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Organic carbon distribution in alluvial soils according to different flood risk zones

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This study examines the spatial distribution of organic carbon in alluvial soils subjected to frequent flooding according to different flood risk zones, that is, interval recurrences of 0-20 years (FFz) and 20-100 years (MFz). Sites located outside of flood zones (NFz) were also selected to compare the soil organic carbon (SOC) in different zones. The selected sites are located in floodplains covered by forest dominated by silver maple (*Acer saccharinum* L.) and green ash (*Fraxinus pennsylvanica* Marsh.) in southern Québec. These floodplains are affected by frequent flooding, especially in the last decades, which has a direct impact on pedogenic processes, particularly in terms of in situ soil biomass and organic matter. The soil samples (0-20 cm depth) collected in a frequent flood zone (FFz), generally show a lower content of soil organic carbon (SOC%) ranging from 1.74 to 2.59% (median values), and mean values between 1.79 and 2.83%, respectively. In areas not affected by the floods, levels of SOC (%) are generally higher, with values ranging between 2.86 and 3.73% (mean), and mean values between 3.18 and 5.17%. Loss of biomass (litter) during the flood recession causes a net loss of organic matter to the subsurface soils. Successive flooding leads to an impoverishment of alluvial soils and undermining of the pedogenic processes and soil development. This confirms the trends observed in our previous work on soil depletion in active floodplains in the study area.

Key words: Alluvial soils, soil organic carbon (SOC), floods, spatial variability, climate change.

INTRODUCTION

The number of studies on global warming and their impact on river systems have grown over the past few years (Monirul et al., 2003; Alcamo et al., 2007; Kay et al., 2008; Whitehead et al., 2009; Wilby and Keenan, 2012). Hydroclimatic changes have had a direct impact on river flow and play a key role in the homeostasis of riverside environments (Tockner et al., 1999; Steiger and Gurnell, 2003; Rokosh et al., 2009). The effect of floods on riverside ecosystems, in particular on microflora and microfauna, have been widely documented (Heimann and Roell, 2000; Clinton et al., 2006, Schilling et al., 2009; Kayranli et al., 2010). Conversely, there are fairly few studies on the pedogenetic development of riverside soils and their physical and chemical properties regarding the increase in flood recurrence (Daniels, 2003; Bailey and Guimond, 2009; Ruiz-Sinoga et al., 2012). Frequent flooding may result in soil depletion with a loss of litter and reduced input in organic matter (Saint-Laurent et al.,

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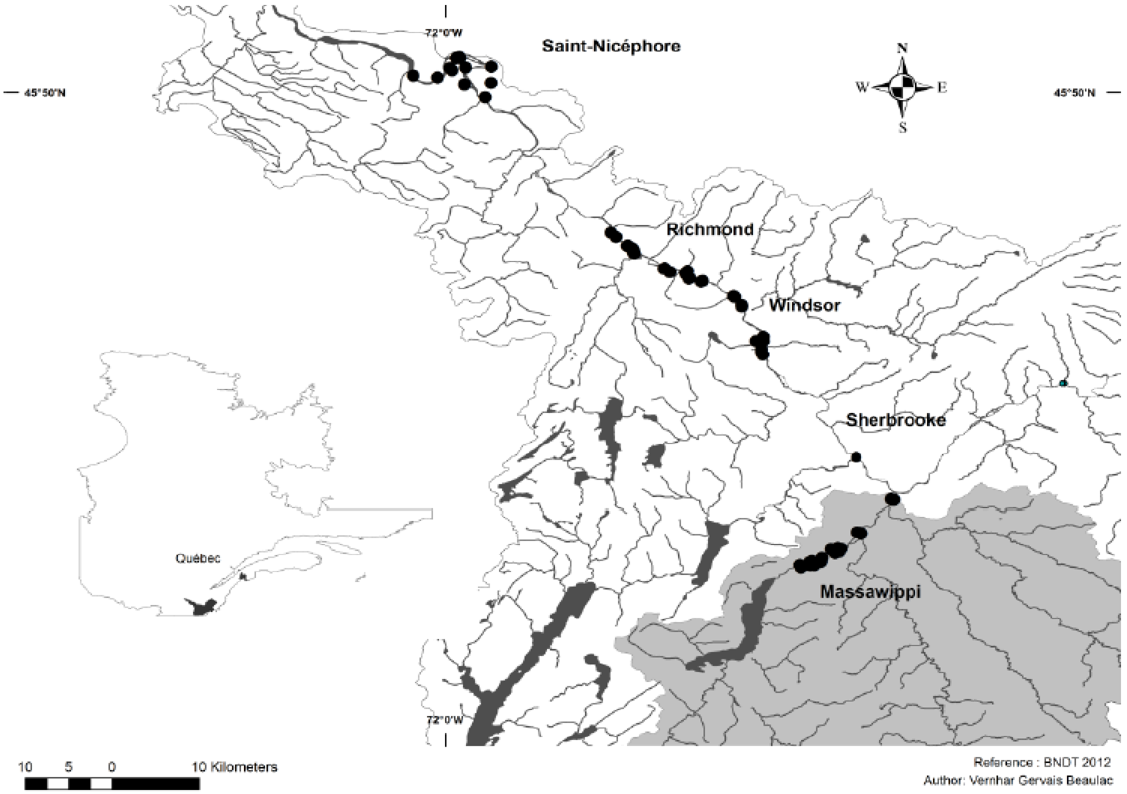

Reference : BNDT 2012
Author: Vernhar Gervais Beaulac

Figure 1. Location of sampling sites along the Massawippi and Saint-François rivers (Southern Québec, Canada).

