

Impact of drainage on soil evolution: A morphological quantitative approach

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Abstract

In order to better understand the process of morphological degradation and the impact of drainage on this process, morphological evolution of soil volumes was studied using image analysis of decimetric soil monoliths in Albeluvisol sampled along a soil sequence perpendicular to a drain. The geomorphological interrelationships of four different volume types (black, white-grey, pale-brown and ochre) are quantified. Results show that morphological degradation progresses by the progressive transformation of the ochre volume into pale-brown from their inner, around porosity, and their border. Black volume is simultaneously formed by centrifugal condensation of Mn into the ochre volume. As the process goes on, with decreasing distance to the drain, the ochre volume is atomised and the black volume is released into the pale-brown matrix. This pale brown matrix is further transformed into a white-grey volume formed into its core by centripetal evolution.

Key Words

Luvisols, agricultural practices, pedogenesis, image analysis

Introduction

Human activities were early recognized as a factor affecting soil evolution (Bidwell and Hole, 1965; Yaalon and Yaron, 1966), but their impact on soil evolution were poorly quantified. Montagne *et al.* (2007, 2008) showed that drainage modifies morphological degradation in Albeluvisols. This phenomenon consists in a combination of eluviation of clay minerals and redox processes (Jamagne, 1978; Pedro *et al.*, 1978; Dreissen *et al.*, 2001). Over time these elementary soil processes induce the formation of a complex juxtaposition of bleached eluvial soil volume (E) with a residual soil volume of the illuvial Bt-horizon. However the mode of propagation of these processes in soil and their consequences on the geometry of the different soil volumes were, to our knowledges, never studied, neither under natural conditions nor under the influence of soil drainage.

Redox processes evolve through transforming fronts as defined by Boulet *et al.* (1982), Fritsch *et al.* (1986) and Lucas *et al.* (1988) among others. These fronts correspond to a succession of mineralogical and chemical transformations (Fritsch *et al.*, 1986). Description of the progression of these fronts as well as the locus of segregation allows characterising soil processes. Such fronts were used to map soil spatial distribution at the landscape scale (Boulet *et al.*, 1982; Fritsch *et al.*, 1986; Lucas *et al.*, 1988) but rarely characterised at a decimetric scale (Lucas, 1989), which is the scale of propagation of the morphological degradation.

In this paper we aimed at demonstrating how the process of morphological degradation propagates with the distance to the drain. We used a meso-morphological approach based on image analysis of pictures of decimetre size from soil monoliths sampled at four distances to the drain. The objective is to identify how the different pedological volumes derived from each other and if the process is centripetal or centrifugal.

Methods

Site and soil

The studied Albeluvisol, developed in Quaternary loam, lies on the crest of the Yonne plateau (France). It is cultivated since at least 200 years and shows the following succession of horizons: (i) the ploughed horizon; (ii) a silty E-horizon; (iii) a horizon constituted by a complex mixture of several soil volumes of distinct colours and called E&Bt-horizon hereafter. Its most abundant volumes are silty and white-grey to pale-brown and its less abundant ones are clayey and ochre with black concretions and impregnations; (iv) the Bt-horizon which upper part is degraded.

In the studied plot, a subsurface drainage network was installed, in 1988 (16 years before sampling), by subsoiling, perpendicular to the main slope, at 1 m depth and spaced 15 m apart. We dug a 4 m long trench perpendicularly to one of the drains, providing the following macroscopic observations. (i) The thickness of the different horizons does not vary along the trench. (ii) As the distance to the drain decreases from 2 to 0.5 m, the quantity of white-grey, pale-brown and black soil volumes increases both in the E&Bt- and in the

degraded Bt-horizons. On the contrary, the clayey ochre soil volume decreases. (iv) Beyond 2 m from the drain, the amounts of the different soil volumes do not change significantly.

Sampling, image acquisition and analysis

We sampled four decimetric soil monoliths in the Eg&Bt- horizon along a soil sequence comprising portions affected and unaffected by soil drainage, at four distances to a drain: 60, 110, 210, and 400 cm, the last distance being considered as a reference. The surface of each monolith (in a horizontal x, y-plane) was photographed in colour (RGB mode) using natural light, with a resolution of 450 μm per pixel. A 1.5 cm slice from the monolith surface was then cut off with a knife. The new face was then photographed. This was repeated over the whole monolith thickness, i.e. 8 times.

Image analysis was based on (i) a supervised training method using ERDAS IMAGINE[®] (www.erdas.com) to assign the different pixels to the different types of soil volumes and (ii) ArcInfo[™] (www.esri.com) for characterisation of the morphology of the different soil volumes.

