Criteria and Mathematical Expressions for Evaluating an Illuvial Accumulation of Clay in Luvisols

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Abstract. One of the most important aspects of soil development is to establish the initial states of the parent material and of the soil material at each position of the soil profile. Luvisols have a higher clay content in the argic horizon than in the eluvial horizon, as a result of pedogenetic processes, especially clay migration. The illuvial nature of the argic horizon may be established using a lot of criteria and the quantity of migrated clay can be calculated with mathematical expressions. For Luvisols situated in the south-western zone of Romania, named region Banat, have been effectuated the next analysis: particle-size, chemical, mineralogical for index minerals present in the nonclay fraction, mineralogical for clay fraction – X-ray, differential thermal and infrared. Calculations for the amount of clay formed at each horizon or less at each horizon were made using some mathematical expressions. Luvisols cover in the south-west of Romania an area of 427779 ha, representing 26.51% from the total area of 1,613,538 ha. The scientific research was made on an Albic Luvisols – Lalasint, formed from a Cretaceous flysch, composed of conglomerate and silicate with pieces of quartzite. Calculation of the fine sand/coarse sand ratio, the quartz and feldspar content at each horizon, the change of index minerals with depth, and the eluviation index (k) calculated with the mathematical expressions, allowed to establish the quantities of clay migrated on the soil profiles and the uniformity of the soil material. In the soil type the soil materials were initially bistratified and during soil forming processes clay migrates down into an argic horizon.

1. Introduction
In the natural environment the Pedosphere is in a strong relationship with the Lithosphere (parent material), Atmosphere (climate), Biosphere (Fauna and Flora) and Hydrosphere (water) at which can be added Geomorphology and the new distinctive geological period „Anthropocene”.

In fact, in the 21st Century there are many threats to soil as a result of our activities within the environment [1]: loss of soil, contamination, inundation, decline in soil organic matter soil compact, salinization, decline in soil biodiversity, and loss of soil through sealing.

The development of soils is highly influenced by processes that redistribute mass at the surface, but also within the soil profile [2].

One of the most important aspects of soil development is to establish the initial states of soil material of each horizon. For evaluating soil profile development a mineralogical analysis of coarser fractions for primary minerals, and of finer fractions for secondary minerals, such as clay minerals.

Primary minerals, inherited from the parent rocks, make up the main part of the sand and silt fractions of most soils [3].
Because of the great variety of parent materials of soils there are a variety of criteria for establishing uniformity: particle-size analysis, particle – size distribution of the whole nonclay and clay fraction, total mineralogical analysis, with a great attention to resistant and non-resistant minerals. A constancy of the particle – size distribution pattern indicates that the soil profile was formed from a uniform parent material [4][5].

Barshad (1964) and Wambeke (1972) [6] proposed a method for measuring gain and losses or other changes that may occur during soil formation.

Barshad recommended as index mineral zircon, tourmaline, garnet, anatase or rutile, quartz, albite and microcline.

Wambeke proposed some mathematical expressions for calculating clay formation and migration on the soil profile.

The present thesis deals with the soils with pedogenetic clay differentiation, especially clay migration between a topsoil with a lower and a subsoil with a higher clay content, like Luvisol [7][8]

2. Materials and methods
The study proposed for evaluating clay formation, clay migration and parent material uniformity has been made in a hilly area named Dealurile Lipovei, in the south-west of Romania, near the settlements Lalașinț.

Since the soil material may be defined as possessing distinct morphological, physical, mineralogical and chemical properties, they were determined particle – size distribution, light and heavy minerals with polarizing microscope, clay minerals by X-ray analysis, differential thermal analysis, and infrared analysis.

Using the real analytical data, we have calculated the uniformity of soil material and the eluviation index (k) with the mathematical expressions recommended by Wambeke (1972).

3. Results and discussions
The paper is based on a pedological report with soil profile description and sampling. The results of the profile description with its morphology, and of the particle – size, chemical and mineralogical analysis are presented in table 1.

This soil is named, in the World Reference Base for Soil Resources (WRB - 2014) [9,10] as Albic Stagnic Luvisol, similarly with Romanian Soil System Taxonomy (2012) [11]. The main diagnostic criterion is the presence of an argic horizon, with an illuvial accumulation of clay or destruction of clay in the surface horizon. There are some differences between WRB and Romanian system in the characterization of the argic horizon of the clay content:

WRB:
- if the coarser textured horizon has < 10% clay, the argic horizon has ≥ 4% more clay;
- if the coarser textured horizon has > 10% clay, and < 50 % clay, the ratio of clay in the argic horizon (B/A) is ≥ 1.4;

