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SOILS AND SEDIMENTS IN URBAN AND MINING AREAS

Are urban soils similar to natural soils of river valleys?

Joël Amossé · Renée-Claire Le Bayon · Jean-Michel Gobat

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Abstract
Purpose Urban soils and soils of river valleys are constituted of heterogeneous materials that have been manipulated, disturbed or transported at different spatial and temporal scales. Despite these similarities, little is known about soil evolution in urban soils and their comparison with natural soils remains therefore highly useful. We hypothesized that, according to their degree of perturbation, urban soils and natural soils of river valleys have similar soil processes related to their structure, physical and chemical characteristics.
Materials and methods Using a synchronic approach, we compared two soil gradients, one located in the natural reserve of the Allondon River (canton of Geneva, Switzerland) and the other in and around the city of Neuchâtel, Switzerland. A total of five alluvial and 18 urban soil profiles were described according to vegetation type and alluvial terraces formed at different distances from the river for the river valley ecosystem and to soil age for the urban ecosystem. Correlations between soil gradients and classical physical (soil depth, particle-size distribution, coarse fraction) and chemical (C_{org}, pH_{H2O}, P_{tot}, N_{tot}, $CaCO_3$, CEC and C/N ratio) parameters of soils were first tested in order to identify similarities and differences among soil gradients. Data of soil properties were then clustered hierarchically in order to identify soil group classification.
Results and discussion Our results showed similarities and differences between soil gradients. In the urban context, soil thickness was positively correlated to soil age, while the coarse fraction, sand content and C/N were negatively correlated to soil age gradient. In soils of the river valley, most of the chemical variables were either negatively (pH_{H2O} and $CaCO_3$) or positively (CEC, C_{org} and N_{tot}) correlated to soil distance from the river. These differences between gradients can be mainly explained by parent material, depositional conditions and land use which can influence soil processes. However, alluvial soils were well clustered with two identified urban soil groups according to soil maturity. Evolved alluvial soils far from the river were grouped with natural and near natural urban soils. Conversely, "young" perturbed alluvial soils were most clustered with human-made soils.
Conclusions From the two selected soil gradients, soils on alluvial sediments are similar to urban soils in some characteristics. However, parent material, depositional conditions and soil and vegetation interactions on soil processes (e.g. matter cycle, energy flux) still need more investigation. This study contributes to the development of a natural soil reference for urban soils.

Keywords Perturbed ecosystems · River valley · Soil gradients · Soil properties · Soils on alluvial sediments · Urban soils

1 Introduction

Soils form from a wide range of parent materials. They often develop directly from rock weathering (in situ), but many of them are formed from materials that have been transported and deposited by various agents including water, wind, gravity, ice or humans (Duchaufour 1972; Pickett and Cadenasso 2009). Among them, soils of river valleys are mainly influenced by seasonal hydrological dynamics (Haase and Neumeister 2001). Their formation is conditioned by river

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J. Amossé (✉) · R.-C. Le Bayon · J.-M. Gobat
Laboratory of Soil and Vegetation, University of Neuchâtel, Canton de Neuchâtel, Emile Argand 11, 2000 Neuchâtel, Switzerland
e-mail: joel.amosse@unine.ch

transport, fluvial sedimentation and by the dynamics of surface and groundwater (Bertrand et al. 2012). The functioning of the fluvial sedimentation is a dynamic and irregular process in space and time, which results in sudden changes of textural compositions in the vertical and horizontal sections of the soil profile (Bullinger-Weber and Gobat 2006; Mendonça Santos et al. 2000). Alluvial soils often accommodate genetically young deposits of base-rich weathering material. The sequence of horizons at a given location is the result of sedimentation and in situ pedogenesis; these two processes overlap, but inheritance is often predominant (Gerrard 1992; Mendonça Santos et al. 2000).

As alluvial soils, urban soils are also considered as young soils and they can have an *ex situ* development (McKinney 2002; Lehmann and Stahr 2007). They are substantially altered due to mixing, sealing, filling and contamination and are often created by anthropogenic activity rather than natural weathering processes (Craul 1992; Lehmann and Stahr 2007; Pavao-Zuckerman and Byrne 2009). Urban soils are closely related to the history of a city and its hinterland (Morel et al. 2005). They are sometimes characterized by a high quantity of artefacts (e.g. bricks, pottery, glass), “technical” organic carbon (e.g. compost) and usually elevated pH. Nevertheless, even if urban soils are slightly or completely disturbed by human activities, they can develop under the influence of natural external factors of soil formation (De Kimpe and Morel 2000; McKinney 2008).