2010; Drouin et al., 2011). During flood recessions, the litter (annual or biennial) is transported further downstream by the current, which ultimately depletes organic matter sinks and causes a decrease in organic carbon for the soil.

Organic carbon is known to play a key role in pedogenetic processes and soil fertility (Schilling et al., 2009; Dai et al., 2011; Ngailo and Vieira, 2012). Furthermore, soil is known to be a natural storehouse for organic carbon and to contribute to the various biogeochemical exchanges (sinks and sources) between the atmosphere and other environmental components (Zhang and Mitsch, 2007; Kayranli et al., 2010). Given that soil plays a key role in the conservation of sinks of organic carbon and their impact on variations in atmospheric CO_2, one can see the importance of measuring this pedological parameter on different spatial scales and in various physical environments. It appears in fact, important to understand the spatial variability of soil organic carbon in environments subject to constant fluctuations such as river environments, especially those subject to periodic flooding. What would be the long-term impact of successive floods on the soil organic content of floodplains, for instance?

This study aims at measuring the soil organic carbon of subsurface soils based on the various flood risk zones (recurrence intervals of 0-20 years and 20-100 years). Our preliminary work (Drouin et al., 2011; Saint-Laurent et al., 2010) conducted in the same study areas, shows that frequent river overflowing results in a depletion of SOC% in active sedimentation zones (recurrence of 0-20 years). The zones less affected by periodic flooding (recurrence of 20-100 years) generally show higher SOC%, while no-flood zones show higher SOC% compared to the flood risk zones. For this study, the number of sampling sites was increased in order to assess and compare the SOC% in the various flood and no-flood zones.

MATERIALS AND METHODS

Description of the study area

The study was conducted along the Massawippi (MAS) and Saint-François (STF) rivers located in southern Québec (Figure 1). These rivers cross through wooded or partially wooded areas, farmland, and urban areas with a moderate to high population density (Drummondville and Sherbrooke areas). The middle section of the Saint-François River is characterized by low floodplains (1-3 m in height) covered mainly by fluvial deposits (recent and ancient). Under these fluvial deposits are mainly found glaciolacustrine sediments, glaciofluvial outwash materials and rocky outcrop (Lavoie et al., 2006; Saint-Laurent et al., 2008). The middle section of the Massawippi River is also characterized by low alluvial terraces (1 to 2 m) made up of recent fluvial deposits based on

Table 1. Hydrological characteristics and river discharges of the Massawippi and Saint-François sectors

Rivers	Mean channel width (m)	Mean channel depth (m)	Mean channel height (m)	Gauging station number	Location	Period recorded	Mean annual discharge (m^3/s)	Peak discharge (m^3/s)
Massawippi	30	2.2	1.50	02OE019	$45^o17'03''N$ $71^o57'45''W$	1955-2011	10	67
Saint-François (Richmond)	180	16.0	1-2	02OF001	$45^o39'32''N$ $72^o08'37''W$	1915-1965	183	2080
Saint-François (Drummondville)	260	8.0	1-2.50	02OF002	$45^o51'42''N$ $72^o27'11''W$	1925-2002	189	2719
Saint-François (Windsor)	180	16.0	1-2	02OF004	$45^o33'50''N$ $72^o00'23''W$	1936-1972	165	2080

Sources: Environment Canada/CD-HYDAT (2011) ; MDDEP/CEHQ (2013a).

various quaternary deposits (e.g. moraines, glaciofluvial). The peak discharge registered in 1925-2002 in the Saint-François River (middle section/ station no. 030203) is 2719 m^3/s and the mean annual discharge is 189 m^3/s (Table 1) (Environment Canada, 2011; MDDEP, 2013a).

Southern Québec is characterized by a cool and humid climate with mean annual temperatures ranging from -10.2 to 20.8°C, with a mean annual temperature of 6.06°C and annual precipitation ranging from 68.7 to 107.1 mm, with total annual precipitation of 1107 mm (1981-2010) (EC, 2012; MDDEP, 2013b/Drummondville station no. 7022160). The mean and maximum flow rates obtained for the two rivers differ significantly due to the depth and width of the river sections. For the Massawippi River, the mean flow rates recorded from 1955 to 2010 are 10 to 67 m^3/s, respectively, which is 12 to 20 times lower than those recorded in the medium section of the Saint-François River (Table 1).

The Massawippi and Saint-François rivers are frequently affected by flooding (Saint-Laurent et al., 2009), owing to the number of tributaries and shallow riverbeds that favour overflowing during spring floods or periods of heavy rain. An increase in flood frequency was noted especially in the last decades (Saint-Laurent et al., 2008; 2009), which favours the formation of large alluvial plains and the aggradations of river terraces, along with affecting the development process of riverside soils (Saint-Laurent et al., 2010; Drouin et al., 2011). For instance, the sedimentation and erosion processes observed in the river corridor take the form of a loss of fine materials at the foot of the riverbanks during strong currents, especially spring floods; however, during flood recessions, the fine sediment that is transported along the river is accumulated on the alluvial plain bench and can be up to 4-5 cm thick. For example, a mean sedimentation rate of 36.8 mm was recorded over a decade in the medium section of the Saint-François River between Windsor and Richmond (Saint-Laurent et al., 2010).

