Impacts of long-term intensive potato production and conservation terraces/grassed waterway on runoff hydrology and soil quality

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Abstract

Few quantitative data are available to assess impacts of agricultural cultivation and soil conservation terraces in the soil quality and runoff characteristics. Paired drainage basins were established with objectives to evaluate runoff characteristics between drainage basins with and without conservation terraces and temporal changes in selected soil physical and chemical properties in these basins and adjacent forested soils. Intensive agricultural activities increase soil bulk density and reduce depths of the Ap and B horizons as results of soil compaction during agricultural operations. Soil conservation terraces reduce runoff and soil loss by 87 and 95 %, respectively. Peak flow rate was reduced and time of concentration was increased. Terracing also makes drainage basin runoff characteristics less prone to causing flooding. On average, soil organic carbon under terracing was significantly reduced.

Key Word

Potato production, conservation terraces, soil quality.

Introduction

Sustainable agricultural production is dependent upon maintaining healthy soils with the capacity to support crop growth without resulting in soil degradation or otherwise harming the environment. However, the desire to increase crop production throughout most of the last century has placed enormous pressures on Canada's agricultural lands. There was relatively little quantitative data that could be used to assess temporal changes in the soil quality of Canada's agricultural land resources. Potato is recognized as the most important cash crop in Canada, 42% were grown in Atlantic Canada, representing farm cash receipts of $233 million yearly. Most of the land under potato production is shallow till-derived soil material on bedrock controlled rolling landscapes with slopes often ranging from 5 to 9%. Not only is the land base marginal in quality, its quality has been further deteriorating as a result of water erosion, soil compaction and loss of organic matter. As a row crop, potato production is known to be a potential source of soil degradation and in this region is affected by some of the most serious soil erosion by water in all of Canada. Soil losses in excess of 20 t/ha/yr are of major concern both economically and environmentally. The objectives of this study were to report the differences in selected soil physical, chemical and biological properties and crop yield and associated spatial patterns measured over a 10 yr period in paired drainage basins with (22-NB) and without soil conservation structure (20-NB) located in northwestern New Brunswick. The runoff characteristics of the paired basins were also evaluated.

Materials and methods

The paired drainage basins were located in the potato belt of New Brunswick along the Upper Saint John River Valley (20-NB: 47° 00' 05" N, 67° 41' 21" W at an elevation of 204 m and 22-NB: 46° 59" 24'N; 67° 39" 43W at an elevation of approximately 205 m). The soils were predominantly moderately well drained Orthic Humo-Ferric Podzols developed on coarse textured till on a rolling landscape under intensive potato production where water erosion, soil compaction and soil organic matter depletion were the dominant soil degradation problems . For Site 20-NB, a diversion on the eastern edge of the field was constructed to prevent from any external surface flow, whereas Site 22-NB was isolated on the up-slope side by a diversion that intercepted and diverted surface runoff away from the site (Figure 1).

Both sites have been in agricultural production for well in excess of 60 years. They are part of fields on a commercial potato farm and are managed in the same way as the rest of the operation. Agricultural production evolved from mixed farming for dairy and livestock (grain, forages and pasture land uses) to mixed farming coupled with some row crop production, to intensive row crop (potato) production. The crop rotation has been variable, including potato-potato-grain, continuous potato for six years, potato-grain and occasionally a forage crop. Site 20-NB was in potato 15 out of 30 years between 1960 and 1989. In 1975 a conservation system was constructed at Site 22-NB consisting of a grassed waterway in approximately the

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center of the site, collecting runoff contributed by three equally spaced diversions 62 m apart, on either side of the waterway (Figure 1). These terraces made the cultivation from up-and-down slope to contour planting. Crop grown between 1990 and 1999 for site 20-NB and 1991 to 2000 for site 22-NB is shown in Table 1.