Through their similar characteristics, soils of river valleys appear a good reference for urban soils in that they are both characterized by temporal instability and spatial heterogeneity (Naiman and Bilby 1998; Godreau et al. 1999). The parent material is inherited from diverse origins: from former soils upstream in the case of alluvial soils and from different soil transfers by humans in the case of urban soils. In the literature, there is nevertheless a paucity of knowledge concerning the comparison of urban and near natural alluvial soils in terms of soil evolution and its physical and chemical properties. Most of the studies refer to the direct or the indirect impacts of human activities on natural soils (Bullinger-Weber and Gobat 2006; Prokofyeva et al. 2010; Jordanova et al. 2013) using soil disturbance gradients (Craul 1992; McDonnell et al. 1997). However, little is known about the comparison of independent soil disturbance gradients from near natural river valley and urban ecosystems in order to assess the potential of soils on alluvial sediments as a natural reference for urban soils.

The aim of this study was therefore to compare two soil gradients, one from a river valley ecosystem and the other from an urban ecosystem, with various stages of soil formation. Despite their different initial soil settlement conditions, we hypothesized that both soil gradients follow similar dynamics in terms of soil processes related to their structure, physical and chemical characteristics.

2 Material and methods

2.1 Study sites

The study was carried out in and around the city of Neuchâtel, Switzerland (46° 59′ 51″ N; 6° 55′ 86″ E) and in the natural reserve of the Allondon River (46° 12′ 19″ N; 5° 59′ 958″ E, canton of Geneva, Switzerland). These two sites were selected according to their similar characteristics: altitude (approximately 400 m of altitude), climate and initial soil properties (calcareous bedrock). Using a synchronic approach, different levels of soil disturbance by water or humans allow us to design two soil gradients of soil evolution. In the alluvial floodplain, a total of five soil profiles were described according to vegetation type (Guenat et al. 1999; Bullinger-Weber et al. 2007) and alluvial terraces formed by flood events (Hugett 1998) at different distances from the river (Fig. 1 and Table 1). Based on historical documents and land use, a series of 18 soils spanning more than two centuries were selected in the city of Neuchâtel (Table 2). We first investigated “native” soils close to the city centre of Neuchâtel and then explored “human-made” ones in the city and its suburbs.

2.2 Soil description, physical and chemical analyses

Urban and alluvial soils were described in situ with the classical approach (IUSS Working Group 2007; Baize and Girard 2009). Soil horizons were sampled, air-dried, sieved at 2 mm and analyzed in the laboratory. They were analyzed according to classical physical parameters: soil depth, coarse fraction (% of the total weight), particle-size distribution (% clay, % silt, % sand); and chemical parameters: pH_{H2O}, C_{org} (%), N_{tot} (%), P_{tot} (%), CEC (cmolc.kg^{-1}), $CaCO_3$ (%) and C/N ratio (Carter and Gregorich 2007).

2.3 Numerical analyses

Soil gradients (soil age or the distance from the river) and their correlations with physical and chemical variables were first tested using Pearson or Kendall’s coefficient of correlation (for normal and non-normal data) in order to identify similarities and differences among soil gradients and to state how soil properties change along gradients. Similarities between urban and alluvial soil profiles were then tested using clusters based on the Ward’s minimum variance method after soil data transformation: pair-wise dissimilarity distance (Gower 1971) and algorithms for quantitative pedology (Beaudette et al. 2013). An ordinal regression tree was finally performed in order to explain soil profile group classification by physical and/or chemical variables. Soils were described morphologically and designed using the “aqp” package (Beaudette et al. 2013). All calculations were carried out with R (R Development Core Team 2010) using the “vegan” (Oksanen

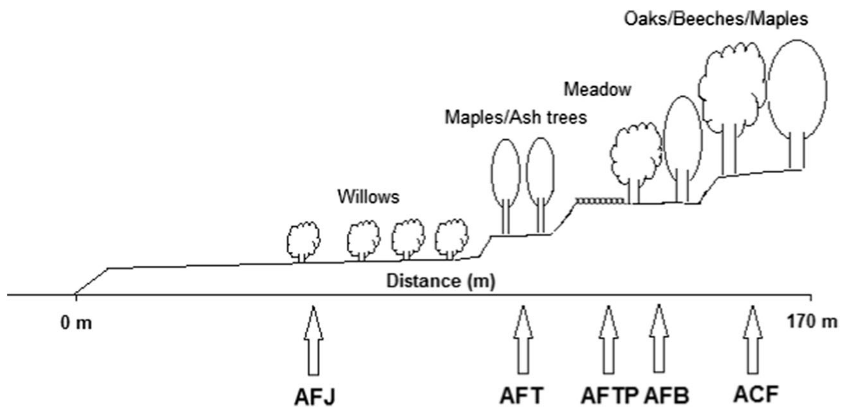


Fig. 1 River valley soil gradient according to vegetation type and alluvial terraces located at different distances from the river

et al. 2010), "cluster" (Maechler et al. 2013) and "party" (Hothorn et al. 2006) packages.