Data gathering

The sites selected for the soil sampling were spread out based on the flood risk zones, including the flood zones with a recurrence interval of 0-20 years (FFz: Frequent Flood zone) and 20-100 years (MFz: Moderate Flood zone), along with an adjacent zone located outside the floodplains (NFz: No Flood zone). The delimitation of the flood zones was established based on flood risk maps (scale of 1:10,000 or 1:15,000) produced by Environment Canada and Québec's environment ministry (EC and MENV, 1982), as well as flood risk maps created in the municipal development plans in the areas under study. A total of 90 quadrats (20 x 10 m) were selected along the MAS and STF rivers (middle section), including 42 quadrats in Frequent Flood zones (FFz), 17 quadrats in Moderate Flood zones (MFz) and 31 quadrats in No Flood zones (NFz). The soil samples were collected at each end of the quadrat using a cylindrical manual auger (Eijkelkamp model) at a depth of 0-20 cm. In addition, other samples were taken every 20 cm in depth (0-20, 20-40, 40-60, 60-80 and 80-100 cm) at the end of the quadrat. More than 600 soil samples were collected for all the quadrats in the two study areas (MAS and STF). Samples were collected according to the criteria established by the Canadian System of Soil Classification (McKeague, 1978; CSCW, 1998).

Data analysis

A total of 180 soil samples was selected (2 samples at 0 to 20 cm in depth for all the quadrats) for the physical and chemical analysis (particle size, soil organic carbon (SOC %), and pH) in accordance with the analytical standards of the Soil Sampling and Methods of Analysis (McKeague, 1978; Carter and Gregorich, 2006). Soil samples were air-dried (2 to 3 weeks) and sieved at 2 mm (copper sieve, U.S. No. 10). The sandy fraction (<2 to 0.05 mm) was obtained by sieving (dry materials), and the finer fractions (silt/<0.05-0.002 mm and clay/<0.002 mm) were obtained using laser diffractometry techniques (Fritsch/Analysette 22, Micro Tec Plus) with a measurement range of 0.08 to 2,000 µm. The protocol developed by Yeomans and Bremner (1988) was used for the total organic carbon. Soil samples were placed in a digestion tube to which was added 5 ml of acidified dichromate solution (K2Cr2O7-H2SO4) for 30 m. The tube was placed in a preheated digestion block at 170°C for 30 m. The titration was performed with an ammonium ferrous sulfate solution at 0.05 mol L^{-1} (Yeomans and Bremner, 1988). Soil nitrogen was determined with the Kjeldahl method (Quikchem Method, 1996). The samples were placed in glass tubes with a reactive solution (sulfuric acid) and placed on a block digester for 2 h. The residues were analyzed using a Flow Injection Analyser based on Lachat Method (no. 13-107-06-2-D). A 1:2 soil-solution ratio (CaCl2, 0.01M) was used to determine the pH of the soil samples and the liquid solution was measured with pH meter electrodes (Carter and Gregorich, 2006).

Table 2. Chemical and physical properties of subsurface soils along the Massawippi (MAS) riverbanks in different flood zones (FFz and MFz) and no flood zones (NFz)

Soil samples (0-20 cm depth)	pH ($CaCl_2$)	Organic carbon (%)	Sand (%)	Silt (%)	Clay (%)	Texture[a]
Frequent Floods (FFz) (*n* = 13)						
Mean	4.69	2.83	36.60	60.24	3.15	Silt loam
Maximum	5.68	5.13	52.60	81.55	4.64	
Minimum	3.69	1.08	14.56	45.18	1.71	
Median	4.68	2.59	39.00	58.20	3.13	
Standard deviation	0.57	1.29	12.86	12.06	0.93	
Moderate floods (MFz) (*n* = 8)						
Mean	4.30	3.13	32.43	63.77	3.80	Silt loam
Maximum	5.12	5.21	46.74	82.03	6.20	
Minimum	3.47	1.75	11.76	51.16	2.10	
Median	4.27	2.73	34.23	63.18	3.32	
Standard deviation	0.65	1.17	10.31	9.18	1.54	
No floods (NFz) (*n* = 10)						
Mean	4.05	3.18	38.11	57.32	3.65	Silt loam
Maximum	5.19	5.28	70.69	85.58	8.39	
Minimum	3.18	1.76	6.01	27.72	1.37	
Median	3.98	2.86	43.30	54.15	2.56	
Standard deviation	0.69	1.09	20.23	17.27	2.45	

[a] Textural classes are based on the Canadian System of Soil Classification (CSCW, 1998).

Statistical analysis

Soil properties were treated with standard statistics and other statistical tests (Shapiro-Wilk and Mann-Whitney U) were performed to evaluate the distribution and normality of the soil data (soil organic carbon (SOC), pH, and texture). The student's *t*-test was also used to test the significance of mean differences in the SOC and the two recurrence interval flood zones (FFz and MFz) and no flood zone (NFz). Before analyzing the Student's *t*-test, we checked the distribution of the data with the Shapiro-Wilk's test for the series of three different zones (FFz, MFz and NFz). Next, we used the Mann-Whitney U test since two of the three groups (FFz and NFz) did not have a normal distribution. Pearson's and Spearman's correlation analyses were also done between the two SOC (%) and Silt (%) variables. The correlations were done on all the data, after which a second series of correlation analyses was done by removing a value deemed marginal from the lot, that is, the value with a concentration of 30.67% (SOC). All the statistical analyses were done with a significance level of $p = 0.05$ using SPSS PASW Statistics v18 software.

RESULTS AND DISCUSSION

Soil properties in different flood-risk zones

Tables 2 and 3 provide the mean, maximum, minimum and median values for the different soil properties for the two study areas (MAS and STF) based on the different zones (FFz, MFz and NFz). The pH values obtained for the subsurface soils (0-20 cm in depth) are relatively comparable between the two study areas, although greater acidity is noted for the STF area soils (Figure 2). In general, the soils located in the no-flood zone (NFz) had the highest acidity levels, with median values of 3.98 and 3.77, compared to 4.68 and 5.31 for the soils in the frequent-flood zones (FFz), and 4.27 and 4.15 for the soils in the moderate-flood zones (MFz). Based on the vertical distribution of the pH values in the soil profiles (0-100 cm in depth), the most acidic soils are found in no-flood zones. The litter, which is substantially greater in no-flood zones, may be contributing to acidifying the soils through a greater input of organic matter (e.g. fulvic and humic acids) which comes from the decomposition of the organic matter in the litter (Duchaufour, 2001; Brady and Weil, 2008).

