on cropland where tillage mixes the upper soil layer.

Study Description

In 1990 and 1993, fully instrumented wind erosion sites were established near Lethbridge in southern Alberta as validation sites for the new process-based WEPS (Wind Erosion Prediction System) model[3]. The aim of the WEPS validation sites was to quantify the mass of soil material moving during wind erosion events on fallow land in southern Alberta. This presented a unique opportunity to examine the quality characteristics of windblown sediment trapped during fallow erosion events, and compare them with soil surface nutrient contents.

Site 1 was established in November 1990, on a Dark Brown Chernozemic clay loam soil about 15 km southeast of Lethbridge, Alberta[4]. The study site consisted of a single circular plot, 200 m in diameter with an area of 3.14 ha. The circle was cultivated with an offset disk to create an erodible surface surrounded by a non-erodible surface protected by direct seeded winter wheat. Thirteen clusters of Big Spring Number Eight windblown sediment samplers[1] were installed on the circle in January 1991. A cluster comprised an upright with four samplers positioned approximately 10, 25, 50, and 100 cm above the soil surface. Six clusters were located in each of two concentric circles at 60 and 95 m from the centre of the circle.

Site 2 was selected in April 1993, about 3 km southwest of Site 1 on a similar soil type, and instrumented in the same configuration.

At Site 1, 16 erosion events were monitored from April 1991 to April 1992. Total soil loss was 152.2 t/ha. More detailed information on soil losses from Site 1 was reported previously[4]. At Site 2, 13 erosion events were monitored between February and April 1994, with a total soil loss of 56.6 t/ha. Soil losses were calculated by the method of Fryrear et al.[2]

Only windblown sediment trapped at the 25-cm height was analyzed for this particular aspect of the study. This represented material that was capable of moving in saltation or in suspension for very short distances. At Site 1, 18 soil surface samples were taken on March 31, 1992, at the 0 to 2.5 cm depth on a west-east transect across the circle. The chemical and textural properties of these samples were compared with the properties of the windblown sediment trapped at the 25-cm height from five events in December 1991 and eight events in April and May 1992. At Site 2, surface soil samples were taken at the 0 to 2.5 cm depth on March 14, 1994. Twenty samples were taken on a west-east transect at 10-m intervals across the circle, and these were compared with properties of windblown sediment trapped at 25 cm from the February to April 1994 events.

Windblown sediment trapped at 25 cm and soil surface samples were analyzed for total C, total N, inorganic C, organic C (total less inorganic C), C/N ratio, total P, available P, available NO_3-N and NH_4-N, inorganic N (NO_3-N plus NH_4-N), exchangeable Ca, Mg, and K, and particle size analysis. An enrichment ratio (ratio of nutrients in sediment to that in the source soil) is often used as an index of soil productivity loss. Enrichment ratios greater than 1 imply that the windblown sediment is enriched compared with the source soil. Ratios less than 1 imply that the sediment is depleted compared with the source soil.

Major Findings

For the December 1991 events at Site 1, windblown sediment trapped at 25 cm showed enrichment ratios of 1.03 to 1.06 for total N compared with the soil surface on March 31, 1992 (Table 1). Organic C content of windblown sediment was slightly lower than that of surface soils (enrichment ratios less than 1, Table 1). Available P showed no consistent trend with enrichment ratios varying from 0.85 to 1.04. Inorganic N was much higher in the surface soil than in the windblown sediment as shown by enrichment ratios well below 1 (Table 1). With exchangeable bases, there was no definitive trend in enrichment ratio. Ca showed slight enrichment for four of the five events. Mg and K both had average enrichment ratios of 0.94.

The windblown sediment trapped at 25 cm for the December 1991 events had lower sand content, higher silt content and lower clay content than that of the surface soil from March

31, 1992 (Table 1). The enrichment of windblown sediment with silt-size particles rather than clay-size particles suggests that the silt-size particles (2 to 50 µm in diameter) were transported at 25 cm above the soil surface while most of the clay-size particles (less than 2 µm diameter) were transported at heights greater than 25 cm or within microaggregates at the 10-cm height.

Table 1. Enrichment ratios (concentrations in windblown sediment trapped at 25-cm height/concentrations in surface soil on March 31, 1992) for the December 1991 events at Site 1

Soil characteristic	Enrichment ratios for windblown sediment					Surface soil* Mar. 31, 1992
	Dec. 6, 1991	Dec. 9, 1991	Dec. 10, 1991	Dec. 11, 1991	Dec. 16, 1991	
Total N	1.03	1.03	1.05	1.04	1.06	1.44 g/kg
Organic C	0.97	0.96	0.97	0.97	1.00	15.1 g/kg
Available P	1.04	1.02	0.99	0.85	0.85	13.1 µg/g
Inorganic N	0.43	0.47	0.46	0.47	0.64	49.3 µg/g
Ca	0.87	1.01	1.03	1.04	1.07	15.5 cmol/kg
Mg	0.78	0.92	0.95	1.00	1.03	3.7 cmol/kg
K	0.92	0.93	0.91	0.95	0.99	1.04 cmol/kg
Sand	0.92	0.98	0.97	0.99	0.93	32.0%
Silt	1.34	1.30	1.31	1.32	1.39	29.4%
Clay	0.81	0.79	0.79	0.76	0.76	38.6%

* Surface soil: 0 to 2.5 cm depth

Enrichment ratios for total N in windblown sediment trapped at 25 cm from the April and May 1992 events at Site 1 versus surface soil from March 31, 1992 varied from 1.05 to 1.41 (Table 2). For organic C, the enrichment ratio varied from 0.93 to 1.43. Available P enrichment did not occur except for the April 4, 1992 event (Table 2). As in the December 1991 events, windblown sediment showed an increased silt content and a decreased clay content compared with that of the surface soil (Table 2).

