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EXPLORING SOIL COMPACTION IN THE LIGHT OF RECULTIVATION DURING TEMPORARY LAND USE FOR ALTERNATIVE PURPOSES IN HUNGARY

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Abstract: After some interventions (including building investments) and other industrial activities involving or affecting the use of agricultural land, altered soil conditions and/or harmful compaction of the soil can be a very strong limiting factor for the continuation of agriculture. Examination of soils in selected Hungarian plots (field study, laboratory tests, 'Spatendiagnose' analysis, soil compaction test using the 'Packungsdichte' method, volume density probes with Krauss rings) provide insights on the soil physical properties, pores distribution, soil layers/stratification, and changes from different interventions. The results revealed the impact of constructions and other industrial investment activities involving extreme trampling on the soil. The results show that the degree of compaction – very low, low, moderate, high, and very high – and the extent of the deformed layer varies according to the force of compression, number of repetitions and moisture content. The purpose of recultivation activities is to restore the soil to its original state. The results of our research can be directly applicable to the field for soil protection. Assessing the baseline condition, detecting changes, and conducting post–recultivation soil tests are necessary for evaluating the recultivation success.
Keywords: human activity; soil condition; harmful soil compaction; recultivation

1. INTRODUCTION

Soil is one of the key components of the global ecosystem, and as such, it is a prerequisite for human existence, the emergence of human civilization, and a primary resource for agricultural production [1,2]. Thus, monitoring soil conditions, examining and eliminating harmful soil compaction is a priority task of soil protection [3], because the destruction of soil has been accelerated by “industrial” farming [4,5]. The aim of mitigating or eliminating soil compaction is to maintain the soil in a cultivated state suitable for agricultural use, [6,7] which also entails legal obligations. For example, construction and other industrial investments also use sites classified as agricultural land. Non–agricultural interventions – involving earthworks – or laying pipes and cables (water, sewage, gas, electricity and telephone lines) – of more than 500 m – involve the dismantling of the soil surface, which (may) lead to unfavorable changes in the soil. In order to reverse these harmful processes and to eliminate the resulting adverse soil condition, it is necessary to re–cultivate the areas according to the guidelines set out in the soil protection plan [8]. During the examination of the soil condition resulting from the temporary utilization of the soil for other purposes, the complex problem approach, or the harmonization of the ecological/environmental goals and the technical interventions and plans are emphasized.

It is a key principle that agricultural land can only be used for purposes and activities which do not decrease its quantity, degrade its quality or limit its processes, nor do they pollute or harm other environmental elements.

For interventions other than agricultural use, soil conditions can and should be studied and evaluated mainly in field conditions, taking into account soil biological processes, since soil structure can (also) be a limiting factor for agricultural use [9,10].

Consequently, any intervention in the soil must be based on experience, expertise and knowledge. In addition to official standards, science–based professional considerations and guidance often appear in legislation. Legislative protection is also necessary, for the fulfillment of soil protection farming as an obligation, since the most important natural resource of farming is the soil, which is a conditionally renewable natural resource [11]. In Hungary, pursuant to Law 2007/CXXIX [12] on soil protection, as amended, and under Decree 90/2008. (VII. 18.) of the Ministry of Agriculture [8], the establishment of a soil protection plan for the recultivation and re–utilization of agricultural land is necessary for determining the soil protection requirements related to investments and activities which use or affect the use of land. Soil protection means first and foremost quality protection, that is, the protection and the improvement of quality, but above all, prevention of physical, chemical and biological deterioration. Human intervention, however, such as certain investment activities, inevitably results in soil degradation, which is most often manifested by changes in physical properties due to trampling and rupture. The disintegration of the structure and pulverulence are often followed by a strong compaction effect, which causes harmful compaction in the soil. It should be noted that harmful soil compaction occurs when the pore system of the soil is altered to such an extent that the pores responsible for air and water supply to the plants cannot perform their original function, resulting in long–term crop failure and production risk [13]. The disintegration of the structure and compaction not only has a detrimental effect on soil water management, but also on soil biology. [14] called earth–living creatures, including earthworms "ecosystem engineers" because of their versatile mission, detailed below. Earthworms, being one of the most important macrofauna group in temperate agricultural areas, ensure the proper penetration of tillage equipment, their burrows can function as drainage channels, but they can also play a role in aeration and root growth [15].