Regarding the textural properties of the soils, differences were noted between the two study areas (Tables 2 and 3; Figure 3). The surface soils (0-20 cm) in the MAS area in fact, had higher proportions of silt than the STF area, with mean values of 60.24, 63.77 and 57.32%, compared to 49.98, 46.15 and 42.37% (FFz, MFz and NFz), respectively.

These textural variations are most likely due to the type of materials that make up the riverbanks of the two study areas (MAS and STF). The higher proportion of silt in the MAS area soils is due to a dominance of fine fluvial deposits which provide a finer matrix. For instance, the Massawippi riverbanks extend over a total of 37 km and fluvial deposits account for 66% of the channel banks in this sector (Lavoie et al., 2006; Saint-Laurent et al., 2008). The riverbanks between Sherbrooke and Drummondville (Saint-Nicéphore area) extend over 80 km

Table 3. Chemical and physical properties of subsurface soils along the Saint-François (STF) riverbanks in different flood zones (FFz and MFz) and no flood zones (NFz).

Soil samples (0-20 cm depth)	pH ($CaCl_2$)	Organic carbon (%)	Sand (%)	Silt (%)	Clay (%)	Texture[b]
Frequent Floods (FFz) (*n* = 29)						
Mean	5.12	1.79	47.95	49.98	2.07	Silt loam
Maximum	6.07	4.56	76.84	67.29	3.72	
Minimum	3.53	0.63	29.43	21.85	1.05	
Median	5.31	1.74	42.58	55.44	2.15	
Standard deviation	0.76	0.83	13.25	12.81	0.53	
Moderate floods (MFz) (*n* = 9)						
Mean	4.49	2.78	51.89	46.15	1.95	Sandy loam
Maximum	5.36	5.39	72.80	65.39	3.74	
Minimum	3.95	1.54	32.19	26.00	1.10	
Median	4.15	2.22	49.40	49.01	1.63	
Standard deviation	0.56	1.31	13.58	13.04	0.78	
No floods (NFz) (*n* = 21)						
Mean	3.84	5.17	56.35	42.37	1.72	Sandy loam
Maximum	5.78	30.67	81.07	74.44	2.70	
Minimum	2.79	0.85	30.47	18.29	0.63	
Median	3.77	3.73	58.48	39.91	1.63	
Standard deviation	0.74	6.12	14.50	14.81	0.68	

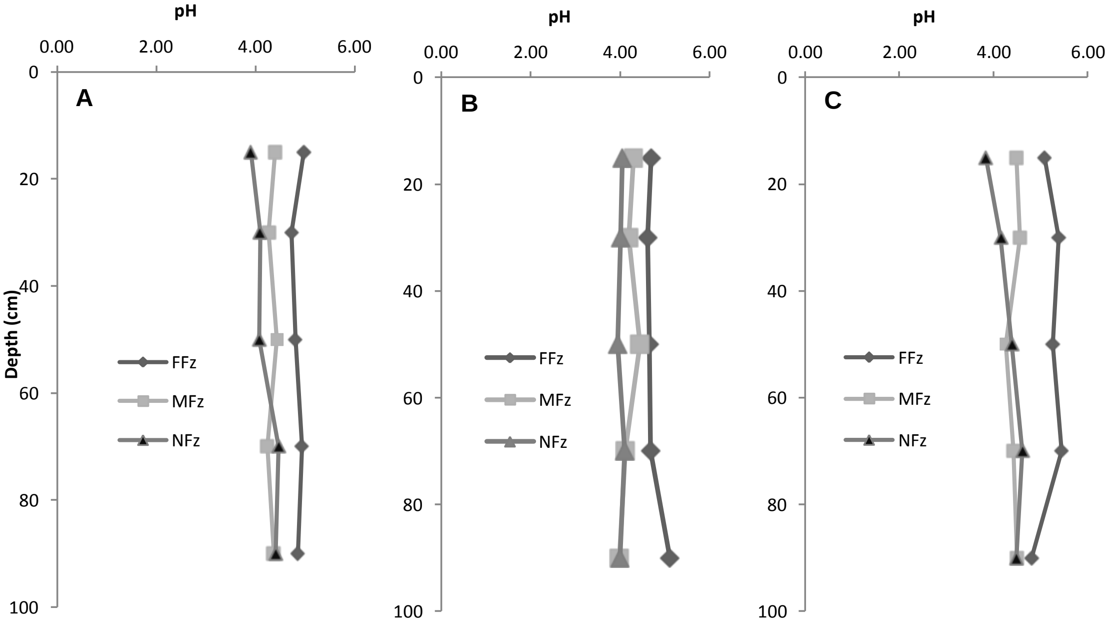

Figure 2. Vertical distribution of mean values of the pH in soil profiles in the three study zones (FFz, MFz and NFz). A: Total of soil samples (n = 90); B: Soil samples of the Massawippi sector (n = 31); C: Soil samples of the Saint-François sector (n = 59).

and are composed of fluvial deposits and other materials (e.g. glacial, fluvioglacial, glaciolacustrine). Between Windsor-Richmond specifically, the banks consist predominantly of fluvial deposits (42%) and glaciolacustrine deposits (22%), along with a large proportion of glacial materials (18%) (Lavoie et al., 2006). Lastly, the hydrological characteristics, which differ from one area to another, must also be considered. The flow rate of the Massawippi River differs substantially from that of the Saint-François River, which can explain why,