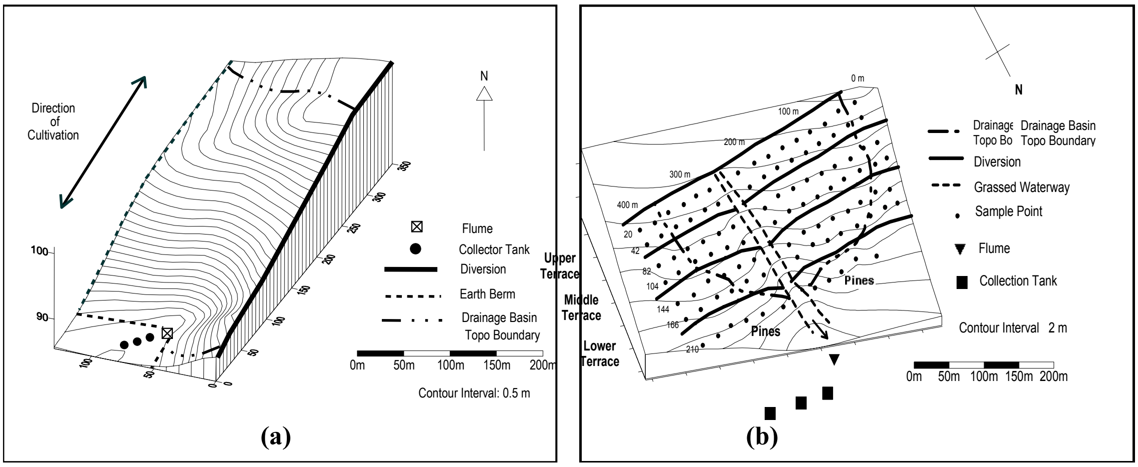

Figure 1. Layout and boundaries with location of runoff sampling instrumentation on the digital elevation model of the study sites 20-NB (a) and 22-NB (b).

Weather data (i.e., precipitation amount and intensity) from a nearby Agriculture and Agri-Food Canada research site with an automated weather station were used to calculate rainfall erosivity as per Wischmeier and Smith (1978). A topographic survey was conducted with XYZ coordinates measured on a 25 x 25 m grid at 25 m intervals along parallel transects at 10, 35, 60, 85 and 110 m running up and down slope. Locations and elevations of field boundaries, drainage features (diversions, earth berms, etc.), monitoring equipment and all major sampling grid points were established (Figure 1). Soil resources were characterized in a detailed soils map prepared at a scale of 1:1000. The sites were instrumented with a monitoring system consisting of a 3-ft H-flume and series of three above ground collector tanks for runoff monitoring and collection and the detailed are presented in Chow *et al.* (1990, 1999). Loose soil samples from 20 x 25 grids for chemistry and total carbon were collected from October 1989 and 1999 and October 1990 and 2000 for site 20-NB and 22-NB, respectively. Additional sampling for total C was conducted in 1992 and 1996 for site 20-NB and 1993 and 1996 for site 22-NB. Field-saturated hydraulic conductivity (Kfs) was measured at two depths, 12-22 cm and 27-37 cm, at 66 locations on the 25 m x 25 m grid, and at a depth of 50-60 cm at 17 of the grid points located systematically (every 4th point). A Guelph Permeameter with a 10-cm head was used to measure Kfs, as described by Reynolds (1993). Measurements were taken after crop harvest in October of each year. In years 1997-1999, Kfs measurements at similar depths were made at six sites on a 50 m interval spacing along a transect in the adjacent, undisturbed forested area.

Table 1. Cropping sequences and seasonal runoff and soil loss from site 20-NB (May 01 to Nov. 30, 1990-1999) and 22-NB (May 01 to Nov. 30, 1991-2000).

Year	Rainfall (mm)	Erosivity (MJ mm/ha hr yr	Crop		Runoff (mm)		Soil loss (kg/ha)	
			20-NB	22-NB	20-NB	22-NB	20-NB	22-NB
1990	953	2941	Rye grass		25.4		285	
1991	788	1728	Potato	Potato	202.6	41.9	15604	1678
1992	782	1840	Potato	Potato	159.2	19.6	21825	1156
1993	902	696	Barley	Barley	33.6	8.1	489	63
1994	750	1585	Potato	Potato	182	14	24852	200
1995	695	642	Barley	Potato	0.1	6.3	2	12
1996	853	1242	Clover	Barley	0	0	0	0
1997	599	856	Potato	Potato	16.3	0	704	0
1998	853	1202	Potato	Potato	14.1	0.1	1216	1
1999	809	1922	Barley	Barley	9.3	2.5	239	0
2000	763	1243		Potato		0		0
Mean	795	1445			64.3	9.3	4339	311
Potato*	754	1442			114.8	15.1	12840	607
Other crops*	853	1287			14.3	3.5	243	12
Normal	804	1276						