Soil compaction can sometimes occur in deeper layers due to poorly performed recultivation, so the degree of compaction also depends on the effectiveness of recultivation, the actual structure of the soil and the moisture content of the soil. In the case of a recultivation practice, where the reclaimed soil/loess material is made into artificial structures (spheres, so–called "roll aggregates") [16], the recultivated layer – much like naturally structured soil – responds flexibly to pressure, and resists to compaction longer [17–19]. Therefore, the key to eliminating compaction is to promote a favorable soil structure and optimal pore conditions, to revitalize biological life of the soil and to enhance earthworm activity.

For our sample areas, we have chosen agricultural lands temporarily taken out of cultivation for the purpose of carrying out (construction) investments and other industrial activities involving or affecting the use of land, that is to say, areas which have been used extensively during temporary use for alternative purposes, often with tremendous soil rupture. Based on the information obtained from monitoring the life cycle of these areas and examining their soils, recommendations for soil protection can be made to reduce (harmful) soil compaction, restore good soil status, eliminate other damage, and, last but not least, provide feedback on the effectiveness of recultivation. Furthermore, this article considers the connections between the agrarian landscape and the ecological processes based on field study and laboratory tests.

2. MATERIALS AND METHODS

For sampling, we selected sites of typical investments, the kinds that regularly occur in practice and require re–cultivation once the investment has been completed. The selection of sampling sites was followed by the collection of information on the soil conditions of the areas (baseline survey, description of planned activity, expected impact of the activity on soil, etc.) and the preparation of the field study [20]. Based on the above, we can identify three intertwined stages of research activity: Assessment of the pre–investment status of the given areas (soil profile, field tests with accredited laboratory tests). These examinations are also prescribed by law, their execution and their methodological obligations are stipulated [8]. Besides the tests required by law, we conducted a 'Spatendiagnose' (spade test) analysis [21], we tested and evaluated soil compaction using the 'Packungsdichte' (PD) method [22–25], and determined bulk density from samples taken with the aid of Krauss rings [26].

The second stage was the assessment of the conditions after investment (but before recultivation). The soil tests in this section are no longer required by law. As the original soil is usually disturbed, its extent was verified by an on–site soil profile test (drilled soil profile). We performed the 'Spatendiagnose' (spade test) analysis again, assessed compactness using the 'Packungsdichte' (PD) method, and carried out bulk density tests using Krauss rings. We then compared the results with the (partial) results we had gained before and after the investments.

The third stage was the assessment of post–recultivation status in the respective areas. Here, in some cases (e.g. agricultural recycling), the legal background again provides for and defines the mandatory tests (field test of soil profile and soil properties, supplemented by accredited laboratory tests). We performed the 'Spatendiagnose' (spade test) analysis, checked soil compaction using the Packungsdichte (PD) method and sampled the volume using Krauss rings.

The tests selected for the three phases were deemed necessary based on the considerations summarized below. The first stage is the recording of baseline soil conditions, for which the legislative background makes methodological recommendations (soil profile, laboratory tests). These are supplemented by the 'Spatendiagnose' (spade test) method, which is more specific to the cultivated soil layer (30–40 cm) and is always applicable. The name of the method itself was coined by Görbing [21]. The spade test is suitable for exploring structure of the soil, its pores, its moisture status, the location of the compacted layer and its suitability for cultivation [6]. Given that a smaller "soil profile" is being prepared in this test, the root distribution and the biological state of the soil, such as the activity of earthworms, can also be determined. In previous publications we have already used the Packungsdichte (PD) index developed to categorize compactness [27], the grades of which properly characterize soil compaction/ looseness, and can determine harmful compaction, total porosity, the capacity of plants to grow roots, as well as the capacity of soil to retain or release water [28]. To further monitor compaction, volumetric mass measurements were also carried out (assuming the same soil texture) [26]. All in all, the legal requirements have been supplemented with soil tests – primarily on–site tests – that are easy to implement, repeatable, and provide information pertaining to soil damage.