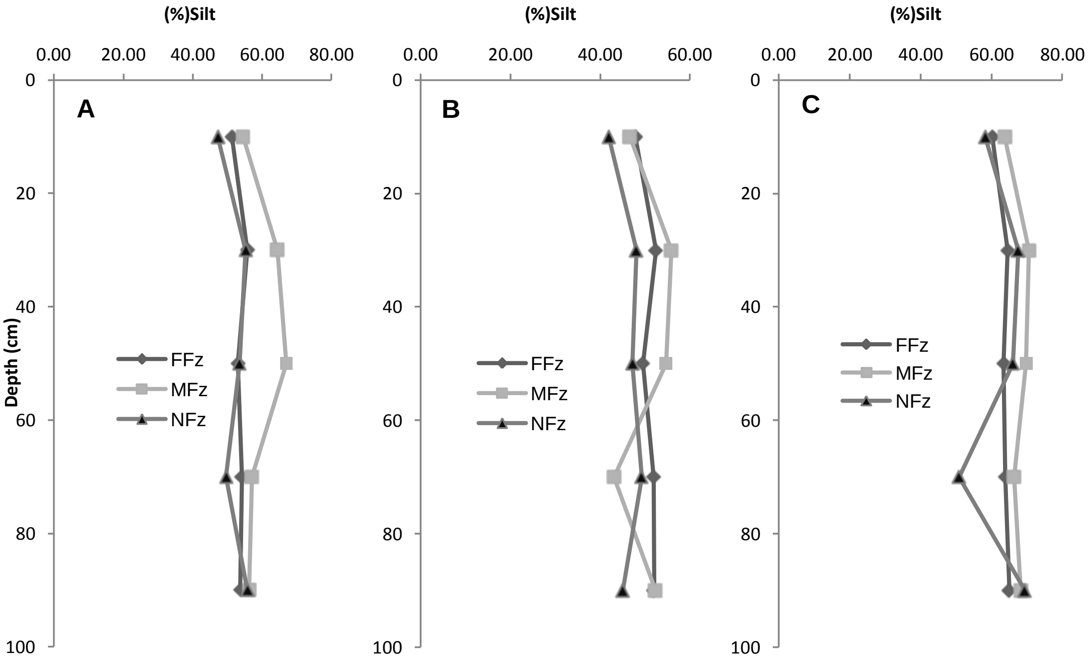

Figure 3. Distribution of silt content (%) in soil profiles in the three study zones (FFz, MFz and NFz). A: Total of soil samples (n = 90); B: Soil samples of the Massawippi sector (n = 31); C: Soil samples of the Saint-François sector (n = 59).

Table 4. Results of student *t*-test and Mann-Whitney U test for the comparison of average (SOC%) of the three groups (zones FFz, MFz and NFz).

Comparison between the three groups[a]	**Group 1 NFz**	**Group 2 MFz**	**Group 1 NFz**	**Group 3 FFz**	**Group 2 MFz**	**Group 3 FFz**
MAS sector (student *t*-test analysis)	0.919*		0.494*		0.601*	
STF sector (Mann-Whitney U test)	0.099*		0.000**		0.040**	
MAS and STF sectors (Mann-Whitney U test)	0.095*		0.000**		0.011**	

[a] H0: *No statistical difference between groups ($p > 0.05$) ; H1: **Statistical difference between groups ($p < 0.05$)

during overflowing in periods of flooding, the deposits left by the Massawippi River contain more fine particulate matter than in the soils in the Saint-François riverbanks.

Organic carbon contents in soils

Soil organic carbon content (SOC %) are relatively different based on the flood zones and the no flood zones. The mean concentrations of SOC% in surface soils (0-20 cm in depth) ranges from 2.83±1.29% and 1.79±0.83% (FFz) to 3.13±1.17 and 2.78±1.31% (MFz) for soils in the flood zones, and for the soils in the no flood zones (NFz), the mean SOC values are 3.18±1.09% and 5.17±6.12% (Tables 2 and 3). These mean SOC values in the no-flood zones are significantly higher than those observed in the flood zones. The results of the Student's *t*-test and Mann-Whitney U test (Table 4) show that there is a significant difference ($p <$ 0.05) between the three zones regarding the SOC% content of the surface horizons (0-20 cm). These concentrations are higher in the NFz zone than in the FFz zone, and are comparable between the MFz and NFz zones. The FFz zone basically consists of the zone with the lowest soil organic carbon content in the surface horizons. The values obtained are statistically significant (p = 0.000), confirming that the soils in frequent flood zones have a lower SOC% content.

Lastly, note that the soils in the MAS area compared to those in the STF area show slightly higher levels in the frequent flood zones (FFz), with mean values of 2.83% versus 1.79% (Tables 2 and 3). However, in the no-flood zones (NFz), the soils in the Saint-François River area have the highest SOC concentrations, with values of 5.17% compared to 3.18%. These variations in SOC content may partly depend on the hydrogeomorphological conditions specific to each area. The riverbanks of the MAS area are less flooded than the STF area (Jones,