3 Results

Physical and chemical properties of river valley and urban soils are presented in the Supplementary material.

3.1 Alluvial soil gradient

Soil description and land use of alluvial soils are described in Fig. 2 and Table 1.

The physical and the chemical properties and the structuration of soils were different between soils of the valley (Fig. 2, Tables 1 and 3). The site ACF, at the border of the river and the hill influences, was the deepest soil profile with high clay content (>37.2 %) allowing a well-developed soil structure. This trend was also observed in the site AFB which was decarbonated in the first horizon. Both of these forest soils (Calcisols, IUSS Working Group 2007) showed also higher C_{org}, P_{tot}, $CaCO_3$ contents and CEC level compared to sites AFT, AFTP and AFJ (Supplementary material), these latter being weakly structured. Decarbonation of the first horizon was also described in the site AFTP with a reprecipitation of carbonates down in the soil profile. In the shallow Fluvisol (Calcaric Arenic) (IUSS Working Group 2007) near the river (site AFJ), the highest sand content and the lowest C_{org}, N_{tot}, P_{tot} contents and CEC level were observed (Supplementary material).

3.2 Urban soil gradient

Soil description and land use of urban soils are described in Fig. 3 and Table 2.

Three main soil groups were identified (Table 2). First, the site REFUFP was the oldest soil found in a relic of forest and was described as a natural urban soil (Calcisol, IUSS Working Group 2007). This soil profile was fully decarbonated with the highest clay content (49.5 %) found in all soil profiles (Supplementary material). Second, near natural urban soils (18thPD, 19thGR, 19thTU and 20thFS) identified as Cambisols (IUSS Working Group 2007) were characterized by a near natural sequence of horizons even if the soils were mixed by human activities. For these soils, the inherited soil structure and the original parent material were present. Finally, human-made soils described as Anthrosols and Technosols (IUSS Working Group 2007) were best delineated by different exogenous material layer deposits as described by the following qualifiers: "hortic", "terric", "technic", "spolic", "urbic" and "garbic" (IUSS Working Group 2007). Among them, an in situ development of the soil structure was observed in the

Table 1 Soil identification for the river valley gradient according to the distance of soils from the river

River valley soil name	Land use	Soil name (IUSS Working Group 2007)	Soil name (Baize and Girard 2009)
ACF	Oak, beech, maple forest	Hypocalcic Calcisol (Colluvic Clayic)	CALCOSOL fluvique, colluvial et profond
AFB	Oak, beech, maple forest	Hypocalcic Calcisol (Clayic)	FLUVIOSOL BRUNIFIÉ décarbonaté en surface, pierrique et polyphasé
AFTP	Meadow	Fluvic Cambisol (Calcaric Siltic)	FLUVIOSOL TYPIQUE décarbonaté en surface, pierrique et polyphasé
AFT	Maples and ash trees	Fluvic Cambisol (Carlcaric Siltic)	FLUVIOSOL TYPIQUE carbonaté, pierrique et polyphasé
AFJ	Willow bush	Fluvisol (Calcaric Arenic)	FLUVIOSOL JUVÉNILE carbonaté, lithique, pierrique et polyphasé