SRTS:
- if the coarser textured horizon has < 15 % clay, the argic horizon has > 3% clay;
- if the coarser textured horizon has 15-40% clay, the ration B/A is ≥1.2.
### Table 1. Analytical data – Albic Stagnic Luvisol [12]

| Analysis                           | Ao                  | Ea                  | EaBtw               | BtW                  | BtC                  |
|------------------------------------|---------------------|---------------------|---------------------|----------------------|----------------------|
| Particle – size distribution, %    |                     |                     |                     |                      |                      |
| Coarse sand, 2-0.2 mm              | 2.0                 | 2.0                 | 3.0                 | 7.0                  | 25.0                 |
| Fine sand, 0.2-0.02 mm             | 37.2                | 35.2                | 34.6                | 30.6                 | 16.2                 |
| Silt I, 0.02-0.01 mm               | 15.0                | 18.7                | 16.4                | 10.0                 | 3.5                  |
| Silt II, 0.01-0.002 mm             | 16.8                | 16.4                | 16.8                | 8.3                  | 2.9                  |
| Clay, < 0.002 mm                   | 29.0                | 27.7                | 29.2                | 44.1                 | 52.4                 |
| Particle – size ratio              |                     |                     |                     |                      |                      |
| CS+FS+S1+SII=100%                  |                     |                     |                     |                      |                      |
| CS - coarse sand, %                | 2.8                 | 2.7                 | 4.2                 | 10.5                 | 32.0                 |
| FS - fine sand, %                  | 52.3                | 48.6                | 48.8                | 54.1                 | 20.8                 |
| S I - silt I, %                    | 21.1                | 25.8                | 23.1                | 17.1                 | 44.5                 |
| S II - silt II, %                  | 23.6                | 22.6                | 23.7                | 14.8                 | 3.7                  |
| FS/CS                              | 18.6                | 18.0                | 11.6                | 5.2                  | 0.6                  |
| Minerals in the granules %         |                     |                     |                     |                      |                      |
| Quartz                             | 31.62               | 15.35               | 25.27               | 13.92                | -                    |
| Feldspar                           | 7.41                | 9.55                | 20.74               | 18.78                | 12.44                |
| Quartz/Feldspar                    | 4.27                | 1.61                | 1.22                | 0.74                 | 0                    |
| Zircon                             | -                   | -                   | 0.80                | 0.98                 | -                    |
| Clay minerals, %                   | -                   | -                   | -                   | 52                   |                      |
| Smectite                           | 30                  | 42                  | -                   | -                    |                      |
| Chlorite                           | 62                  | 49                  | -                   | 40                   |                      |
| Illite                             | 8                   | 9                   | -                   | 8                    |                      |
| Kaolinite                          |                     |                     |                     |                      |                      |

Profile description – albic Stagnic Luvisol

0-19 cm, Ao (ochric horizon), 10YR5/3 moist and 10 YR4/6 air dry, loamy with friable granular structure;

19-37 cm, Ea (eluvial albic horizon), 10YR6/3 moist and 10YR6/4 air dry, loamy, sandy – loamy, weak platy structure, with yellowish spots;

37-48 cm, EaBtw, 10YR6/6 moist, loamy, angular blocky structure, rust – coloured spots, iron – manganese concretions;

48-67 cm Bt1W, 10YR5/8 moist, clay – loamy, prismatic structure, numerous spots and iron – manganese concretions, compact;

67-120 cm Bt2W, 7.5YR5/6 moist, clayey, prismatic structure, numerous and massive iron – manganese concretions, compact;

120-134 cm BtC, 7.5YR5/8 moist, clay with whitish skeletal segments of silicolithe.

There is a clear pedogenetic differentiation of clay content between Ao and Ea and B argic horizon, respectively 29.0 – 27.7 % content of clay in Ao and Ea, and 44.1 – 52.4% clay content in the argic Bt horizon, which means a ratio B clay/A+E clay of 1.52 – 1.89.

Since, as a rule, the largest proportion of the resistant minerals is confined to the coarser fractions, it is important to calculate the particle – size distribution of the hole nonclay fraction, which can indicate the soil material uniformity.
Towards to the sum of coarse sand + fine sand + silt, considerate as 100 %, the percentages of each of fractions were recalculated. The results indicate the presence of three stratification, at the levels 37 – 48 cm (FS/CS=11.6), 67-101 cm (FS/CS= 5.2) and at the depth 106-120 cm (FS/CS=0.6).

The existence of the stratifications is also supported by the particle – size distribution of resistant minerals as Quartz, Feldspar and Zircon, which have great variations at the depth 37- 48 cm and 67-101 cm.