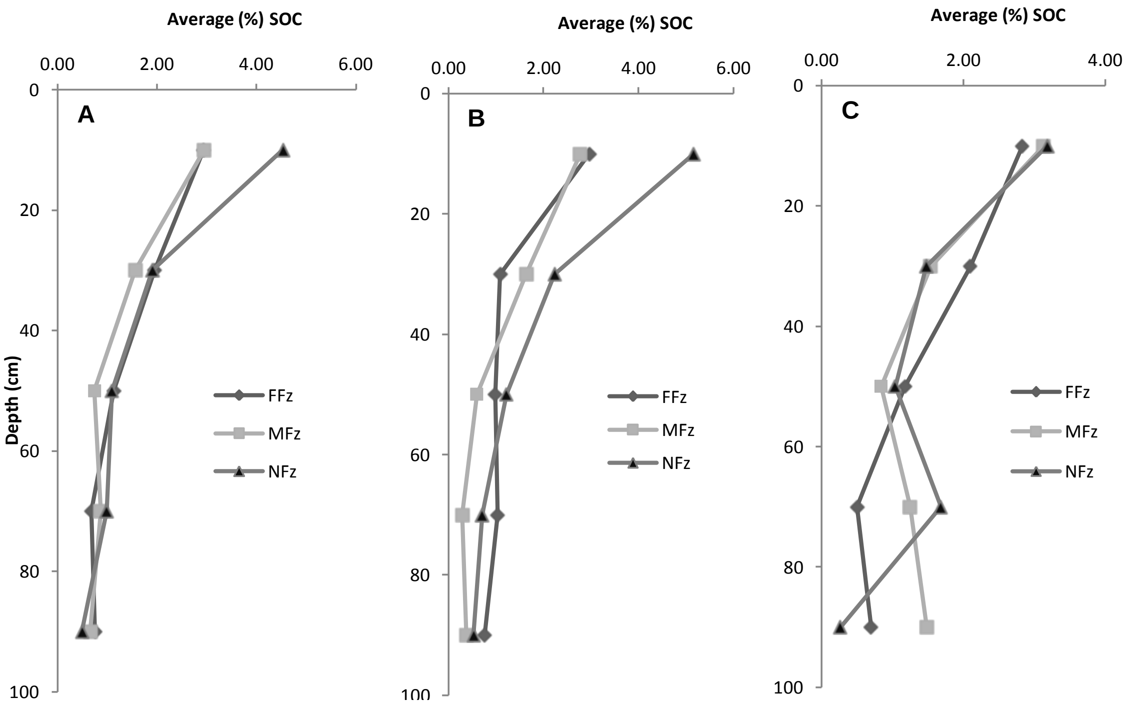

Figure 4. Distribution of SOC (%) in soil profiles in the three study zones (FFz, MFz and NFz). A: Total of soil samples (n = 90); B: Soil samples of the Massawippi sector (n = 31); C: Soil samples of the Saint-François sector (n = 59).

2008; Saint-Laurent et al., 2009; 2010), which is more favourable to maintaining litter and, as a result, provides a more regular organic matter input for the soils. The flood frequency is more than double (8 vs 3 floods) for the STF area (Sherbrooke-Drummondville areas) compared to the MAS area from 2000 to 2013.

It is known that several factors may be involved in the contents of organic matter in the soil, including texture, drainage, soil biomass, pH and microbial activity which itself depends on the acidity of the soil and the nature of the organic materials (e.g. labile C proportion vs. aromatic C) (Lützow et al., 2006; Brady and Weil, 2008). For the soils studied, aside drainage and litter thickness, the other soil properties (e.g. texture, acidity) does not appear to be involved in the content of organic carbon. Soil biomass (litter) is much greater in thickness for soils in the no flood zones (see next sections), which seems to be the determining factor in the explanation of the highest content of SOC (%) in these soils.

Vertical variation of SOC% in soil profiles

Figure 4 shows the vertical distribution of the SOC% based on the depth and the different flood zones (FFz, MFz and NFz) for each area (MAS and STF). The soils not affected by flooding show a more regular pattern of SOC distribution, with a higher concentration in the surface horizons (0-20 cm) with a mean value of 4.53% and a decrease of SOC at the base of the profile (mean = 0.49%) at all the sites. Soils in the flood zones (FFz et MFz) show a more vertical distribution of the SOC content in the surface soil at the base of the profile, in addition to having significantly lower values than the soils in the NFz zones (Figure 4). The mean SOC values in soils in the frequent flood zones (FFz) are 2.93% (0-20 cm), 1.13% (60-80 cm) and 0.75% (80-100 cm), a difference of ±2.18% between the surface and the base of the profile, whereas the average difference is ±4.04% from the surface to the base of the profile for soils in the no-flood zones (NFz). This variation is even more pronounced for the STF area, with a difference of 2.21% and 4.64%, respectively (Figure 4c). For the MFz zones, the soils have values equivalent to those in the FFz zones.

Organic carbon content vs soil texture

Soil texture does not appear to account for the variability of SOC content (0-20 cm depth) observed in the various zones (FFz, MFz and NFz). It is known that fine fractions (clay and silt) retain more organic particles than coarser fractions (Nadeu et al., 2011; Ruiz-Sinoga et al., 2012). Even though the soils in the FFz zone have generally finer matrices (e.g. fine or very fine sand and silt, with low clay particles), their sand and silt proportion is comparable to that determined in the other zones (MFz and NFz).

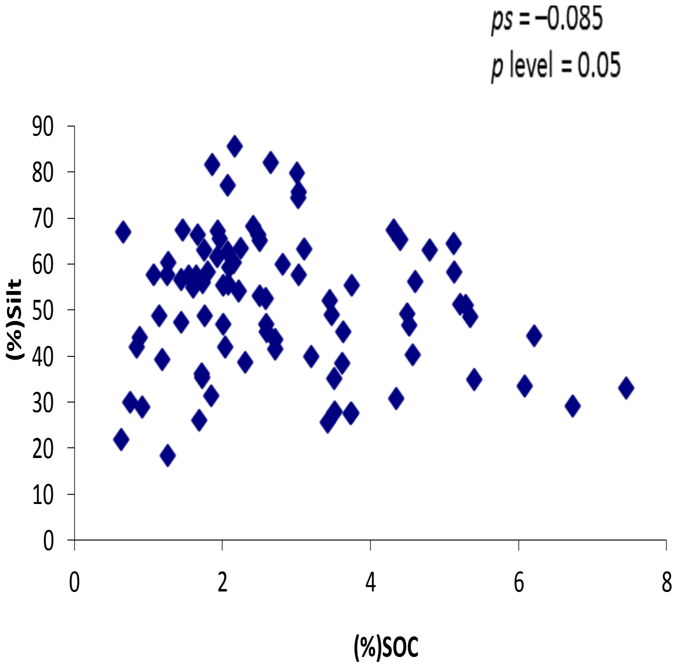

Figure 5. Correlation (Spearman's test) between SOC (%) and Silt (%) contents for all soil samples (n = 89).The significance level considered for statistical tests are 0.05 (confidence interval of 95%).

