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SOIL BULK DENSITY AS IMPORTANT MANAGEMENT FACTOR AND ECOSYSTEM SERVICES WELL FUNCTION

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Abstract

The decisions for a good soil management need many points of support to substantiate the management strategy. These support points must reflect as accurately as possible the field reality. In the present paper, these support points are the physico-chemical characteristics of two Luvisols: one, the crop soil (P1) and other under pasture (P2). The two soils had been analyzed to pointed out how soil bulk density is an important key of soil fertility and consequently of the agriculture management and how influence the well function of an important ecosystem services as the „maintenance of soil structure“. Bulk density (BD) being considered as a referential parameter, it was compared with: packing density (PD), restricting bulk density (BDr), hydraulic conductivity (HC), and organic matter (OM) as parameters used to monitoring the structure quality. The results showed low differences between PD and BD values of both profiles, while the values of BDr drop drastically into the clayey horizons, matching perfectly with the higher clay content, and showed the stressed conditions for the roots in both soils. The HC depends not only on the poral space design, but also on the quality and quantity of the clay coatings that coated the pore walls. The illuvial constituents partially clog the pores, reducing the values of the poral space (as part of BD), and hence the HC. The BD, being one of the physical quantifying characteristics (that assessing quantitatively the water and air in soil) represent an important key of soil fertility and strongly influenced „maintenance of soil structure“ecosystem service, and consequently emphasized the quality of the agriculture management. The paper management recommendations place it on a direct path that meets the problems faced by the farmers, related to the Luvisols physical and mechanical properties (unfavorable aero-hydric conditions and high energy consumption and relatively short working period) on the general background of the increasingly severe climate changes.

Key words**:** *management, bulk density, ecosystem services*

INTRODUCTION

„Bulk density is defined as the mass of solids per unit volume of the soil“ [4]. It „is a simple soil attribute widely assessed by ecologists, engineers, and soil scientists“ [14].

„The bulk density of soil is a function not only of the soil composition but also of management factors such as compaction by machinery, tillage and cropping“ [5].

In soils with large contents of organic carbon, such as pasture soils, complexed organic matter is proportional to the clay content, which could explain why the bulk density is significantly correlated with organic carbon in the arable studied soils.

[4] showed that „bulk density is significantly correlated with organic carbon in the arable studied soils, while in the pasture soils it is significantly correlated with the clay content“.

The soil physic behavior is controlled by the amount of complexed organic carbon (with clay). According to [4], this complex is formed by the association of unit mass (i.e. 1 g) of organic matter with 10 g of clay (for their studied soils).

„Soil quality is usually considered to have three main aspects: physical, chemical, and biological; and it is considered to be important for the assessment of the extent of land degradation or amelioration, and for identifying management practices for sustainable land use“. [1]

„Similar to other soil properties (e.g. texture, infiltration rate and bulk density), soil organic carbon concentration and stock are highly variable over space (horizontally and vertically) and time“ ([6]; [15]; [9]).

[10] concluded in their work that „there are no values below which the soil structure suddenly collapses“.

„Nevertheless, there is a huge amount of literature that shows that decreases in organic matter content are associated with increasingly adverse soil physical conditions“. [1]

The objective of the present paper is to show how soil bulk density is an important key of soil fertility and consequently of the agriculture management and how influence the well function of an important ecosystem services as the „maintenance of soil structure“.

MATERIALS AND METHODS

Two Luvisols (Stagnic Albeluvisol – according to WRB-SR-2014; and Luvosol Albic Stagnic – according to SRTS-2012 respectively) had been studied.

The first soil (P1) is located in Neamţului Subcarphians, middle terrace of Moldova River. On plane relief at absolute altitude of 352 m, formed in loamy clayey deposits. The climate is characterized by a mean annual temperature of 7.8^{o}C and a mean annual precipitation of 635 mm. The evapotranspiration is 608 mm. The natural global drainage is good and the groundwater is at 7 – 9 m. The bioclimatic zone is forested with mixed forest: *Picea excelsa*, *Abies alba şi Fagus silvatica* cu *Dentaria glandulosa, Salvia glutinosa, Oxalis acetosela)*. The soil moisture regime is udic, while the temperature regime is mesic. The land use is arable (rye – *Secale cereale* – in the year of soil sampling).