An important aspect of investigations after disturbance was that the activities caused the soil to undergo severe disturbance, therefore original layers, texture and chemical properties could change due to mixing, which was recorded by the on–site description of the drilled soil profile, but not supplemented by laboratory tests, owing to the heterogeneity of the mixed soil. However, in order to assess physical degradation, we conducted a spade test, assessed compactness, and measured bulk density.

After recultivation, the layers and stratification of the soil are mostly unchanged, and where they are, the description of the soil profile and the performance of laboratory tests are again a legal obligation. The success of recultivation with respect to the physical parameters and certain biological characteristics of the soil, was verified by carrying out a new spade test, compaction assessment and bulk density tests.

3. RESULTS

Considering the fact that under Section 43 (1) of Law 2007/CXXIX, investments and any other activity on or affecting the soil must be designed and implemented in a way that soil management conditions in the affected and surrounding soils are not impaired, information on pre– and post–initiation status was collected with a view to the recultivation, while subsequent changes in the soil and the landscape were (also) recorded. Table 1 summarizes, without being exhaustive, the typical investments and associated soil damage, as well as the necessary soil tests to determine the extent of such damage.

The investments have been selected so that they are located in different geographical microregions. Thus, we investigated the soils of alluvial plain and valley areas, colluvium plains, rolling plains of Eolian origin and hilly landscapes.

Among the investments, the least amount of disturbance was caused by the establishment of the humus repository, while anthropogenic effect size is increasing in the following order: stockpile, service road, pipeline laying, layering, material resource recultivation and agricultural recycling. It is important to understand anthropogenic processes and their impacts on the agrarian landscapes, the sustainable land use especially the soil. Then it is necessary to decrease the impact(s) of anthropogenic processes on agrarian landscapes. The dissimilar operations on humus repositories and stockpiles do not change the original layers and the chemical properties of the soil, but changes in the humic topsoil and physical degradation are expected. In these cases the changes in the soil were rechecked with a drilled section instead of an excavated soil profile due to the unchanged soil layers. In the other cases, despite the final humus reintroduction, the original layers of the soil are altered and the different layers (may) mix, resulting in unstable, mixed soil layers (tiers), which can also be fixed in a drilled section. While the original layers are not expected to change chemically, blending clearly "confuses" chemical properties. Based on our professional considerations, we accepted the above facts, and thus we did not recheck the chemical and other physical properties by laboratory measurements, while the morphological description of the drilled sections were primarily used for data recording.

Table 1. Construction and other industrial investments affecting agricultural land.

