Tillage Translocation and Tillage Erosion within Intensive Potato Production Systems in Atlantic Canada

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Background

Soil erosion is the result of three processes: wind, water and tillage. Tillage has been known to influence the magnitude of wind and water erosion processes for many years. However, recent studies have demonstrated that the direct movement of soil by tillage operations is, in and of itself, a significant erosive process, distinct from wind and water erosion (e.g., Lindstrom et al. 1990; Govers et al. 1994; Lobb et al. 1995; Lobb et al. 1999).

Tillage erosion occurs whenever tillage operations cause more soil to be translocated out of an area of a field than is translocated into that area, and is typically characterized by soil loss from convexities and soil accumulation in concavities. Tillage erosion is a function of both the *erodibility* of a landscape and the *erosivity* of the tillage system used on that landscape. In Canada, soil degradation by tillage erosion is of greatest concern in regions where intensively tilled crop production is practiced on topographically complex landscapes – such as in the potato growing regions of Atlantic Canada (Fig. 1). To date, however, tillage erosion experiments conducted in Canada represent only conventionally tilled corn-based production in Ontario and conventionally tilled cereal-based production in Saskatchewan and Manitoba.

Objectives: The objective of this project was to generate tillage translocation and erosivity values for implements common to conventionally and conservation tilled potato production systems in the eastern Canadian province of New Brunswick. In the process, the study: (i) examined the contribution of primary, secondary and tertiary tillage operations towards the overall erosivity of potato production; and (ii) improved current knowledge regarding tillage translocation and slope gradient (θ), slope curvature (ϕ), initial soil conditions, and tillage depth (D_T) and speed (S_T).

Fig. 1. Severely eroded landscape in the potato producing region of New Brunswick (note the exposed bedrock on the convex slope positions resulting from tillage erosion).

Materials and Methods

• The field site was located 15 km south of the town of Grand Falls, New Brunswick, Canada (46º54'N, 67º47'W).

• Tillage translocation and erosion were measured for each implement using methods established by Lobb et al. (2001) (Figs. 2, 3 & 4):
  • a plot of soil was labelled with a tracer [dyed aquarium gravel, 6 – 13 mm (1/4" – 1/2") in diameter], and tracer redistribution along the path of tillage was used to generate a summation curve to calculate mean soil movement in the direction of tillage.
  • from the summation curve, the mean translocated distance of the tilled layer (T_L), and the mass of translocated soil (T_M) were calculated.

• Tillage practices for the potato crop were conducted up and down the hill (Figs. 5 & 6) and separated into three phases:
  • primary fall tillage (conventional vs. conservation)
  • secondary spring tillage (conventional vs. conservation)
  • tertiary tillage – the soil disturbance associated with (i) planting, cultivating and hilling, and (ii) harvesting operations (Table 1).

Fig. 2. Box plots & plates.

Fig. 3. Example of a Harvester field plot during plot establishment.

Fig. 4. Sampling in the field.

Table 1: Description of the primary, secondary and tertiary tillage implements used in this project

Operation	Implement	Tool arrangement	Tool spacing (cm)	D_T (cm)	S_T (km h^{-1})
Primary (fall)	Mouldboard plough (MP)	Six high speed bottoms	40.6	15 – 20	6 – 8
	Chisel plough (CP)	Three rows, 2 to 4 10-cm twisted shanks/row	30.5	15 – 20	6 – 8
Secondary (spring)	Offset disc (OD)	Two rows, 36-cm diameter discs	30.5	10 – 15	6 – 8
	Vibrashank (VS)	Two rows (1 & 3), 13 to 14 2.5-cm C-tine shanks/row; middle row, 12 20-cm sweeps; rolling baskets behind	17.8	15 – 20	6 – 8
Tertiary (spring)	Planter (PCH sequence)	Four potato rows – discs open and close seed row, fertilizer placed below seed	86.4	2.5 – 5 (seed), 5 – 10 (fertilizer)	6 – 8
Tertiary (summer)	Row Cultivator (PCH sequence)	Four potato rows – two 2.5-cm cultivator shanks (outside potato rows 1 and 4) and five 2.5-cm cultivator shanks (between potato rows), no "horsehoes"	86.4	15 – 20	4 – 5
Tertiary (summer)	Row Cultivator & Hiller (PCH Sequence)	Four potato rows – 2 (outside rows) and 4 (inside rows), 2.5-cm cultivator shanks and "horsehoe" hillers	86.4	10 – 15 (hiller), 15 – 20 (cultivator)	5 – 6
Tertiary (fall)	Harvester (HARV)	Two potato rows dug per pass	86.4	5 – 10 below bottom of hill	1.5 – 2.5

Fig. 5. Example of tertiary tillage - hilling operation (PCH sequence).

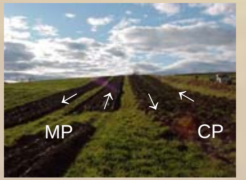

Fig. 6. After primary tillage operations in the fall (mouldboard and chisel plough).

Conclusions

Our results show that conservation, secondary and tertiary tillage operations result in significant soil displacement and can be equally as erosive as conventional primary tillage implements, such as the mouldboard plough. Our results also show that relationships between T_L, T_M and topography are improved by including slope curvature. We recommend that curvature be included in any future tillage translocation and erosion modelling. The effect of slope gradient and slope curvature on tillage translocation will be further examined to improve the tillage erosion model developed by Lobb et al. (1999). This model will be used to predict tillage erosion across the landscape for a full sequence of conventionally and conservation tilled potatoes. It is clear that soil movement by tillage operations must be considered when choosing implements and developing beneficial management practices with regards to reducing the negative impacts of soil erosion within cropping systems in New Brunswick and across Canada.