The second soil (P2) formed in loamy clayey deposits, is located on the upper terrace of Agapia River, on flat relief at absolute altitude of 470 m. The mean annual temperature is 8.2^{o}C and the mean annual precipitation 672 mm. The evapotranspiration is 621 mm. The natural global drainage is good, while the groundwater is at 6 – 8 m. The zone is forested with mixed forest: *Fagus silvatica, Abies alba, Picea abies)*. The land use is pasture (*Agrostis tenuis, Lolium perenne, Trifolium sp., Poa annua, Medicago lupulina, Polytrichum communae, Juncus effusus*). The soil moisture regime is udic and the temperature regime is mesic.

The soil was sampling from each pedogenetic horizon and further analyzed (granulometry, bulk density, hydraulic conductivity, total porosity, aeration porosity, and organic carbon) according to ICPA Methodology.

RESULTS AND DISCUSSIONS

Luvisols are soils formed on the terraces, in stratified parent material. Therefore, their main physical characteristics depend mainly on the texture (inherited from the parent material).

The two soils (P1 and P2) have variable texture: from loamy (into the upper 53 cm corresponding to the Ap-EB horizon sequence, in crop soil; and 0 – 24 cm, Aț-Ao horizons respectively, in pasture) to loamy clayey (in the deeper Btw horizons of both soils).

The crop soil (P1) is deeper (comparing to the pasture), the eluvial Ea horizon is thicker (from 24 cm to 43 cm), and the clayey Btw horizon started at 65 cm.

Under pasture, the eluvial Ea horizon is thinner (from 24 cm to 37 cm), while the finer textured Btw layer appears at 45 cm depth.

In addition to these differences, there are notable differences between the two profiles related to the clay content.

In P1 (crop soil) the clay content is 24.9 – 29.1% in the tilled layer (Ap-Apt horizons) increasing to 47.0 – 48.7 in the clayey Btw horizons (Fig. 1).

Bulk density (BD). Taking into account that BD depends on the clay content, the two parameters positively correlated (Fig. 1 and 2) and had the same tendency to increased with depth.

Nevertheless the BD showed a higher sinuosity, as a result of a higher value in the coarser Ea horizon, and, consequently, a higher porosity, followed by a lower value (1.45 g/cm^3) in the underlined transition horizon (EBw), where the clay increased with 1%.

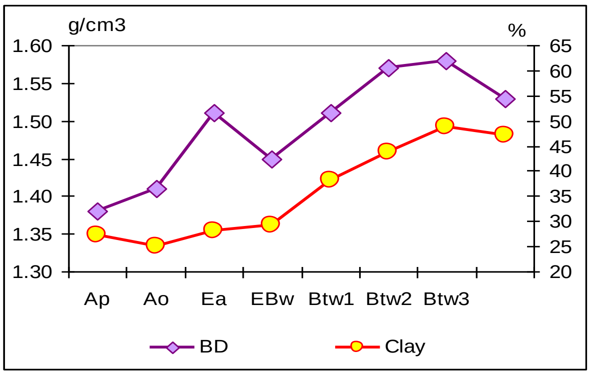

Fig. 1. The correlation between BD (bulk density – g/cm^3) and clay content in P1.
Source: Own determination.

In the P2, the clay quantity is higher (than in P1): 29.3 – 30.1% in the upper horizons (Aț-Ao horizons), increasing to 54.4 – 58.2 % in Btw horizon (Fig. 2).

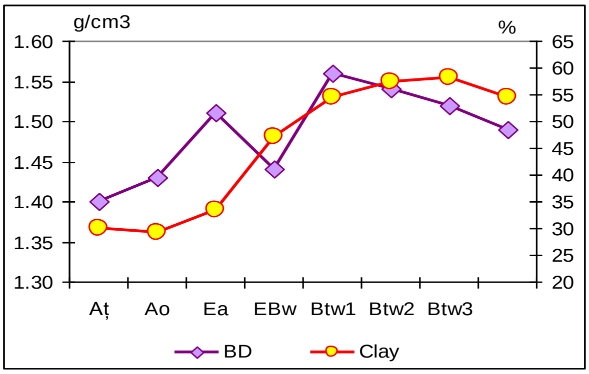

Fig. 2. The correlation between BD (bulk density – g/cm^3) and clay content in P2.
Source: Own determination.