If these soils contained a greater proportion of clay particles (e.g. 20 to 30%), the concentration of SOC (%) may be higher due to the formation of organo-clay complexes that promote the retention of fine organic particles in the soil horizons. To measure the degree of correlation between these two variables (SOC% and Silt %), two standard statistical tests were used. The Pearson and Spearman correlation that was done for the SOC% concentrations and Silt (%) percentage did not show any relationship between the two variables in all the zones (Figure 5). The statistical values obtained are rp = –0.113 and p = 0.292 (Pearson's test) and p_s = –0.097 and p = 0.368 (Spearman's test). The marginal value (30.67 SOC %) was excluded from the correlation analysis, and the correlations remain low (rp = –0.140, and p = 0.193, and p_s = –0.085, and p = 0.431 (Spearman's test) respectively (Figure 5). The significance level considered for all statistical tests is 0.05 (confidence interval of 95%). The low proportion of clay in the soils (low microaggregate particles) that were analyzed may account for the lack of correlation between the two variables (SOC% and Silt%).

Microtopography, drainage and soil biomass

Figure 6 provides additional elements on edaphic conditions (e.g. microtopography, drainage, soil biomass) for the various areas under study (FFZ, MFz and NFZ). In terms of topography, the floodplain zones (FFz and MFz) are characterized by flat (75%) or subhorizontal (10%) landforms that may have irregular surfaces (hollows and bumps), while the outlying areas (NFz) are generally sloping (with slight to moderate or abrupt slopes), and are often characterized by the presence of micro mounds, which indicate old buried stumps. Internal drainage (moisture) is largely determined by the microtopography of the site as well as texture and stoniness. The flat surfaces of the flooded areas (Figure 6a and b) are often poorly (28 to 37%) or moderately drained (15%), although soil mainly consisting of sand or silty sand can facilitate the drainage of water in the soil profiles. The sites with abrupt or moderate slopes have better drainage (63%) than the flat areas, and the presence of gravel in some profiles facilitates internal drainage. The soil outside the flood zones (Figure 6c) has the largest quantity of litter (%), namely three to four times more (29%) than the soil subject to frequent flooding (7%). In fact, these sites (NFz) have the highest concentrations of SOC (%) and nitrogen (%), that is, close to twice the levels found in the other zones (FFz and MFz). The soil pH values were also found to be lower (92%) for soil with more soil biomass (Figure 6c). It is known that litter decomposition and humification releases acidifying products (e.g. fulvic and humic acids), which can increase soil acidity, especially in the surface horizons (Brady and Weil, 2008). High levels of nitrogen (N %) were also found to be correlated with high concentrations of SOC (%).

Conclusion

Soils in the frequent flood zones show lower values of SOC% content compared to the no flood zones. During successive floods, the litter can be transported by currents, which limits long-term enrichment of soil through organic matter. In zones less affected by floods (MFz) or in no-flood zones (NFz), the SOC% content is generally higher. For other soil properties, there are minor differences between the zones and sectors. Soils not affected by the floods are generally more acidic, which can be explained by the decomposition of organic matter that provides organic acid substances (e.g. fulvic and humic acids). The soils in the MAS area generally contain a higher proportion of silt, which is likely attributable to the hydrogeomorphic conditions and dominance of fluvial deposits in this area. However, no positive correlation was noted between the proportion of silt and the organic carbon content for all the soils that were analyzed.

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REFERENCES

Alcamo J, Flörke M, Märker M (2007). Future long-term changes in global water resources driven by socio-economic and climatic change. Hydrol. Sci. J. 52(2):247–275.

Bailey SE, Guimond JK (2009). Aboveground biomass and nutrient limitation in relation to river connectivity in Montane Floodplain Marshes. Wetlands 29:1243–1254.

Brady NC, Weil RR (2008). The Nature and properties of soils, fourteenth edition. Pearson, Columbus, OH, USA.

Carter MR, Gregorich EG (2006). Soil Sampling and Methods of Analysis. Canadian Society of Soil Science, 2e edition, Lewis Publishers, Boca Raton, Fl. 2006.

Clinton SM, Power M, Swenson R (2006). Impacts of inundation regime, floodplain vegetation, and burrowing animals on the incorporation of carbon into floodplain soils, CALFED Science Fellows Program, Project Number : R/SF-1, 2006, pp. 1-9.

CSCW (Canadian Soil Classification Working Group) (1998). The Canadian System of Soil Classification, 3rd ed. Agriculture and Agri-Food Canada Publication 1646. P. 187.

Dai F, Su Z, Liu S, Liu G (2011). Temporal variation of soil organic matter content and potential determinants in Tibet, China Catena, 85:288-294. DOI: 10.1016/j.catena.2011.01.015.

Daniels JM (2003). Floodplain aggradation and pedogenesis in a semiarid environment. Geomorphology 56:225–242.