Table 2 Soil identification for the urban gradient according to soil age

Urban soil name listed according their age	Land use	Soil name (IUSS Working Group 2007)	Soil name (Baize and Girard 2009)
REFUFP	Oak forest	Luvic Hypocalcic Calcisol (Clayic)	CALCISOL lithique
18thPD	Lawn	Cambisol (Calcaric Siltic)	CALCOSOL-ANTHROPOSOL TRANSFORMÉ mélangé, nivelé, profond et à artefacts
19thGR	Lawn	Cambisol (Calcaric Siltic)	CALCOSOL-ANTHROPOSOL TRANSFORMÉ mélangé, nivelé, profond et à artefacts
19thJA	Lawn	Terric Anthrosol (Siltic)	ANTHROPOSOL RECONSTITUÉ carbonaté, nivelé, polyphasé, à matériau terreux et à artefacts
19thTU	Meadow	Cambisol (Calcaric Siltic)	CALCOSOL-ANTHROPOSOL TRANSFORMÉ mélangé, profond et à artefacts
19thTC	Meadow	Terric Anthrosol (Siltic)	ANTHROPOSOL RECONSTITUÉ carbonaté, nivelé, polyphasé, profond et à matériau terreux
20thFS	Oak and maple forest	Cambisol (Calcaric Clayic)	CALCOSOL-ANTHROPOSOL TRANSFORMÉ mélangé et profond
20thER	Lawn	Terric Anthrosol (Siltic)	ANTHROPOSOL RECONSTITUÉ carbonaté, nivelé, polyphasé, à matériau terreux et à artefacts
1930VL	Lawn	Terric Anthrosol (Siltic)	ANTHROPOSOL RECONSTITUÉ carbonaté, nivelé, polyphasé, à matériau terreux à artefacts
1933PL	Lawn	Terric Anthrosol (Siltic)	ANTHROPOSOL RECONSTITUÉ carbonaté, lithique, leptique, nivelé, polyphasé, à matériau terreux et à artefacts
1963WS	Lawn	Terric Anthrosol (Clayic)	ANTHROPOSOL RECONSTITUÉ carbonaté, nivelé, polyphasé, à matériau terreux et à artefacts
1970JR	Lawn	Urbic Garbic Technosol (Ruptic Calcaric Densic Siltic)	ANTHROPOSOL RECONSTITUÉ holorganique, carbonaté, compacté, rédoxique, nivelé, polyphasé, à matériaux terreux et technologique
1995RP	Meadow	Terric Hortic Anthrosol (Siltic)	ANTHROPOSOL RECONSTITUÉ carbonaté, holorganique, nivelé, polyphasé, à matériau terreux et à artefacts
1995HR	Meadow	Spolic Garbic Technosol (Ruptic Calcaric Siltic)	ANTHROPOSOL ARTIFICIEL carbonaté, nivelé, polyphasé, à matériau technologique
2005RU	Lawn	Terric Anthrosol (Siltic)	ANTHROPOSOL RECONSTITUÉ carbonaté, nivelé, polyphasé, à matériau terreux et à artefacts
2005PB	Meadow	Terric Anthrosol (Siltic)	ANTHROPOSOL RECONSTITUÉ carbonaté, lithique, nivelé, polyphasé, à matériau terreux et à artefacts
2010PR	Meadow	Terric Hortic Technic Anthrosol (Siltic)	ANTHROPOSOL RECONSTITUÉ holorganique, carbonaté, nivelé, polyphasé, lithique, à matériaux terreux et technologique
2010VM	Meadow	Terric Anthrosol (Siltic)	ANTHROPOSOL RECONSTITUÉ carbonaté, nivelé, pierrique, lithique et polyphasé

first soil horizon due to recent biological activity. Human-made soils were often younger and shallower with the presence of many artefacts, higher coarse fraction, sand and $CaCO_3$ contents compared to other soils (see Electronic supplementary material).

3.3 Relationships between soil gradients according to the physical and the chemical components of the soil

Differences between soil gradients were observed according to soil properties. Soil depth was positively correlated to soil age (r^2=0.358; p value=0.046) in urban soils, while the coarse fraction, the sand content and C/N were negatively correlated to soil age (respectively, r^2=−0.542, p value=0.001, r^2=−0.477; p value=0.005 and r^2=−0.464; p value=0.007, Table 3). In alluvial soils, pH_{H2O} and $CaCO_3$ were negatively correlated to soil distance from the river (respectively, r^2=−0.945, p value=0.015 and r^2=−0.926; p value=0.024), while CEC, C_{org} and N_{tot} were positively correlated to the gradient (respectively, r^2=0.928, p value=0.023, r^2=0.952; p value=0.013 and r^2=0.912; p value=0.031, Table 3).

However, similar trends were identified among soil gradients, especially for physical (soil depth, coarse fraction and particle-size distribution) and some chemical ($CaCO_3$, CEC, P_{tot}, N_{tot}, and C/N) variables even if correlations were not significant (Table 3). Moreover, alluvial soils were well clustered with two identified urban soil groups (Fig. 4). In group 1, the alluvial forest soils ACF and AFB were clustered with the

