Quantification of lessivage and impact of extreme climatic events on this process: An experimental approach

Laurence Quenard, Anatja Samouëlian, Isabelle I. Cousin, Sophie S. Cornu

Quantification of lessivage and impact of extreme climatic events on this process: An experimental approach

Laurence Quénard[A], Anatja Samouëlian[A], Isabelle Cousin[A], Sophie Cornu[B]

[A] INRA, UR 0272 Science du Sol, Centre de Recherche d'Orléans, CS 40001, 45075 Orléans cedex 2, France, Email laurence.quenard@orleans.inra.fr
[B] INRA Unité GSE, BP 80, 13545 Aix en Provence cedex 04, France, Email Sophie.Cornu@aix.inra.fr

Abstract
Understanding soil evolution requires characterising, quantifying, and modelling the major processes that govern pedogenesis. We proposed to study one of the most widespread processes in soils: lessivage, understood as the vertical transfer of fine particles from a horizon, called eluviated, to another horizon, called illuviated. Lessivage fluxes were never measured to our knowledge due to obvious technical difficulties. In addition, despite its description in many soil types, the existence of this process is somewhat controversial. We designed a laboratory experimental device to imitate the lessivage process and to test the impact i) of extreme events, as heavy rain, and ii) of the structure of the eluviated horizon on lessivage. We used a rainfall generator that allows the examination of the effect of rainfall on soil under controlled conditions. Two climatic modalities were tested: heavy rain on dry soil and small intensity rainfalls on wet soil. We present here the first results of these experiments.

Key Words
Clay translocation, eluviation, illuviation, loamy material, pedogenesis

Introduction
Many soils, particularly in temperate environments, exhibit superficial horizons depleted in fine particles (<2µm) compared to deeper horizons. Different processes can lead to this textural contrast. These soils may result from a geological contrast: weathering of different parent materials or surface deposit of coarser materials. Jamagne (1978) showed that some of these soils resulted thus from lessivage of fine particles from the upper-horizon to the sub-surface horizon: the upper horizon is then depleted (phenomenon of eluviation) in fine particles, while the underlying horizon is enriched (phenomenon of illuviation). The diagnostic features of this process are the presence of clay coatings and clay enrichment in sub-surface horizons (or in some major or trace elements, which are preferentially bound to these particles). Baize (1989, 1995) and others described that some of the soils characterized by a strong textural differentiation as Planosols or clayey soils with surface depleted horizons, result from the lateral departure of clay particles and their export out of the solum via a temporary hypodermic groundwater. For Legros (2007) and Presley *et al*. (2004), accumulation of clay in the underlying horizon results from the in situ weathering of primary minerals. For Phillips (2007), bioturbation also plays a role in the formation of texturally contrasted profiles. However the action of the soil macrofauna is also described as a homogenizing effect of the upper horizons (e.g. Faivre and Chamorro, 1995).
Finally, the lessivage is usually the most common way to explain textural contrast. It is the major process responsible for the formation of Luvisols, which are well spread in the northern half of Europe, in Quaternary Loess, this material being favourable to the development of these soils. Nevertheless it has never been measured by experiments due to technical difficulties.
The objective of this study is to implement a laboratory experiment to quantify the vertical transfer of particles (departure and accumulation) under different climatic conditions: a typical winter rain train on wet soil and a heavy rain event on dry soil. We performed this experiment on soil horizons sampled in different Luvisols with contrasted mineralogical and physico-chemical properties.

Principle of the experiment
Two laboratory experiments were designed. The first one focuses on eluviation and the second one on illuviation. Two factors governing the lessivage were tested: climate and soil structure. For climate, we chose to simulate i) a summer heavy rain on a dry soil monolith and ii) a low intensity winter rain on a wet soil monolith. The structure is tested only for eluviation by using either undisturbed soil horizons or remoulded soil sample.
Eluviation was simulated on a column made of the superposition of a loamy soil horizon (called L1) on a bed of pure quartz and of silt size (called LQ) (Figure 1). We followed the gradual release of L1 particles and

their trapping in the LQ after several rain events. Free drainage was applied at the basis of the quartz bed. During rain events, we avoided long duration waterlogging phenomenon by rainfall interruption in order to not introduce other processes as oxydo-reduction. Between two rain events, the soil columns were allowed to dry up in order to recover their initial water content. The water content in the column was monitored by tensiometers placed at different depths in the column. After several rain events, two monoliths were removed from the experiment and sub-sampled. The incorporation of particles to the quartz bed was quantified by sorting the mobile fraction from the quartz bed and characterizing the clay particles by X-ray diffraction, measurement of the CEC and measurement of the specific surface of this fraction. Indeed, as the quartz used for the quartz bed (LQ) was pure, any clay particle detected in LQ would come from the L1 eluviation.
The associated porosity evolution was also quantified by X-ray tomography.
Illuviation was simulated on a column made of a loamy soil horizon (L1) lying on a second monolith of a loamy soil horizon (called L2) having contrasting mineralogical and physico-chemical properties (Figure 1). The two superposed monoliths were laid on a quartz bed (LQ) to avoid free drainage at the base of L2.