Comparing both soil profiles (Fig. 1 and 2), the BD showed relatively the same sinuosity, while the differences between the values of the two soils ranging between 0.02 – 0.06.
In both profiles, the BD is lower in the top soil and high in Ea horizon (with coarser texture and lower organic matter content) and increased with dept.
In P1 the BD values are ranging in the limits of 1.38 – 1.58 g/cm^3 (Fig. 1). The low value (1.38 g/cm^3) in the upper horizons are a consequence of tillage, while in the deeper horizons, the higher values (1.51 – 1.58 g/cm^3) are due to clay content.
In P2 the values are more randomly distributed (Fig. 2) in the pedogenetic horizons, but maintaining the same tendency (increasing with depth) from 1.40 to 1.56 g/cm^3.
Between the two profiles, the differences in the clay content are 2.7 until 18 times, while the BD differences are smaller, and even negatively (-0.04 to 0.02).
This pointed out that, despite the lower clay content in P1, the spatial fabric of the soil matrix is more stuff, more packing, with a higher compaction (inherited, more probably, from the parent material), to which added the clay illuviation (as a result of pedogenesis).
Showing the volumetric characteristics of the soil, BD emphasizes the balance between aggregates and poral space.
The presence of the clayey horizons in the soil profile induce shallow rooting, but shallow means to develop into the eluvial horizon (Ea) which has favorable physical characteristics, but hostile environment (low: OM, nutrients, clay, etc.).
Penetrating the unfriendly environment of the eluvial horizon, the roots intersect the Btw horizon, both clayey compacted and affected by water stagnation.
The values of BD showed the restrictive conditions for the root growing through Btw.
A higher value of the BD results in slowly-poor infiltration of water through the soil dawn the rizosphere. Taking into account the presence of the clayey Btw horizon, it hinders the water stagnation in the upper part of the soil profile.
All these aspects showed precarious balance between bulk soil and voids (air respectively).
Packing density (PD). „The soil physical state can be synthetically described by bulk density, packing density and compaction degree“ [11].
Instead of BD, or together with the BD, the soil physicists also prefer the packing density (PD), as a physical parameter to describe the soil status, and being calculated with the formula [1]:

$$PD = BD + (0.009 * C)$$

where: PD = packing density (g/cm^3); BD = bulk density (g/cm^3); C = clay content (%).

The type of particle packing strongly influenced the size and the shape of the pores. [7] showed that the „concept of particle have generally been developed assuming the particles to be spherical“. Or, in the studied soils the Ea horizons have also platy structure, and both transition and Btw horizons have manly angular aggregates, or massive structure with fissures.

The data showed low differences between both PD and BD values of both profile, however between PD and BD the differences are important.

The PD values of both soils are higher then BD data, and are drawing a less sinuous curves (Fig. 3).

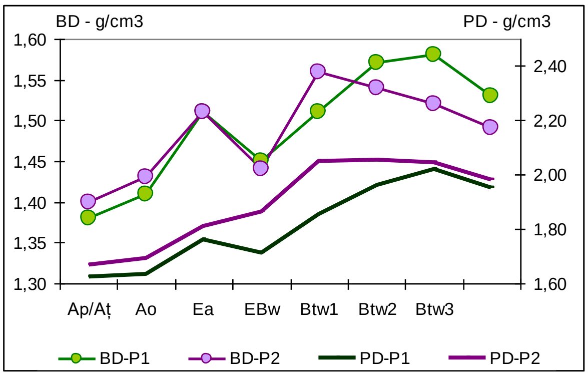

Fig. 3. The data of BD (bulk density – g/cm^3) and PD (packing density – g/cm^3) in both soils (P1 and P2).
Source: Own determination.