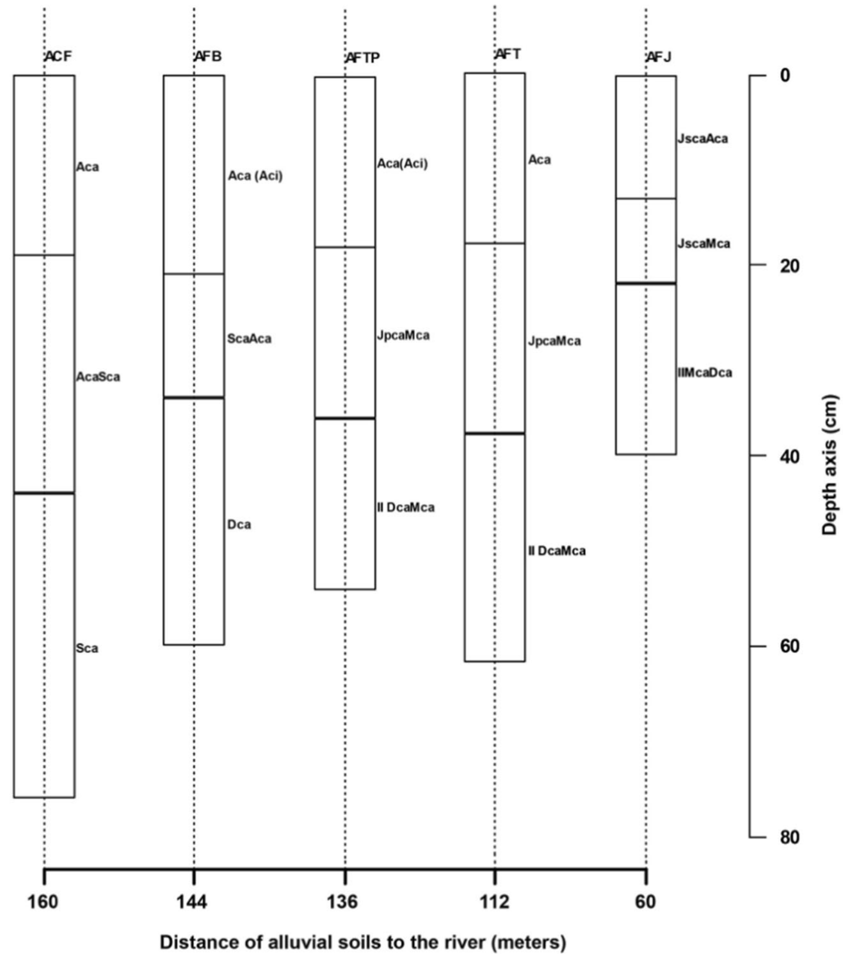


Fig. 2 River valley soil gradient according to the distance from the river. Definitions of soil horizons and indexes (Baize and Girard 2009) are *A* organomineral horizon, *Js* young topsoil horizon, *Jp* young subsurface soil horizon, *S* structural horizon, *M* loose material, *D* fragmented and deposited hard bedrock, *-ca* calcaric, *-ci* calcic

urban sites REFUFP, 20thFS (forest soils) and 1970JR. In the group 2, the alluvial sites AFTP, AFT and AFJ were associated with other urban soils (mainly meadows and lawns). These two soil groups were significantly different according to particle-size distribution (Fig. 5). Higher mean clay content was found in the group 1 with nine of the total 11 soil horizons recorded over than 35.2 % of clay content (Supplementary material). Conversely, coarse fraction (%) and sand content were often higher in soils of the group 2 compared to that of group 1 (Supplementary material). High P_{tot} content observed in the group 1 was mainly explained by the extreme mean P_{tot} value (15 times higher than other soils) observed in the site 1970JR (Supplementary material).

4 Discussion

4.1 Urban and alluvial soil analogies

Urban and alluvial soils are both perturbed systems in which their geneses vary according to the interaction between inheritance and in situ evolution (Bureau 1995; Bullinger-Weber et al. 2007). The main soil processes are often the result of the transfer of matter and the allocation of energy not only by humans or water but also by the activity of vegetation and soil organisms which contribute significantly to soil structure formation and organic matter dynamics (Lavelle et al. 2006; Gobat et al. 2013). Through the comparison of river valley and urban soil properties, we showed that soils on alluvial sediments were well clustered with urban soils. Two main soil categories were found at different stages of soil formation partly related to land use. (1) Thick forest soils which developed for centuries in situ were little affected by hydrological or human mechanical factors. These soils were evolved alluvial soils and natural (Calcisols, IUSS Working Group 2007) to near natural urban soils (Cambisols, IUSS Working Group 2007) with homogeneous structure. Higher clay, CEC and C_{org} contents were also found showing a good aptitude of these soils for the formation of the argillo-humic complex performed by soil organisms and vegetation (Gobat et al. 2013). Conversely, (2) young perturbed soils, mainly located in meadows and lawns, were shallower and were essentially formed by recent *ex situ* materials of different origins (e.g .

Table 3 Correlations between soil age vs physical and chemical variables in urban soils (18 sites) and between soil distance from the river vs physical and chemical variables in soils of the river valley (five sites). Data were calculated from the mean of physical and chemical parameters of soil horizons for each soil profile

Variables	Soil age (urban)		Soil distance (alluvial)	
	r (correlation coefficient)	*p* value (significance)	*r*	*p* value
Physical variables				
Soil depth	0.358	0.046*	0.858	0.063
Coarse fraction	−0.542	0.001*	−0.600	0.233
Clay	0.320	0.069	0.693	0.194
Silt	0.125	0.471	0.852	0.067
Sand	−0.477	0.005*	−0.803	0.102
Chemical variables				
pH H_2O[a]	0.124	0.501	−0.945	0.015*
$CaCO_3$	−0.281	0.112	−0.926	0.024*
CEC	0.412	0.017	0.928	0.023*
P_{tot}	0.118	0.495	0.658	0.227
C_{org}	0.033	0.850	0.952	0.013*
N_{tot}	0.243	0.161	0.912	0.031*
C/N	−0.464	0.007*	−0.704	0.184

[a] Calculated from the mean of $[H_3O^+]$

* *p*-value<0.05

technic qualifier, IUSS Working Group 2007) and textures either from recent floods or material deposits. Higher coarse fragment and sand contents were often found.