Name of the investment	Geographical location and characterization of sampling plots	Short description of the activity	Characteristics of soil damage	On–site inspections, recording of baseline condition
Road construction (see Table 2)	Hungary Kapuvár plain microregion, fluvial plain surface, flat, covered with alluvial matter, alluvial humus soil	establishing service roads, related construction works on agricultural land used as arable land	compaction can occur due to the removal of humus topsoil, but no chemical transformation is expected	morphological examination of drilled soil profile, examination of compaction, spade test, laboratory measurements (pH, K_A, humus content, total $CaCO_3$ content, all dissolved salts, bulk density)
Humus creating repository (see Table 3)	Hungary Csongrád–plain microregion, a spatially flat alluvial area that slopes toward the Tisza Valley; meadow soil	creating a humus repository on agricultural land used as arable land	restoring the upper (50 cm) humus layer compaction of the humic topsoil may occur, but no chemical transformation is expected	morphological examination of drilled soil profile, examination of compaction, spade test, laboratory measurements (pH, K_A, humus content, total $CaCO_3$ content, all dissolved salts, bulk density)
Establishing a stockpile (see Table 4)	Hungary Zagyva–valley microregion, alluvial valley area, alluvial slope effect due to erosion and derasion; slope alluvial soil	establishing a stockpile for road construction on agricultural land used as arable land	degradation and compaction of the humus layer (20 cm thick restorable soil) may occur, but no chemical transformation is expected	morphological examination of drilled soil profile, examination of compaction, spade test, laboratory measurements (pH, K_A, humus content, total $CaCO_3$ content, all dissolved salts, bulk density)
Electric cable laying (see Table 5)	Hungary Central Zala Hills, hilly terrain with steep slopes; slope alluvial soil	laying underground cables for a 24 kV solar panel field on agricultural land used as arable land and pasture	disturbance of soil and soil structure degradation may occur, compaction develops in the soil, resulting in lack of air	morphological examination of drilled soil profile, examination of compaction, spade test
Anthropogenic layering (filling up) (see Table 6)	Hungary Pest alluvial plain, rises eastward with terraced plains, heavily slashed by erosion and derasion valleys; alluvial soil	layering on the disturbed area by human activity with an average of 50 cm depth	without disturbing the original soil layers, the deposition of an approx. 50 cm thick soil, inert waste (soil debris of unknown origin)	morphological examination of drilled soil profile, examination of compaction, spade test, laboratory measurements (pH, K_A, humus content, total $CaCO_3$ content, all dissolved salts, bulk density)
Agricultural recycling (see Table 7)	Hungary South Nyírség microregion, slightly staggered, rolling plain; anthropogenic humic sand soil	discontinuation of mining activities, landscaping for further use as arable land	previous soil layers have been restored, no soil compaction has occurred, soil conditions appropriate for agricultural land use as arable land	morphological examination of drilled soil profile, examination of compaction, spade test, laboratory measurements (pH, K_A, humus content, total $CaCO_3$ content, all dissolved salts, bulk density)

On the whole, the most easily detectable and traceable change occurs in physical degradation (structural degradation and compaction), which results in a change in biological activity, too. To recheck these, we carried out spade tests, PD tests and bulk density tests after the investment, the results of which are summarized in tables (Table 2–7).

In fact, soil compaction reflects the relationship of adhesive and cohesive forces between soil particles, which manifests itself in the resistance of the soil to being worked. When determining PD, we used a scale from PD1 to PD5. PD1 refers to a minimally compacted soil, while PD5 means a heavily compacted soil. For PD2 and PD3 (low to medium compaction), the soil has good, or at least satisfactory, water permeability, air permeability and rooting capacity. A value of PD4 (high compaction) or above indicates an unfavorable soil condition, which (may) also imply the need for loosening [25]. Similar soil structures usually correlate with PD values [25,29–30].

Table 2. Impact of road construction activity on selected sample plots (pre–investment state, post–investment state and recultivated condition)

	Stratification of soil (and bulk density)	Humic topsoil	Chemical properties in the humic topsoil	Texture of the humic topsoil	Structure revealed by spade test	Degree of compaction revealed by spade test	Roots/misc.
Pre–investment state	A–layer 0–40 cm (1.27 g/cm³) AC–layer 40–45 cm (1.34 g/cm³) C–layer 45–100 cm (1.27 g/cm³)	40 cm (A–layer)	pH: 7.56 humus: 1.9% total $CaCO_3$: < 0.1% total salts dissolved in water: 0.04%	K_A: 48 clay loam	slightly grainy	slightly compacted PD3	plowed layer, even root remnants, little earthworm activity
Post–investment state	due to removal of soil and deposition, layers have been slightly mixed (1.45 g/cm³; 1.57 g/cm³; 1.29 g/cm³)	appears in a mixed form in the top 50 cm	humus content in the top 50 cm has decreased due to mixing	slightly mixed clay loam	poor below 50 cm, slightly polyhedral	loose A–level, a heavily compacted layer underneath PD5	no roots on the surface of polyhedrons; no earthworm burrows
Recultivated state	no further change (1.31 g/cm³; 1.48 g/cm³; 1.27 g/cm³)	no further change	organic fertilizers increased total organic matter content	no change	small polyhedrons under 50 cm, improved by soil loosening and organic fertilization	level A is loose with slight/moderate compression below PD3, PD4	more even distribution of roots, low earthworm activity