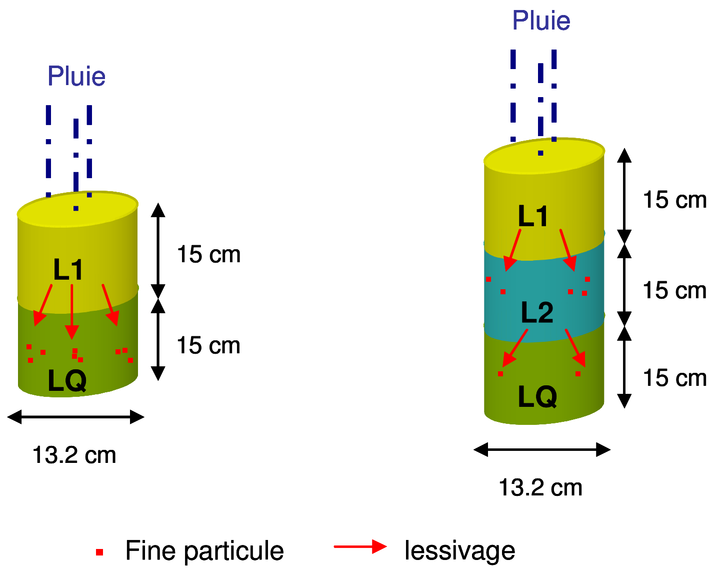

Figure 1. Schematic diagrams of the two experiments: a) Eluviation, b) Illuviation.

Dimensioning of the experiment

Characteristics of the chosen loamy materials and of the repacked columns

As mentioned above the two loamy materials were chosen for their contrasted characteristics in terms of mineralogy, CEC and specific surface of the fraction less than 2 µm. In addition, L1 physico-chemical characteristics were chosen to favour eluviation, say a pH comprised between 5.5 and 6.5; the L2 chemical characteristics were chosen to favour illuviation, say a pH higher than 7.
The chosen L1 was sampled at "Heurtebise" 10km from Chateau-Thierry in the Paris Basin. Its clay mineralogy is largely dominated by smectites, its water pH is of 5.80 and its CEC measured by the cobaltihexamine methods of 10.8 $cmol^+/kg$.
The soil and quartz cylinders height has been set at 15 cm. The undisturbed soil cylinders were sampled in the field and stored at 4°C to avoid evolution of the soil structure by biological activity. The remoulded cylinders were build by repacking soil aggregates dried at 40°C and sieved at 4mm, at a bulk density equal to 1.45 $g.cm^{-3}$, which was a bulk density close to the one observed in the field.

Climatic conditions

The heavy rain event had an intensity of 20mm/h and occurred on a dry soil whose water content was equal to 10%. The classical winter rain event had an intensity of 6 mm/h and occurred on a moist soil with a water content of 20%. These conditions were determined on the basis of climatic records.
We decided to apply rainfall of 40 mm that was equivalent to the porosity volume of the repacked L1. For the heavy rain intensity (20mm/h), 40mm were applied in 4 rains of 30 minutes, separated each by 30 minutes to avoid pounding at the surface of the columns. Under these conditions, only limited pounding occurred. The columns were let to dry for three weeks to return to their initial water content (10% water). After that drying period, a new period of rainfall was applied in the same conditions. These successive

operations (wetting by rainfall and drying by evaporation) were repeated at least ten times.
For small intensity rainfalls (6 mm/h), we applied 40 mm in 3 rains of 2 hours separated each by 24 hours. As for the 20mm/h intensity, only limited pounding occurred on the monolith surface. In one week of drying, the column returns to its initial water content (20% water). As for the other rainfall intensity, the whole process was repeated ten times.

Expected results and conclusions

Three rain events were applied for the heavy rain conditions. One column was the removed from the experiment and sub-sampled. Analyses are ongoing. Result will allow determining the quantities and the nature of the eluviated materials. Longer series of rain events will be conducted to monitor the evolution within time of the eluviated quantities and of its nature, first on disturbed soil and then on soils collected in situ.
This experiment allowed quantifying eluviation and its kinetics. We will then quantify illuviation and its kinetic. The combination of the two experiments allowing quantifying lessivage will help in characterizing the temporal evolution of this process in order to model it and ultimately integrate this lessivage model into a larger model of soil evolution.

References

Baize D (1989) 'Guide des analyses courantes en pédologie'. (INRA édition: Paris).
Baize D (1995) Les sols argileux appauvris en argile sous climat tempéré humide. Planosol texturaux, Pélosols différenciés et autre solum. *Etude et Gestion des Sols* **4**, 227-240.
Faivre P, et Chamarro C (1995) Facteurs biotiques et mécanismes de lessivage particulaire dans les sols. L'exemple des toposéquences caractéristiques des Andes de Columbie. *Etude et Gestion des Sols* **1**, 25-42.
Jamagne M (1978) Les processus pédogénétiques dans une séquence évolutive progressive sur formations limoneuses loessiques en zone tempérée froide et humide. *Comptes Rendus hebdomadaires des Séances de l'Académie des Sciences* **286**(1), 25-27.
Legros JP (2007) 'Les Grands Sol du Monde'. (Presses Polytechniques et Universitaires Romandes: Suisse).
Phillips JD (2007) Development of texture contrast soils by a combination of bioturbation and translocation. *Catena* **70**, 90-104.
Presley DR, Ransom MD, Kluitenberg GJ, Finnell PR (2004) Effect of thirty years irrigation on the genesis and morphology of two semiarid in Kansas. *Soil Science Society of America Journal* **68**, 1916-1926.