Results and Discussion

Runoff amount, characteristics and soil loss

Total accumulated rainfall for June 1994 was 18.8 mm. The peak discharge rate from the basin with up-and-down slope cultivation (site 20-NB) was consistently several orders of magnitude higher than that of the basin with the conservation system. Similarly, time of concentration and lag time were relatively shorter as compared to those of the basin with the conservation system (Figure 2). Time of concentration is the time required for the surface runoff from the entire basin to reach the point of measurement (i.e., time from initiation of rainfall to peak discharge) and the lag time is the time between the center of mass of the rainfall and the center of mass of the runoff. In spite of the yearly variation in rainfall erosivity, a distinctive difference in runoff and soil loss was found between the different cropping years (Table 1). Under potatoes, there was a considerable difference in runoff and soil loss between conventional (site 20-NB) and conservation systems (site 22-NB). Mean runoff from site 20-NB with up-and-down slope cultivation when planted to potatoes was 15.2 % of accumulated rainfall, whereas it was only 2.0 % from site 22-NB where potatoes were planted at a minimum grade along the contour. Mean soil loss from site 22-NB was only 4.7 % of the site 20-NB. In addition, total available N and P losses from site 22-NB were only 4.6 and 1.4 % of the site 20-NB.

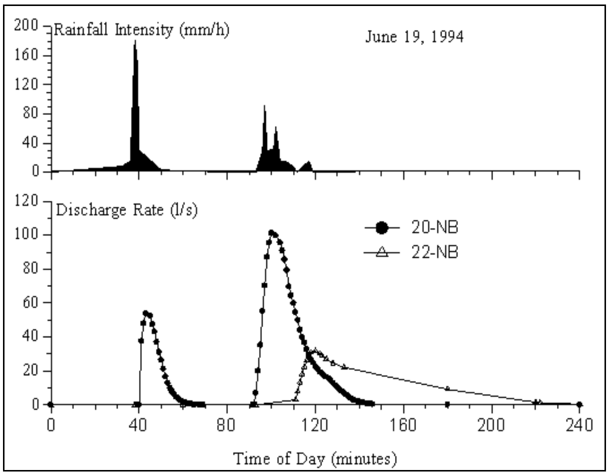

Figure 2. Runoff characteristics from a storm of June 19, 1994 under potatoes.

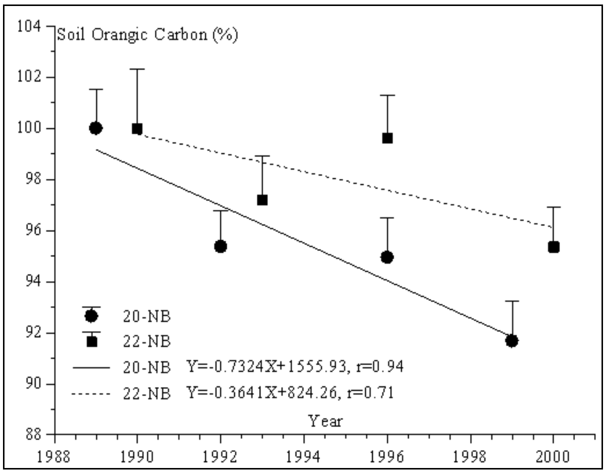

Figure 3. Soil organic carbon losses from sites 20-NB and 22-NB over a 10 year period.

Soil pedons, soil physical and chemical properties

The impacts of long-term agriculture on soil quality were analyzed by comparing horizon sequence and selected soil properties for representative cultivated and forested pedons. Results indicate that the forest soils have similar texture to that under agricultural production, but with more natural variation due to soil formation, such as the reduced sand and elevated silt contents in the Ae horizon, which were due to weathering. Using the BC horizon as a reference level, solum depth was 40 cm in the forested pedon and ranged from 18-32 cm in the cultivated pedon, given that the Bf horizon in the cultivated soil was discontinuous. The bulk density of the solum of cultivated soil was found to be approximately 45% higher (0.85 vs 1.23 g/cm^3) than the forested soil, indicating compaction and/or erosion could account for some of these differences. There was also a corresponding reduction in macro-pores from 24% in the forested solum to 14% in the cultivated solum. The impacts of soil conservation structures on soil quality were evaluated by comparing the data obtained from the paired drainage basins, sites 20-NB and 22-NB. The initial measurements of soil organic carbon (SOC) of Ap horizon from site 20-NB and site 22-NB were 20.2 and 17.0 g/kg, respectively indicated that soil conservation alone does not increase SOC of the soils (Table 2). When setting the first SOC measurement as 100%, a steady reduction of about 0.7 % per year was found from the up-and-down slope cultivation (site 20-NB), whereas a reduction of 0.36 % per year was for the terraced field with contour cultivation (Figure 3). The coefficient of determination were 0.94 and 0.71 for the site 20-NB and site 22-NB, respectively. This reduction in SOC may or may not have been exaggerated by the different cropping sequence. Changes in pH and other available nutrients in Ap and C horizons between the paired drainage basins are shown in Table 2. Because of the application of dolomitic limestone in 1990 and 1995 at a rate of 2.5 Mg/ha, pH of site 20-NB increased from 5.27 in 1989 to 5.67 in 1999. However, in 22-NB, similar amount of lime was applied in 1996 and 1998, pH