Results

Morphology of the different soil volumes at the reference position (400 cm to the drain)

At 400 cm to the drain, the surface of the ochre and pale-brown volumes are almost equivalent, each one covering about 45 % of the total surface while the white-grey and black volumes exhibit considerably smaller surfaces (less than 10 % each) (Figure 1). The ochre volume mainly neighbours the pale-brown one, the black volume the ochre one, and the white-grey volume the pale-brown one. The lengths of the perimeter of the different pedological volumes rank like their relative surfaces; however, the ratio perimeter/surface (called relative perimeter for simplicity) of the different volumes is larger for the black volume, followed by the white-grey volume. The smallest relative perimeters are recorded for the ochre and pale-brown volumes. A pedological volume is composed of several distinct items for which some characteristics (number, surface, etc.) were quantified. At 400 cm to the drain, the different pedological volumes are in about the same number of items. But if the number of items composing a pedological volume is considered relative to its surface, the larger numbers of items are recorded for the black volume, followed by the white-grey volume. These numbers are much smaller for the ochre and pale-brown volumes than for others.

Some pedological items include items of another pedological volume: the last can be considered as a hole in the first (Figure 1). These holes are mainly located in the ochre and pale-brown volumes. They are mainly black and pale-brown in the ochre volume and mainly white-grey and ochre in the pale-brown volume (Figure 1).

From these results we can conclude that pale-brown and ochre volumes consist in large items and that white-grey and black soil volumes occur as small items embedded into respectively the pale-brown and ochre volumes. The morphological relationship between pale-brown and ochre volumes is more complex as both form holes in the other. As the ochre volume is considered as residuals, this morphological distribution means that ochre volume is transformed into pale-brown volume both from its core and its border, white-grey volume being a further evolution step occurring only in the pale-brown volume.

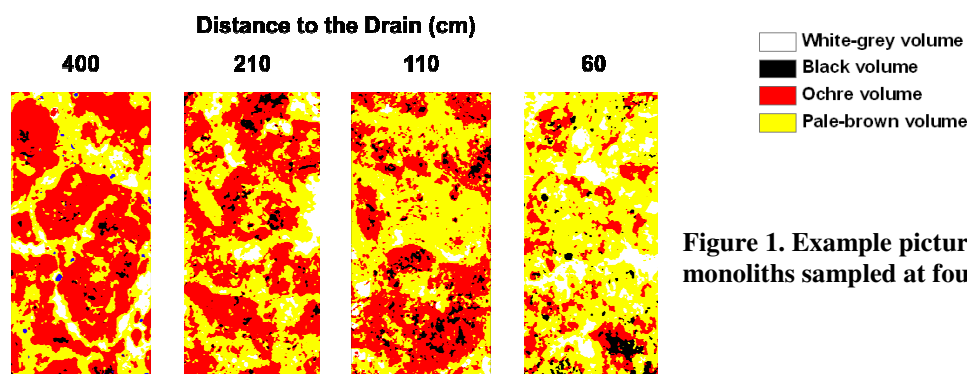


Figure 1. Example pictures representative of the monoliths sampled at four distances to the drain.

Evolution of the volume morphology with the distance to the drain

The relative surface of the different pedological volumes varies with the distance to the drain: the ochre volume surface decreases significantly with the distance to the drain, while the surface of the other volumes increases (Figure 2).

The contact length between the ochre and the pale-brown and between the black and the ochre volumes increases significantly when moving from 400 to 210 and 110 cm to the drain respectively and then decreases significantly from 110 to 60 cm to the drain, while the length of contact between white-grey and

pale-brown volumes is significantly higher at 60 cm to the drain. At this last position, the black volume comes into contact with the pale-brown one.

While the distance to the drain decreases, the perimeter of the white-grey, black and pale-brown volumes increases significantly (Figure 2). The perimeter of the ochre volume increases significantly from 400 to 210 cm to the drain, stabilizes from 210 to 110 cm and then decreases significantly from 110 to 60 cm. In terms of relative perimeter, the only significant variations observed with the decrease of the distance to the drain are an increase for the ochre volume and a decrease for the pale-brown one.

While the distance to the drain decreases, the total number of items increases significantly for three of the four soil volumes (black, white-grey and ochre; Figure 2). The number of items of the pale-brown volume increases significantly from 400 to 210, stabilizes from 210 to 110 cm and then decreases significantly from 110 cm to 60 cm to the drain.

The relative number of items of the ochre volume increases significantly as the distance to the drain decreases. The relative number of items for the black volume increases significantly from 400 to 210 cm and decreases to return to its initial value for distances below 2 m to the drain. No trend with the distance to the drain is observed for the relative number of items of the white-grey volume, while this relative number is significantly lower at 60 cm to the drain than at the other distances for the pale-brown volume.