Drouin A, Saint-Laurent D, Lavoie L, Ouellet C (2011). High-Precision Digital Elevation Model to evaluate the spatial distribution of Soil organic carbon in active floodplains. Wetlands 31:1151-1164.

Duchaufour P (2001). Introduction à la science du sol : sol, végétation, environnement. 6e édition, Dunod, Paris, P. 331.

Environment Canada (2012). National Climate Data and Information Archive, Canadian Climate Normals 1971-2000. http://climate.weatheroffice.gc.ca/ climate_ normals/index_e.html.

Environment Canada (2011). Hydrological Data, Hydat CD-Rom, version 2.02, Canada.

Environment Canada (EC) and Ministère de l'Environnement (MENV), (1982). Flood risk map: Saint-François River Basin (scales 1: 15,000, 1:10,000). Québec, Canada.

Heimann DC, Roell MJ (2000). Sediment loads and accumulation in a small riparian wetland system in northern Missouri. Wetlands 20(2):219-231.

Jones NK (2008). An Overview of Recent Climate Change and Streamflow in the Massawippi River Basin. J. Eastern Townships Stud. 32-33:23-38.

Kay AL, Jones RG, Reynard NC (2008). RCM rainfall for UK flood frequency estimation. II. Climate change results. J. Hydrol. 318(1-4):163-172.

Kayranli B, Scholz M, Mustafa A, Hedmark A (2010). Carbon storage and fluxes within freshwater wetlands: a critical review. Wetlands 30:111–124.

Lavoie L, Saint-Laurent D, St-Laurent J (2006). Analyse pédologique et sédimentologique des sols alluviaux et paléosols des terrasses d'inondation. Can. J. Soil Sci. 86:1-14.

Lützow MV, Kögel-Knabner I, Ekschmitt K, Matzner E, Guggenberger G, Marschner B, Flessa H (2006). Stabilization of organic matter in temperate soils: mechanisms and their relevance under different soil conditions - a review. Eur. J. Soil Sci. 57:426-445.

McKeague JA (1978). Manual on Soil Sampling and Methods of Analysis. Canada Soil Survey, Subcommittee on Methods of Analysis. (2th ed.), Ottawa, pp. 212-211.

MDDEP (2013a). Centre d'expertise hydriques du Québec (CEHQ). Ministère du Développement durable et des Parcs, gouvernement du Québec. http://www.cehq.gouv.qc.ca/hydrometrie/index.htm

MDDEP (2013b). Normales climatiques du Québec 1981-2010. Ministère du Développement durable et des Parcs, gouvernement du Québec. http://www.mddep.gouv.qc.ca/climat/normales/sommaire.asp.

Monirul QM, Warrick RA, Ericksen NJ (2003). The Implications of Climate Change on Floods of the Ganges, Brahmaputra and Meghna Rivers in Bangladesh. Climatic Change 57(3):287-318.

Nadeu E, De Vente J, Martinez-Mena M, Boix-Fayos C (2011). Exploring particle size distribution and organic carbon pools mobilized by different erosion processes at the catchment scale. J Soil Sedim. 11(4):667-678.

Ngailo JA, Vieira SR (2012). Spatial patterns and correlation of soil properties of a lowland soil J. Soil Sci. Environm. Manag. 12:287-296.

Rokosh AE, Bouchard V, Fennessy S, Dick R (2009). The use of soil parameters as indicators of quality in forested depressional wetlands. Wetlands 29(2):666-677.

Ruiz-Sinoga JD, Pariente S, Diaz AR, Martinez Murillo JF (2012). Variability of relationships between soil organic carbon and some soil properties in Mediterranean rangelands under different climatic conditions (South of Spain). Catena 94:17–25.

Saint-Laurent D, St-Laurent J, Lavoie L, Ghaleb B (2008). Use geopedological methods for the evaluation of sedimentation rates on river floodplains. Catena 73:321-337.

Saint-Laurent D, Mesfioui M, Evin G (2009). Hydroclimatic variability and relation with flood events (Southern Québec, Canada). Water Resources, 36(1):43-56. DOI:10.1134/S0097807809010047.

Saint-Laurent D, St-Laurent J, Lavoie L, Drouin A, Ghaleb B (2010). Floodplain sedimentation rates, soil properties and recent flood history in Southern Québec. Global. Planetary Change 70:76-91.

Schilling KE, Palmer JA, Bettis III EA, Jacobson P, Schultz RC, Isenhart TM (2009). Vertical distribution of total carbon, nitrogen and phosphorus in riparian soils of Walnut Creek, southern Iowa. Catena 77:266-273.

Steiger J, Gurnell AM (2003). Spatial hydrogeomorphological influences on sediment and nutrient deposition in riparian zones: observation from Garonne River, France. Geomorphology, 49(1-2):1-23. DOI: org/10.1016/S0169-555X(02)00144-7.

Tockner K, Pennetzdorfer D, Reiner N, Schiemer F, Ward JV (1999). Hydrological connectivity, and the exchange of organic matter and nutrients in a dynamic river – floodplain system (Danube, Austria), Freshwater Biol, 41:521-535.

Whitehead PG, Wilby RJ, Battarbee RW, Kernan M, Wade AJ (2009). A review of the potential impacts of climate change on surface water quality. Hydrol. Sci. J. 54(1):101–124.

Wilby RL, Keenan R (2012). Adapting to flood risk under climate change. Progr. Phys. Geogr. 36(3):348–378.

Yeomans JC, Bremner JM (1988). A rapid and precise method for routine determination of organic carbon in soil. Soil Sci. Plant Ann. 19:1467-1476.

Zhang L, Mitsch WJ (2007). Sediment chemistry and nutrient influx in a hydrologically restored bottomland hardwood forest in Midwestern USA. River. Res. Applic. 23(9):1026-1037.