In the crop soil (P1), PD values show moderately loosened soil in the tilled layer (Ap-Apt horizons) and slightly compacted into the transition horizons. In the clayey ones (Btw) the soil is compacted.

Under the pasture (P2) the soil is moderately loosened in the upper 24 cm (Aţ-Ao horizons) and compacted in the underlined horizons.

The PD emphasizes „the arrangement of the solid in a given volume“[7]. In this respect, PD is strongly influenced not only by the type of packing (loose or densely), but also by the shape and the size of the aggregates, as well as by the roughness of their surfaces.

PD is also considered one of the soil properties useful for monitoring soil quality.

Both physical parameter (BD and PD respectively) help to an accurate evaluation of the bulk soil matrix quality.

In this respect, it could also be considered the bulk density which restricting rooting: „*restricting bulk density*“.

Restricting bulk density (BDr). This type of density is calculated with the formula [1]:

$$BDr = 1.52 - (0.00646 * C)$$

where: BDr = restricting bulk density (g/cm^3); C = clay content (%).

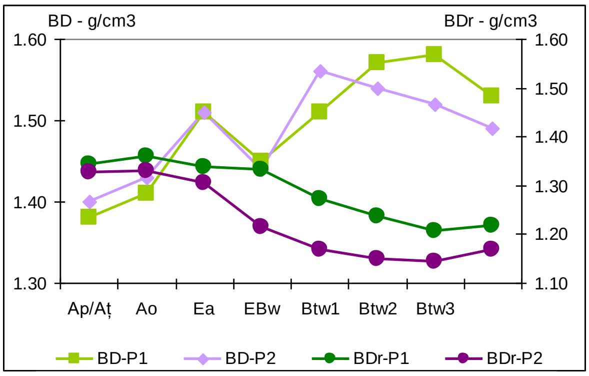

Fig. 4. The correlation between BD (bulk density – g/cm^3) and BDr (restricting bulk density– g/cm^3) in both soils (P1 and P2).
Source: Own determination.

The values of the BDr are lower and their graphic (Fig. 4) expressed the negative relationship with the BD. The values drop drastically into the clayey horizons, showing the stressed conditions for the roots in both soils. In P2 the values are lower, BDr matching perfectly with the higher clay content.

Hydraulic conductivity (HD). If soils have the same degree of compaction, the same correlations between physical characteristics should appear.

„Soil hydraulic conductivity describes water-soil relations and affects soil water balance and, by extension, plant growth“[13].

„The hydraulic properties of soils with identical texture depend on bulk density and structure, and the increasing bulk density not only induces changes in the pore-size distribution but also affects the ability of soil to shrink and to conduct water under unsaturated conditions“[3].

HD being a parameter that depends on the soil permeability, and consequently on the poral space, it varies with BD.

Therefore the HC data showed the same evolution (with depth) in both profiles, and mainly into the more compacted horizons (Fig. 5).

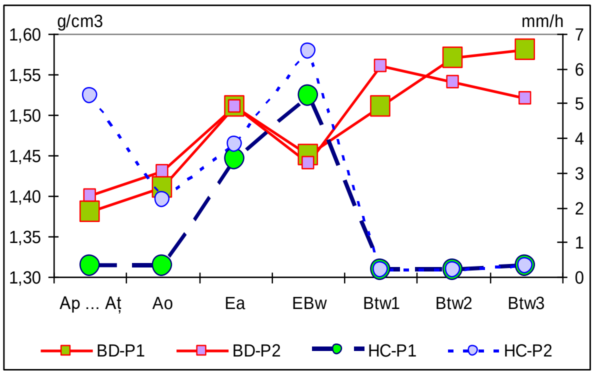

Fig. 5. The correlation between BD (bulk density – g/cm^3) and HC (hydraulic conductivity – mm/h) in P1 and P2.
Source: Own determination.

Comparing the studied soils, the analytical data of HC showed very small values in the crop soil (P1), except Ea-EBw horizons (24 – 46 cm), where the values are medium.

But the soil under the pasture (P2) is more compacted, comparing to the P1: two times in the upper part of the profile, till four times into the transitional EBw horizon. Into the more clayey Btw horizons, the degree of compaction is emphasized by the same values.