The number of holes in the ochre volume significantly increases from 400 to 110 cm to the drain and then sharply decreases at 60 cm just as the number of holes in the pale-brown volume increases suddenly (Figure 2). These trends are also observed as the number of holes per surface unit is considered. The number of black holes in the ochre volume increases from 400 to 100 cm to the drain and then decreases strongly to reach, at 60 cm, the number observed at 400 cm. The number of pale-brown holes increases when moving from 400 to 210 cm, stabilizes from 210 to 110 cm and decreases, when moving to 60 cm, to half that number at 400 cm. In terms of surface of the holes, the evolution with the distance to the drain is somewhat different. The surface of the black holes in the ochre volume is stable from 400 to 210 cm to the drain, but increases from 210 to 110 cm and then decreases strongly at 60 cm with a surface at 60 cm half of that measured at 400 cm. The surface of the pale-brown holes increases slightly from 400 to 210 cm to the drain and then decreases until 60 cm.

The number of ochre holes in the pale-brown volume increases from 400 to 210 cm then stabilizes, while the number of white-grey holes increases at 60 cm. The surface of the ochre holes increases from 400 to 60 cm to the drain, while the situation is more complex for the white-grey holes with nevertheless a higher surface at 60 cm.

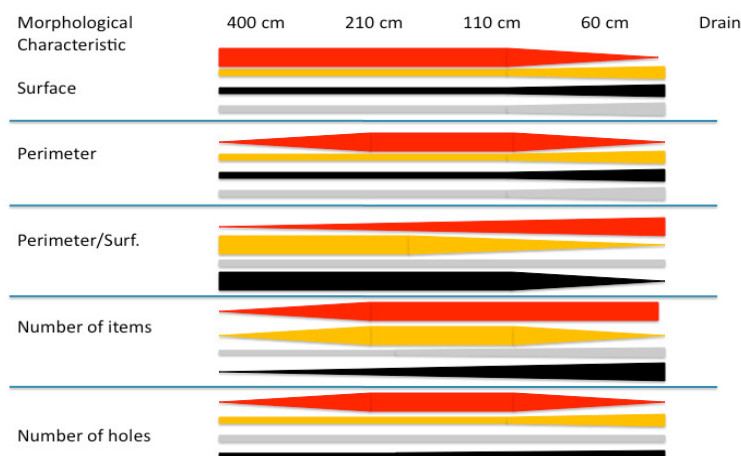


Figure 2. Evolution with the distance to the drain of the main morphological characteristics for the different soil volumes: ochre (in red), pale-brown (in yellow), black (in black) and white-grey (in grey).

We calculated the constant of Euler-Poincaré for the different soil volumes at the different distances to the drain. This constant represents the connectivity of a volume: it is positive for disconnected objects and negative for objects with redundant connections, i.e. with holes. In the studied images, the constant is positive for the white-grey and black volumes and negative for the pale-brown volume whatever the distance to the drain. For the ochre volume, the constant is negative from 400 to 110 cm to the drain and positive at 60 cm to the drain, meaning that, at this last distance, the ochre volume is composed by small disconnected items, while it was constituting a more or less connected matrix with the pale-brown volume at the other distances (Figure 1).

These results show that, with the distance to the drain, the ochre volume that constitutes the matrix at 400 cm to the drain is progressively transformed into a pale-brown volume. The black volume is first formed into the

ochre volume and then released into the pale brown matrix at 60 cm to the drain where the ochre volume partially disappears. Transformation of the ochre volume into pale-brown occurs both by the inner of the ochre items, around pores, and at the border of the ochre items. The process acts first by indentation of the ochre items, from 400 to 110 cm to the drain, that are then atomised at 60 cm to the drain.

Conclusion

Montagne *et al.* (2008) showed that the black volume has the same composition in clay and goethite than the ochre one, but are slightly richer in ferrihydrate and largely in Mn-oxides, while the pale-brown volume is mainly impoverished in goethite and ferrihydrite and the white-grey volume is further impoverished in those minerals and in Mn-oxides compared to the ochre volume. The morphological analysis confirms that the pale-brown volume results from the alteration of the ochre volume and the white-grey one from the further alteration of the pale-brown volume as no white-grey volume was recorded in contact with the ochre one. This analysis also confirms that black volume results from the centrifugal condensation, into the ochre volume, of Mn and secondarily Fe released from the alteration of the ochre volume. As the process progresses along the drainage sequence, progressive indentation and final atomisation of the ochre volume is responsible for the release of the black volume into the pale-brown matrix. Ochre volume alteration takes place both at the border and in the volume, along pores, as demonstrated by the geometry of the pale-brown and ochre volumes. Finally, the formation of the white-grey volume from the pale-brown one occurs in the core of this last one and is centripetal.

These preliminary results allow concluding that the transformation evolutions by drainage are both centrifugal and centripetal. Centrifugal evolutions of the ochre volumes can be due to physical transfer of particles via preferential flows occurring in the clear volumes, while centripetal evolution could correspond to the redox processes. Quantification of the respective importance of centrifugal versus centripetal evolution will thus allow quantifying the relative importance of the two processes in the morphological degradation phenomenon that is well spread in soils but still insufficiently characterized.

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