Few studies reported similar trends in natural alluvial (Gerrard 1992; Bullinger-Weber and Gobat 2006; Salomé et al. 2011) and urban soils (Bullock and Gregory 1991; Baumgartl 1998; Lefort et al. 2007). For example, Lefort et al. (2007) found higher sand, lower CEC and C_{org} contents in human-made soils compared to natural or near natural urban soils. These differences can be explained mainly by the origin and the nature of soil layer deposits which often constitute the limiting factor of pedogenetic processes (Pickett et al. 2001). In our case, the effects of soil perturbation are primarily physical, but indirectly, the biological and the chemical components of the soil are affected (Bullock and Gregory 1991; Guenat et al. 1999; Bullinger-Weber et al. 2007).

However, as observed in soils of river valleys, natural pedogenetic processes are not excluded in newly formed urban systems. If soil profiles showed an evidence of stratification of different soil layer deposits in our study, an in situ development of the soil structure may be present in the topsoil (Bureau 1995; Bullinger-Weber and Gobat 2006). In an artificial soil, Strehler (1997) also reported initial stages of soil formation which were close to alluvial soils following earthworm and root activity in few years, as for example, the rapid formation of bioaggregates. Decarbonation was also observed in few of our identified alluvial and urban soils, even if this process was difficult to detect in the urban

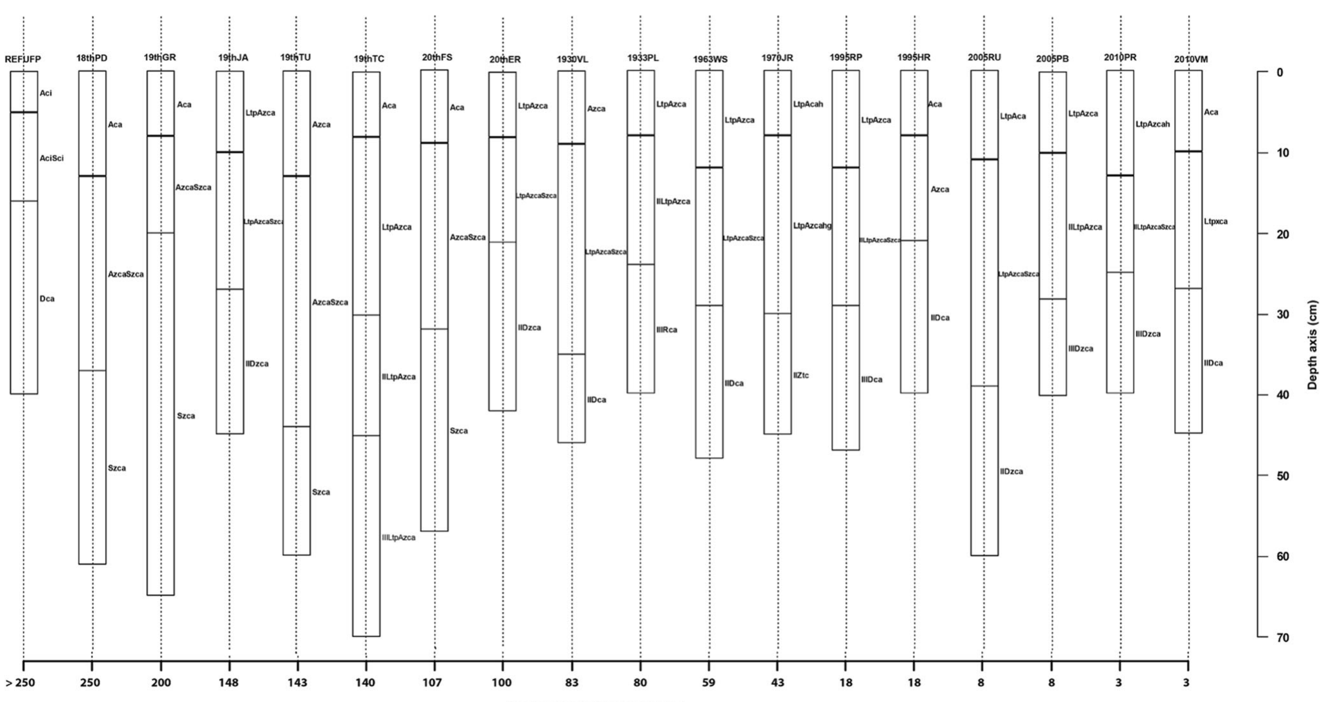


Fig. 3 Urban soil gradient according to soil age. Soils with the same age were ordered randomly. Definitions of soil horizons and indexes (Baize and Girard 2009) for the identified urban soils are *L* plowed soil horizon, -*tp* transported pedological or geological material, *Z* anthropological material (or -z if the volume <20 %), -*tc* technic material, *h* hologanic, *g* redoxic, *II*, *III*, or *IV* polyphase, *R* continuous hard bedrock