Consequently, the HC vary in the upper part of the soil profile, but had the same values (as crop soil) in the Btw horizons.

The HC depends not only on the poral space design, but also on the quality and quantity of the clay coatings that coated the pore walls.

In Luvisols, many pores are covered with a high diversity of discontinuous clay coatings (Fig. 6): from impure clay coatings (composed of clay±Fe±humus) to pure clay coatings and clay±Fe coatings. Each type influenced differently the permeability, depending on their composition and extension on the pore walls.

The impure clay coatings retain a high quantity of soil solution on the pore walls even after drainage.

In the studied Luvisols also the illuvial constituents (clay±Fe±humus) partially clog the pores, reducing the values of the poral space (as part of BD), and hence the HC, and accordingly the correlation between BD and HC.

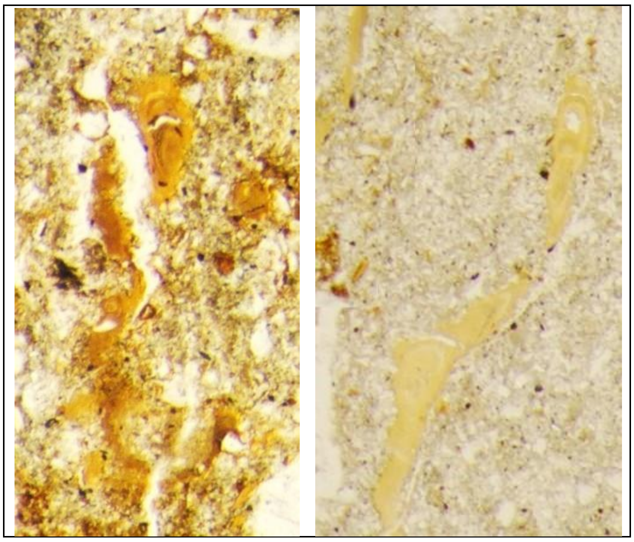

Fig. 6. The impure clay coating (composed of clay±Fe±humus) and pure clay coating (composed of clay±Fe) on the pore walls and clogging the voids.
Source: Own determination.

In these conditions, even if soil fauna is active, building poral space, the illuvial process is also active and induced the pores clogging (partially or totally).

Consequently, the HD values drastically decreased.

Therefore, the measured porosity is smaller then the real structural porosity formed in the bulk soil.

In this order, it could be statute that HD is directly proportional with the biological activity intensity and inversely proportional with the illuvial process (and clay coatings amount respectively).

For an accurate image of the soil physics, the correlation between BD and: HC, AP (aeration porosity – %v/v) and TP (total porosity – %v/v) had been approached for both soils (Fig. 7 and 8).

TP of the crop soil (P1) showed high to medium values in the upper part of the soil profile, ranging in the limits of 45.8 – 48.6 %v/v (Fig. 7). Accordingly, the AP values gradually decreased with depth from low (13.60 – 14.10 %v/v) in the tilled layer to extremely low (0.13 – 5.10 %v/v) in the Btw horizon.

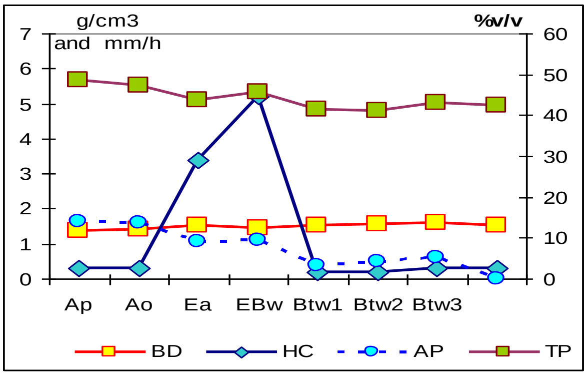

Fig. 7. The correlation between BD (bulk density – g/cm^3) and: HC (hydraulic conductivity – mm/h), AP (aeration porosity – %v/v) and TP (total porosity – %v/v) in P1.
Source: Own determination.