At Site 2, the average total N concentration in windblown sediment trapped at 25 cm in the February to April 1994 storms showed enrichment ratios from 1.06 to 1.12 (Table 3). The enrichment ratio for organic C averaged 1.05. Total P showed an enrichment ratio of about 1.13 to 1.20, while available P was much higher in windblown sediment than in surface soil (enrichment ratios of 1.68 to 1.75, Table 3). Compared with the surface texture from March 14, 1994, windblown sediment was enriched in clay and not sand or silt (Table 3). The increase in clay content in windblown sediment was much higher than that observed at Site 1. Because the erosion event of February 15, 1994 was only the third one at Site 2, the enrichment ratio of 1.37 for clay may be related to the capture of intact microaggregates containing embedded clay-sized particles.

Table 2. Enrichment ratios (concentrations in windblown sediment trapped at 25-cm height/concentrations in surface soil on March 31, 1992) for the April and May 1992 events at Site 1

Soil characteristic	Enrichment ratios for windblown sediment								Surface soil*, Mar. 31, 1992
	Apr. 3, 1992	Apr. 4, 1992	Apr. 5, 1992	Apr. 9, 1992	Apr. 13, 1992	Apr. 18, 1992	Apr. 27, 1992	May 11, 1992	
Total N	1.13	1.05	1.07	1.21	1.13	1.06	1.10	1.41	1.44 g/kg
Organic C	1.02	0.93	0.97	1.07	1.01	0.91	1.05	1.43	15.1 g/kg
Available P	0.98	1.05	0.97	-	0.89	0.65	-	-	13.1 µg/g
Sand	1.00	1.05	1.04	-	-	-	-	-	32.0%
Silt	1.08	1.06	1.25	-	-	-	-		29.4%
Clay	0.94	0.91	0.78	-	-	-	-	-	38.6%

* Surface soil: 0 to 2.5-cm depth

Table 3. Enrichment ratios (concentrations in windblown sediment trapped at 25-cm height/concentrations in surface soil on March 14, 1994) for February-April 1994 events at Site 2

Soil characteristic	Enrichment ratio for windblown sediment				Surface soil*, Mar. 14, 1994
	Feb. 15, 1994	Mar. 13, 1994	Mar. 21, 1994	Apr. 13, 1994	
Total N	1.06	1.12	1.09	1.06	1.76 g/kg
Organic C	0.99	1.07	1.08	1.06	17.2 g/kg
Available P	-	1.68	1.71	1.75	9.2 µg/g
Total P	-	1.13	1.20	1.20	0.3 g/kg
Sand	0.82	-	-	0.86	34.3%
Silt	0.82	-	-	1.08	31.9%
Clay	1.36	-	-	1.07	33.8%

* Surface soil: 0 to 2.5-cm depth

In general, total N and organic C had enrichment ratios greater than 1. Enrichment ratios were higher for total N than organic C, which suggests that the fine humus or most valuable part of the soil had been removed in the windblown sediment. Since total N and organic C decrease rapidly with soil depth, the data provide further evidence that every effort should be made by producers and government agencies to prevent further erosion of the thin layer of surface soil that ensures the future sustainability of agriculture on the semi-arid Canadian prairies. Rebuilding eroded soils to their former productive capacity is a slow and costly process.

Applied Questions

Can windblown sediment have higher enrichment ratios than those of the present study?

Yes. The enrichment ratio is very much related to the sample depth of the surface soil that is compared with the windblown sediment. Since nutrient contents decline rapidly with soil depth, thicker sampling increments (e.g. 0 to 5 cm or 0 to 7.5 cm) allow a dilution of nutrient concentrations and hence higher enrichment ratios when compared with windblown sediment originating from the top few millimetres of the surface layer.

Why did windblown sediment at Site 2 have a higher clay content than the surface soil from where it originated?

This is because clay particles are smaller than sand and silt particles, and are more easily transported by the wind. The higher clay content may also reflect the capture of microaggregates containing embedded clay particles. The smaller clay particles also contain disproportionately greater amounts of plant nutrients since soil organic matter and clay particles are closely bound. With continued erosion, the soil surface becomes more coarse as the clay is removed and the sand particles are left behind.

Does wind erosion represent a net loss of soil nutrients per se?

Generally, most wind erosion events redistribute nutrients within the landscape, rather than "exporting" them very long distances. Most of the eroded material is deposited within a short distance of the source, for example, in standing stubble on the downwind side of a fallow strip, in roadside ditches or in waterways. However, the reduction in productivity from topsoil loss is difficult and costly to correct.

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