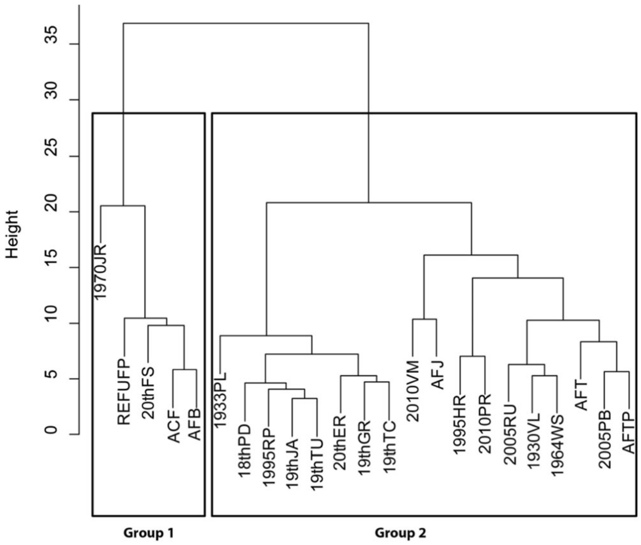


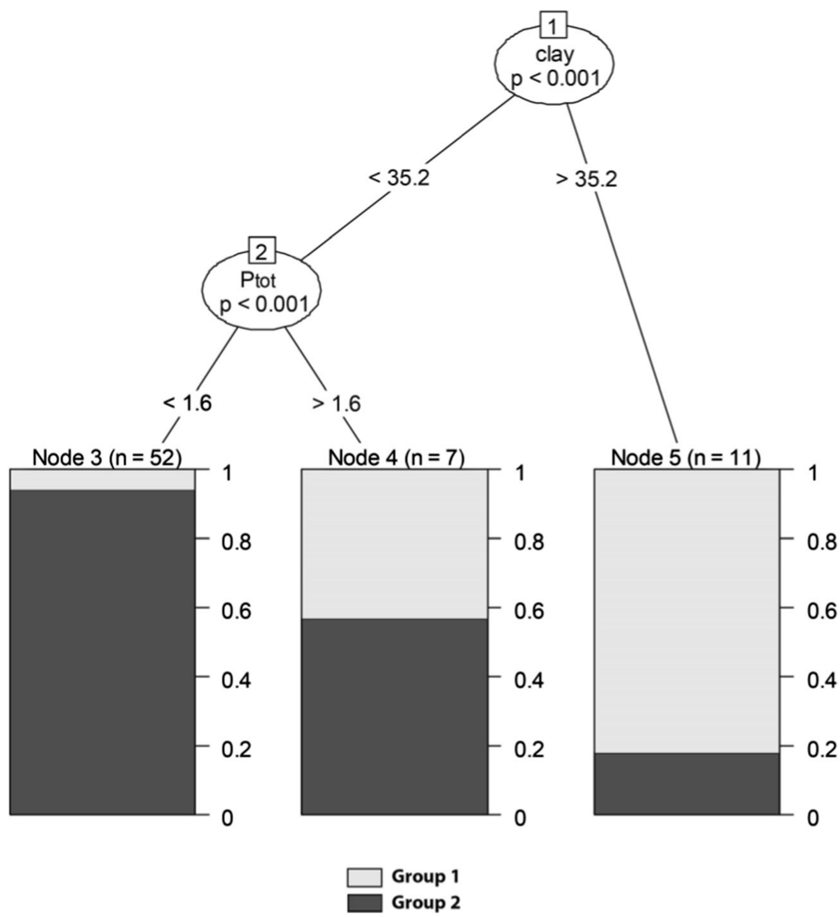
Fig. 4 Cluster dendrogram of urban and river valley soils based on physical and chemical properties of soils

ecosystem due to the permanent mix and/or input of calcareous particles on the soil surface. Nevertheless, Strehler (1997) found an active decarbonation in artificial soils with a reprecipitation of carbonates at the bottom of the organomineral horizon only after 15 years. The decarbonation process can constitute a good indicator of soil age (Bureau 1995, in Strehler 1997; Gobat et al. 2013). However, in urban or alluvial ecosystems, the heterogeneity of soil texture and the permanent instability lead to difficulty in the estimation of soil age. For example, Bureau (1995, in Strehler 1997) found that decarbonation varied between few decades to few centuries in Fluvisols (IUSS Working Group 2007), which constitutes too large of a temporal scale for our study.