Under pasture (P2), TP is medium (46.7 – 48.2 %v/v) in the bioaccumulation layer, to low (43.5 – 46.3 %v/v – Fig. 8) in the deeper horizons. Accordingly the AP values are low (13.20 – 14.10 %v/v) in the bioaccumulation layer, to extremely low (4.20 – 5.20 %v/v) in the Btw horizon.

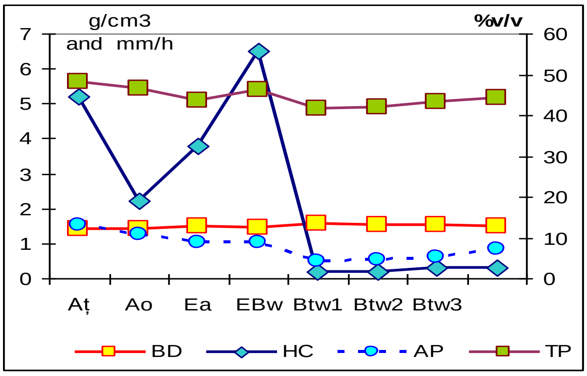

Fig. 8. The correlation between BD (bulk density – g/cm^3) and: HC (hydraulic conductivity – mm/h), AP (aeration porosity – %v/v) and TP (total porosity – %v/v) in P1 and P2.
Source: Own determination.

In this respect, the two graphics (Fig. 7 and 8) showed that BD is low correlated to the AP and TP for both soils.
Comparing the two graphics, even if BD curves are featuring relatively the same allure for both soils, the HC curves are highly different in the upper part of the soil profiles. Into the clayey Btw horizons, HC clearly correlated to all the physical parameters.

Although the physical-mechanical characteristics of the studied soils are relatively favorable in the upper horizons (tilled layer and bioaccumulation layer respectively), they became unfavorable into the deeper transition and Btw horizons, which give the soil profiles, as a hole, unfavorable conditions (concerning the moisture/aeration balance).
During the maximum period of humidity which creates moisture excess on soil surface, anaerobic conditions prevailing even in the top A horizon.
Organic matter (OM). If the physical characteristics are basically inherited from the parent material, the differences between the two soils should be given by the land use and, consequently, by the organic matter content.
Taking into account that BD could be estimated from the soil organic matter, it appears to be a correlation between BD and OC (organic carbon) (Fig. 9 and 10).
In the crop soil (P1) the organic carbon content is low to extremely low (Fig. 8).

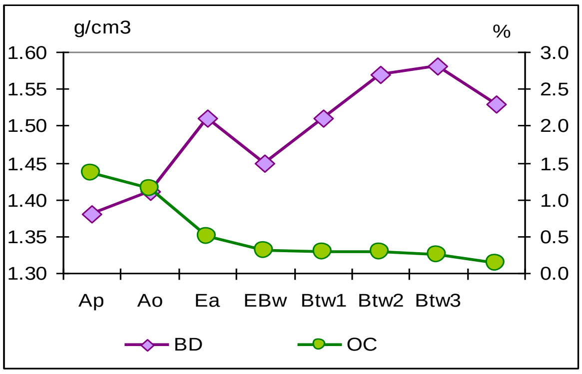

Fig. 9. The correlation between BD (bulk density – g/cm3) and OC (organic carbon - %) in P1
Source: Own determination.

Under pasture (P2) the higher content of the humic substances (4.20 – 2.34%) in the upper two horizons drops drastically to extremely low (0.96 – 0.52%) in the deeper clayey horizons (Fig. 10).
High BD mirrors the low values of OC (Fig. 10) which exhibit low retention of water in soil.

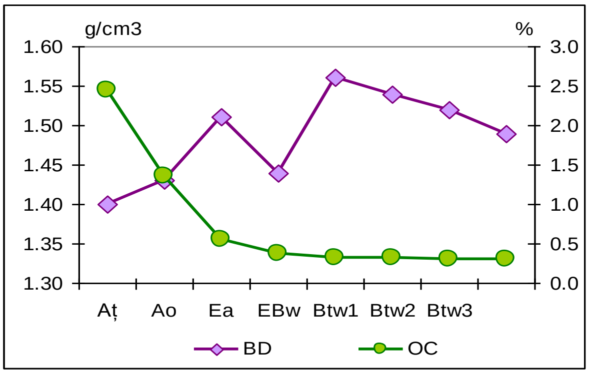

Fig. 10. The correlation between BD (bulk density – g/cm^3) and OC (organic carbon - %) in P2.
Source: Own determination.