Results

• After one pass, each primary, secondary and tertiary tillage operation moved soil at least 3 m, with the farthest translocated distances ($T_{L(Max)}$) observed for the PCH sequence (up to 24 m), CP and HARV (Table 2).

• The mass of translocated soil (T_M) was greatest for the PCH sequence, followed by the HARV, CP, MP, OD and VS (Table 2).

• A direct relationship was observed between T_L and T_M and slope gradient (θ) for the CP, MP, OD and PCH sequence. Linear regression functions were further improved after including slope curvature (ϕ) (Table 3).

• Overall, the potential for tillage erosion ($T_M β$) was high for the PCH sequence, HARV, CP, MP and OD (Table 3):
  • soil losses > 100 Mg ha^{-1} $pass^{-1}$ were measured for both the MP and CP on shoulder slope landscape positions.

Table 2. Summary data for the primary, secondary and tertiary tillage implements

Operation	Implement	Tillage direction	# plots	S_T (km h^{-1})	D_T (m)	$T_{L(Max)}$ (m)	T_L (m)	T_M (kg m^{-1})	Tracer recovery (%)	Error (%)
Primary (fall)	Mouldboard plough (MP)	Upslope	7	4.8	0.17	1.59	0.116	27.4	98.3	14.4
		Downslope	7	7.8	0.18	2.37	0.242	59.2	98.1	13.1
		Mean		**6.3**	**0.18**	**1.98**	**0.179**	**43.3**	**98.2**	**13.8**
	Chisel plough (CP)	Upslope	7	6.0	0.16	4.51	0.224	48.2	98.1	21.8
		Downslope	7	7.6	0.17	5.31	0.358	80.7	97.1	15.4
		Mean		**6.9**	**0.16**	**4.91**	**0.291**	**64.4**	**97.6**	**18.6**
Secondary (spring)	Offset disc (OD)	Upslope	4	5.3	0.09	1.80	0.120	11.7	96.2	27.2
		Downslope	5	7.8	0.13	3.44	0.335	53.7	97.3	9.2
		Mean		**6.7**	**0.11**	**2.71**	**0.239**	**35.0**	**96.8**	**17.2**
	Vibrashank (VS)	Upslope	5	6.0	0.15	3.44	0.190	35.4	98.6	9.3
		Downslope	5	6.8	0.15	4.40	0.186	34.3	98.3	12.8
		Mean		**6.4**	**0.15**	**3.92**	**0.188**	**34.9**	**98.5**	**11.1**
Tertiary (spring & summer)	Planter, cultivator & hiller (PCH sequence)	Upslope	6	5.7	0.22	9.80	0.357	98.0	98.2	16.4
		Downslope	6	5.9	0.22	12.53	0.474	133.9	98.0	7.7
		Mean		**5.8**	**0.22**	**11.17**	**0.415**	**115.9**	**98.1**	**12.1**
Tertiary (fall)	Harvester (HARV)	Upslope	3	1.6	0.10	4.60	0.526	57.3	98.5	4.9
		Downslope	5	1.4	0.15	4.40	0.575	83.2	98.2	9.9
		Mean		**1.5**	**0.13**	**4.50**	**0.553**	**71.7**	**98.3**	**7.7**

Table 3. Summary of regression analysis for T_L and T_M as a function of slope gradient, and slope gradient and curvature for all primary, secondary and tertiary tillage operations

	Mouldboard Plough (MP)					Chisel Plough (CP)				
Model[a]	α	β	γ	R^2	n	α	β	γ	R^2	n
$T_L = α + βθ$	0.178	0.0063 *	-	0.42 *	14	0.290	0.0082 **	-	0.60 **	14
$T_L = α + βθ + γϕ$	0.184	0.0057 *	0.0365 *	0.60 **	14	0.282	0.0096 **	0.0455 †	0.70 **	14
$T_M = α + βθ$	42.96	1.79 **	-	0.47 **	14	64.33	1.88 ***	-	0.62 ***	14
$T_M = α + βθ + γϕ$	44.69	1.60 **	10.60 *	0.70 **	14	62.22	2.23 ***	11.43 *	0.74 ***	14

	Offset Disc (OD)					Vibrashank (VS)				
Model	α	β	γ	R^2	n	α	β	γ	R^2	n
$T_L = α + βθ$	0.235	0.0093 *	-	0.54 *	9	0.188	0.0017	-	0.03	10
$T_L = α + βθ + γϕ$	0.222	0.0074 †	-0.0663	0.66 *	9	0.210	0.0013	0.0560	0.26	10
$T_M = α + βθ$	34.19	1.75 *	-	0.46 *	9	34.87	0.30	-	0.02	10
$T_M = α + βθ + γϕ$	31.05	1.29	-15.83	0.62 †	9	39.58	0.21	11.60	0.27	10

	PCH sequence					Harvester				
Model	α	β	γ	R^2	n	α	β	γ	R^2	n
$T_L = α + βθ$	0.420	0.012 *	-	0.39 *	12	0.549	0.008	-	0.12	9
$T_L = α + βθ + γϕ$	0.352	0.007	0.054	0.46 †	12	0.591	0.008	-0.079	0.15	9
$T_M = α + βθ$	117.33	3.59 †	-	0.32 †	12	70.27	2.95	-	0.28	9
$T_M = α + βθ + γϕ$	93.46	2.10	19.02	0.39	12	89.09	3.03	-35.35	0.39	9

[a]Units for α, β, and γ vary depending on the model.
†, *, **, *** significant at $P < 0.10$, 0.05, 0.01 and 0.001 respectively.

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