Table 2. Selected soil chemical properties between sites with (22-NB) and without (20-NB) conservation terraces Over a 10 year period.

	Means				Differences		Significances*	
	20-NB	22-NB	20-NB	22-NB	22-NB	20-NB	20-NB	22-NB
Year	1989	1990	1999	2000	1989-99	1990-2000	20-NB	22-NB
A_p (0-15 cm)								
n	93	89	93					
pH (H_2O)	5.27	5.73	5.67	89				
P (mg/kg)	319.2	263.7	334.6	5.70	0.40	-0.03	<0.001	0.68
K (mg/kg)	149.0	130.4	153.0	350.4	15.4	86.7	0.050	<0.001
Ca (mg/kg)	769.4	879.0	789.5	143.8	4.0	13.4	0.513	0.008
Mg (mg/kg)	40.0	109.5	149.6	869.5	20.1	-9.5	0.677	0.741
Total SOC (g/kg)	20.2	17.0	18.6	63.7	109.6	-45.8	<0.001	<0.001
				16.5	-1.6	-0.51	<0.001	0.024
C (30-65 cm								
n	18	15	18					
pH (H_2O	5.21	5.63	5.56	15				
P (mg/kg)	126.0	59.8	91.5	5.98	0.35	-0.35	<0.001	0.041
K (mg/kg)	37.5	44.2	43.8	36.2	-34.5	-23.6	0.004	0.002
Ca (mg/kg)	190.2	517.0	191.4	49.9	6.3	5.7	0.291	0.049
Mg (mg/kg)	34.0	48.9	34.8	845.4	1.2	327.5	0.973	0.054
Total SOC (g/kg)	3.2	2.7	1.9	74.3	0.8	25.4	0.915	0.011

*Based on paired *t*-test.

remained relatively constant. This may be attributed to type and rate of fertilizer and altered soil moisture regimes resulting from terraces. Significant increased in P and K in the Ap was found in site 22-NB compared to site 20-NB. These increases may be related to the reduction of soil loss. Compared to the relatively undisturbed forest soils, permeability of site 20-NB and 22-NB was reduced substantially as results of soil compaction and soil erosion. The permeability of Ap from the site 22-NB under terraces was 1.33 cm/hr compared to 1.03 cm/hr for the site 20-NB under up-and-down slope cultivation. This 29 % reduction in permeability may be related to the reduction in soil loss. Rees *et al.* (2007, 2008) reported more comparisons of other parameters in term of crop yield, Cs-137 estimated soil loss and worm counts.

Table 3. Permeability of comparable soil depths for site 20-NB, site 22-NB and adjacent forest.

Depth (cm)	Field measured permeability (cm/hr) 20-NB Mean	n	SE	Site 22-NB Mean	n	SE	Adjacent forest Mean	n	SE
10-20	1.03	498	0.07	1.33	590	0.07	5.24	18	0.80
26-36	0.98	198	0.07	0.95	590	0.05	2.06	18	0.28
50-60	1.61	51	0.27	1.02	150	0.17	1.37	18	0.43

Conclusions
Intensive agricultural activities increase soil bulk density and reduce depths of the Ap and B horizons as results of soil compaction during agricultural operations. Soil conservation terraces reduce runoff and soil loss by 87 and 95 %, respectively. Peak flow rate was reduced and time of concentration was increased. Terracing also makes drainage basin runoff characteristics less prone to cause flooding. In average, soil organic carbon under terracing was significantly reduced.

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