The higher content of humus in P2 is a consequence of an important rooting which further influenced the porosity (by nourishing soil fauna that generated biogenic channels). [8] found „highly significant negative relationships between percentage clay or silt+clay and the bulk density at which rooting was at a maximum or the bulk density at which rooting was 0.2 of that maximum".

The upper part of the Luvisols with low organic matter and silty – to silty clayey texture inherited a dense arrangement of the soil particles that restrict root growth, and further compaction processes that increased bulk density and limiting root growth passes to the subsidiary

Since root penetration is affected by soil strength and aeration conditions, and both are related to BD, then root penetration should be a function of BD.

The differences between the land use (crop and pasture) and vegetal cover respectively are emphasized not only by the quantity, but also by the quality of the OM, the important brick of the soil architecture and a good „maintenance of soil structure".

In what concerning the correlation between OC and BD, the two parameters are negatively correlated (Fig. 8 and 9) in both studied soils.

[12] reports „relationships between soil organic carbon (SOC), soil organic matter (SOM), and bulk density (BD), in acidic loamy to sandy loam fine fractions of forest soils".

The organic matter being complexed by clay, it results a double influence on BD of the bulk soil.

The management. This study was carried out as a result of the signals received from the farmers who face problems caused by the physico-mechanical properties specific to Luvisols and which imprint unfavorable aero-hydric conditions on soil profiles and high energy consumption and relatively short working period.

According to the yearly management and plant rotation respectively, the „land use" changed every year (and even seasonally), and consequently the soil biodiversity specific (more or less) to every crop. Further, the soil architecture also changed according to the crop roots characteristics, emphasized by the bulk soil and the adjacent poral system.

The prediction of the evolution of BD could be drawing according to the intensity of soil biodiversity activity.

In the two Luvisols the fauna activity is relatively high, building and hardly renewing the poral space into the bulk soil.

In this respect, the good management of the Luvisols (both pasture and crop) should include the increasing of the OM content as supply for soil biodiversity. Thus because a good management favored a *crescendo* improvement of soil characteristics that potentiate each other, i.e.: the increase of OM stimulates the biological activity which burrowing intensely the soil and consequently decreased BD and BDr and increased HC and AP.

Table 1. The physico-chemical status of the crop soil (P1).

<table>
<tr><th>Horizons</th><th>BD/TP</th><th>PD</th><th>AP</th><th>HC</th><th>OM</th></tr>
<tr><td>Ap</td><td>loosened</td><td rowspan="2">moderately loosened</td><td>low</td><td rowspan="2">very low</td><td rowspan="2">low</td></tr>
<tr><td>Ao</td><td rowspan="3">slightly compacted</td><td rowspan="3">very low</td></tr>
<tr><td>Ea</td><td rowspan="2">slightly compacted</td><td rowspan="2">medium</td><td rowspan="2">very low</td></tr>
<tr><td>EB</td></tr>
<tr><td>BE</td><td rowspan="2">moderately compacted</td><td rowspan="4">compacted</td><td rowspan="3">extremely low</td><td rowspan="4">very low</td><td rowspan="4">extremely low</td></tr>
<tr><td>Btw_1</td></tr>
<tr><td>Btw_2</td><td rowspan="2">compacted</td></tr>
<tr><td>Btw_3</td><td>very low</td></tr>
</table>

Source: Own determination.

According to the data of the studied physical parameters the soil in the crop (P1) is loosened (Tab. 1) into the top horizon and from slightly compacted to compacted in the deeper horizons, while the soil under pasture (P2) is compacted on a higher depth (Tab. 2).

Table 2. The physico-chemical status of the pasture soil (P2).

Horizons	BD/TP	PD	AP	HC	OM
Aț	slightly compacted	moderately loosened	low	medium	medium
Ao			very low		low
Ea	moderately compacted	compacted			extremely low
EBw					
Btw_1	compacted		extremely low	very low	
Btw_2					
Btw_3					

Source: Own determination.