Nature of clay minerals distribution is also relevant for the irregular distribution because smectite appears in the layers of 67-101 cm depth, and Illite disappear in the layer 37-48 cm depth. Because of the great variation of parent and soil material it is necessary to apply, also, a method for clay migration computation using the mathematical expressions proposed by Wambéke (1972). The computations need to use the following symbols:

- A – g. clay/100g mineral soil in the A horizon;
- B – g.clay/100g mineral soil in the B horizon;
- C – g. clay/100g mineral parent material;
- C’ – g.clay/100g mineral parent material present before clay migration from A and B horizons;
- Δ – the difference in the clay content, B-A;
- l – g.clay/100g mineral parent material migrated in the B horizon;
- k=l/C, eluvial index;
- P=horizon thickness;
- N – ratio Pb/PA

R=B/A

When the thickness of the A and B horizons are distinct, the ratio N= Pb/PA can be used.

In this case:

\[ \Delta = \frac{(1 + N) \cdot l \cdot (100 - C)}{100N + (1 - N) - l^2/100} \]  

from which can be solved l.

The rearrangement of the equation (1) in the form:

\[ \Delta l^2 + 100(1 + N) \cdot (100 - C)l - 100\Delta \cdot (99N + 1) = 0 \]  

permitted to computation the value l.

The data can be graphic represented and indicate that in order to achieve 10 % texture differentiation when the horizon l has 52.4 % clay is necessary to migrate 12.65 g clay see table 2.

For a specific N were calculated the values l depending on the values R and resulted see table 3;4

| Δ  | 10  | 15.17 | 20  | 30  | 40  | 50  | 60  | 70  | 80  | 90  | 100 |
|----|-----|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| l  | 12.65 | 19.66 | 24.61 | 35.32 | 44.70 | 52.75 | 59.55 | 65.4 | 70.35 | 74.64 | 78.32 |

The data can be graphic represented and indicate that in order to achieve 10 % texture differentiation when the horizon l has 52.4 % clay is necessary to migrate 12.65 g clay see table 2.

For a specific N were calculated the values l depending on the values R and resulted see table 3;4

| R  | 10  | 1.2  | 1.4  | 1.55 | 1.66 | 1.80 | 2.00 |
|----|-----|------|------|------|------|------|------|
| l  | 0   | 11.3 | 19.12 | 23.51 | 24.76 | 28.79 | 30.97 |

For the condition of WRB in order to be an argic horizon – ratio 1.4, it is necessary to migrate 19.12 g clay and for SRTS – ratio 1.2 it is necessary to migrate 11.3 g clay.
From the genesis point of view, it is convenient to calculate the eluviation index – k – which indicates the proportion of eluviated clay from A+E horizons.

Equation 3:
\[ \Delta C^2k^2 + 100C \cdot [\Delta (1 - N) - (N + 1) \cdot (C - 100) \cdot k - 100^2NA] = 0 \]

Table 4. Lalasint, N=1.6

| C  | 10  | 20  | 30  | 40  | 52.4 | 60  | 70  | 80  | 90  | 100  |
|----|-----|-----|-----|-----|------|-----|-----|-----|-----|------|
| k  | 1   | 0.63| 0.48| 0.42| 0.41 | 0.43| 0.49| 0.62| 0.94| 1    |

It is a valid observation that for opposed values of the clay content in the parent material, the eluviation’s index k is similarly:

C=20% clay, k=0.63 and
C=80% clay, k=0.62

Because the clay content from the parent material has a great variability, will be use the clay content from A and B horizons.

Then can be utilized the equation:

\[ C' = A + l \cdot \left(1 - \frac{A}{100}\right) \quad (4) \]

The analytical data from the soil profile see table 5 allow to calculate the quantities of migrated clay, the initial clay content in the parent material, the eluviation index and the texture differentiation index.

Table 5. Lalasint, soil index

| A  | B   | N   | l   | C'  | k   | \(\Delta\) |
|----|-----|-----|-----|-----|-----|-----------|
| 15 | 3.08| 17.62| 0.17| 4.06|
| 28.35 | 44.1| 1.6 | 6.4 | 28.81| 0.20| 6.83     |
| 40 | 11.31| 46.79| 0.24| 10.22|

It can be concluded that in a soil with fine texture, the process of clay migration is not possible because of the low level of permeability and consequently there is not an argic horizon.

4. Conclusions

The presence of diagnostic argic horizon is used to define Luvisols. The genesis of an argic horizon is resulted to eluviation of clay from an eluvial horizon near the surface. Textural differentiation is the main feature as diagnostic criteria, but there are too much, and this creates problems in the field.

For the purpose of evaluating and establishing uniformity of parent material and soil development were necessary some analyses like particle – size distribution, mineralogical analysis of the nonclay and clay fractions, and mathematical expressions which allows to calculate the quantities of migrated clay and the eluviation index. The results indicate for Luvisols – Lalasint the presence of three stratifications at the levels 37 - 48 cm, 67 - 101 cm and 106 - 120 cm.

It was also proved the usefulness of eluviation index (k) computation.

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