4.2 Urban and alluvial soil differences

Soil processes are driven by physical, chemical and biological factors which can highly differ between soils, especially in disturbed systems such as alluvial and urban soils (Bullock and Gregory 1991; Petts and Amoros 1996; Bullinger-Weber et al. 2007). Although urban and alluvial gradients showed some similarities according to their morphology, the nature and the duration of soil processes in urban and alluvial soils may be differentiated (Strehler 1997; Prokofyeva et al. 2010). Our results showed that correlations between soil gradients with physical and chemical properties of soil varied in urban and river valley ecosystems. The river valley soil gradient was

Fig. 5 Ordinal regression tree of the two selected soil groups according to their physical and chemical properties. Values between 0 and 1 indicate the proportion of soil horizons for each identified soil group according to clay and P_{tot} contents (n=the total number of soil horizons)



correlated best with chemical variables, while the urban soil gradient was correlated best with physical variables. In alluvial soils, Bureau (1995) also reported that lower pH and higher organic carbon storage, nitrogen and CEC over time in the first soil horizon were explained mainly by soil and vegetation interactions. The differences observed between urban soils and soils of river valley are also most likely due to parent material, depositional conditions and land use (Bullock and Gregory 1991). In the urban context, soil age, based on well-documented historical periods, was defined according to the date of soil settlement but the “real” date of birth was difficult to estimate because most of soils were originally formed by geomorphic processes (Gobat et al. 2013). Several authors also reported an acceleration of soil pedogenetic processes due to human activities in urban soils (Strehler 1997; Baumgartl 1998; Vidal-Beaudet et al. 2012). This trend can be first explained by the nature of the deposit. In soils developed on alluvial sediments of our gradient, at least in low and medium parts of the river valley, initial deposits were often constituted of coarse mineral fraction and sand content with weaker soil structure due to the river influence (Bullinger-Weber and Gobat 2006). By contrast, in urban soils, most inherited *ex situ* well-developed materials such as terric horizons (IUSS Working Group 2007) were often finer textured in the surface layers. In theory, the older the soils are, the higher their evolution (Rossignol et al. 2007). However, it is not always the case in urban soils. For example, a “young” human-made soil (e.g. Technosol, IUSS Working Group 2007) can be constructed with formerly evolved soil layer material, explaining the clustering of young soils with native soils in the same soil group (group 2).

Moreover, if organic matter can constitute an interesting indicator of soil evolution in river valley ecosystems (Pautou 1984; Bureau 1995; Fierz et al. 1995), it remains difficult to apply it in the urban context. In urban ecosystems, organic matter quantity and their quality vary a lot between soils according to soil and land management modifying soil processes (Fierz et al. 1995; Vidal-Beaudet et al. 2012). First, the exportation of the litter can affect soil organic matter integration through the soil fauna activity. Second, most recent human-made soils (1970JR, 1995HR, 2010PR and 1995HR) were made with different organic amendments such as compost. The effects of the input of “anthropic” materials (organic or mineral) on soil processes are little known (Vidal-Beaudet et al. 2012) although Strehler (1997) showed a rapid organic matter turnover in urban soils compared to natural soils.

Other variables such as spatial deposition (diffused deposition vs linear deposition) or groundwater also play a key role on soil processes (Prokofyeva et al. 2010) and remain difficult to assess. In alluvial soils, water movement in soil is highly variable and controls part of soil processes including organic matter and nutrient dynamics (Pautou 1984; Petts and Amoros 1996). Conversely, in urban systems, the soil water content is often controlled by irrigating in order to maintain the existing vegetation. Stresses due to wetting and drying cycles are lower in urban systems compared to alluvial soils and the duration of soil processes likely differ.

5 Conclusions

Our study highlighted similarities and differences between the identified urban and river valley soil gradients. Physical variables were most strongly correlated to soil age in the urban context, while chemical variables were correlated best with the distance from the river in the Allondon valley. Regarding clusters of soil properties, similarities among urban and alluvial soils were identified at different stages of soil formation. Moreover, if anthropogenic pedogenetic processes are often considered as dominant in urban soils, and suppose to change the “natural” component of soils, natural processes such as decarbonation or the formation of well-developed topsoil were not excluded, as observed in soils of river valleys. The comparison of soil processes and their durations between urban and river valley soils still need more investigation, especially those related to parent material, depositional conditions, soil and vegetation interactions. This study contributes to the development of a natural reference for urban soils which is difficult to define because of the heterogeneity of parent materials and the various levels of soil disturbance in such systems.

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