The compaction directly influences water retention capacity of the soil, as well as the permeability, which inevitably lead to a bad water and air regime of the soil. Directly increased both penetration resistance and plough resistance, with further negatively effects on the root life.

The low content of the organic matter could also favor the crusting process in the top layer and negatively affect the „maintenance of soil structure" ecosystem service.

Inappropriate management could strongly affect on long term, the ecosystem services well function, as maintenance of soil structure. Furthermore, it affects physical status and inevitably soil fertility and soil life.

In this respect the following management practices are recommended for the studied Luvisols.

Elimination of temporary excess rain moisture through agro-pedo-amelioration works and surface drainage works.

To improve the aerohydric and soil nutrition regime, organic fertilization with 30 – 40 t / ha manure is required (once at every 3 – 4 years).

The correction of the soil reaction with the help of calcareous amendments (around 5 t $CaCO_3$) is strictly necessary.

Re-amendment works must be done on time (at every 5-6 years) to ensure the effectiveness of chemical fertilizers, and the doses must be rigorously determined according to soil acidity indices.

The application of the complex NPK fertilizers must be in accordance with the agrochemical condition of the soil.

The management required for the pasture (P2) also includes the animal grazing control and reseeding with a mixture of forage plants with different type of roots and rooting able to breaking down the higher structural elements in the compacted layers.

Consequently, the biodiversity activity is stimulated at different depth of the soil, and mainly earthworms burrowing, which means highly porosity, lower bulk density and compaction respectively.

Inappropriate management could strongly affect on long term, the ecosystem services well function, as maintenance of soil structure. Furthermore, it affects physical status and inevitably soil fertility and soil life.

Good management practices reclaim the decrease of the bulk density. Thus, „many soil management decisions can be made from measured dry bulk density of the soil" [5].

„The delivery of ecosystem goods and services depends on the structure and functioning of ecosystems, which are affected by (global) environmental change and land management effects on the soil biota" [2].

The BD, being one of the physical quantifying characteristic (that assessing quantitatively the water and air in soil) represent an important key of soil fertility and strongly influenced „maintenance of soil structure" ecosystem service, and consequently emphasized the quality of the agriculture management.

The paper, through the management recommendations, is a point of support for agricultural technologies that require important adjustments in the conditions of the increasingly severe climate changes.

CONCLUSIONS

The correlation between the important physical parameter with BD, as an important manager factor and ecosystem services well function, concluded:

The values of BD showed the restrictive conditions for the root growing through the Btw clayey horizons. The presence of the Btw in both profiles induced shallow rooting, what means forcing them to develop into the eluvial horizon with relatively favorable physical characteristics, but hostile environment (low: OM, nutrients, clay, etc.).

The analytical data showed low differences between both PD and BD of both profile, these two parameters helping to an accurate evaluation of the bulk soil matrix quality.

The values of BDr drop drastically into the clayey horizons, showing the stressed conditions for the roots in both soils; moreover, in P2 the values are lower, BDr matching perfectly with the higher clay content.

The HC depends not only on the poral space design, but also on the quality and quantity of the clay coatings that coated the pore walls. The illuvial constituents (clay±humus±Fe) partially clog the pores, reducing the values of the poral space (as part of BD), and hence the HC, and accordingly the correlation between BD and HC.

In the crop soil (P1) the OC content is low to extremely low, as in the clayey horizons of P2, affecting the stability of the structural aggregates. The differences between the land use (crop and pasture) and vegetal cover respectively are emphasized not only by the quantity, but also by the quality of the OM, the important brick of the soil architecture and a good „maintenance of soil structure“.

The BD is one of the physical quantifying characteristic (that assessing quantitatively the water and air in soil) represent an important support point for an efficient management to provide at a higher level possible the „maintenance of soil structure“ ecosystem service, and consequently the quality of the soil life.

Throughout the management recommendations, the paper comes to the aid of farmers which tilled the Luvisols, soils with unfavorable aero-hydric conditions, high energy consumption and relatively short working period.

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