Table 3. Impact of establishing humus repository activity on selected sample plots (pre–investment state, post–investment state and recultivated condition)

	Stratification of soil (and bulk density)	Humic topsoil	Chemical properties in the humic topsoil	Texture of the humic topsoil	Structure revealed by spade test	Degree of compaction revealed by spade test	Roots/misc.
Pre–investment state	A(B)–layer 0–50 cm (1.32 g/cm³) BC–layer 50–60 cm (1.38 g/cm³) C–layer 60–120 cm (1.45 g/cm³)	50 cm (A(B)–layer)	pH: 6.97 humus: 2.6% total $CaCO_3$: 0.1% total salts dissolved in water: 0.09%	K_A: 52 clay	slightly granular, polygonal	loose PD3	root system is even, moderate earthworm activity
Post–investment state	no significant change in stratification (1.68 g/cm³; 1.44 g/cm³; 1.46 g/cm³)	slightly modified (40 cm)	changes in topsoil only	no change	became poorer, pulverulence	moderately compacted soil PD4	roots in previous earthworm burrows, earthworm activity is reduced
Recultivated state	no further change (1.52 g/cm³; 1.42 g/cm³; 1.45 g/cm³)	no further change	organic fertilizers increased total organic matter content	organic fertilizers reduced cohesion	improved with soil loosening and organic fertilization, change only in compactness	improved in topsoil PD3–PD4	more even distribution of roots, earthworm activity increased significantly

Table 4. Impact of stockpile establishment activity on selected sample plots (pre–investment state, post–investment state and recultivated condition)

	Stratification of soil (and bulk density)	Humic topsoil	Chemical properties in the humic topsoil	Texture of the humic topsoil	Structure revealed by spade test	Degree of compaction revealed by spade test	Roots/misc.
Pre–investment state	A–layer 0–20 cm ($1.37 g/cm^3$) AC–layer 20–45 cm ($1.42 g/cm^3$) C–layer 45–100 cm ($1.28 g/cm^3$)	20 cm (A–layer)	pH: 7.39 humus: 1.4% total $CaCO_3$: 0.7% total salts dissolved in water: 0,1%	K_A: 48 clay loam	slightly crumbly	loose PD3	plowed layer, even distribution, moderate earthworm activity
Post–investment state	changed because of the removal deposition of the A–layer ($1.48 g/cm^3$; $1.65 g/cm^3$; $1.32 g/cm^3$)	more mixed, in a more even layer	slightly changed due to mixing	mixing, changed	became poorer, polyhedron structure under topsoil	topsoil slightly compacted but heavy compaction underneath PD4	even in topsoil, below topsoil roots are on the surface of polyhedrons
Recultivated state	no further change ($1.32 g/cm^3$; $1.50 g/cm^3$; $1.36 g/cm^3$)	no further change	the organic matter content of soil changed with organic fertilization	no further change	improved by soil loosening and organic fertilization, improved in compacted layers	slight improvement in the whole of the profile PD3	improving root distribution and earthworm activity

Table 5. Impact of laying electric cables (underground cable) activity on selected sample plots (pre–investment state, post–investment state and recultivated condition)

	Stratification of soil (and bulk density)	Humic topsoil	Chemical properties in the humic topsoil	Texture of the humic topsoil	Structure revealed by spade test	Degree of compaction revealed by spade test	Roots/misc.
Pre–investment state	A–layer 0–30 cm ($1.28 g/cm^3$) C1 layer 30–60 cm ($1.36 g/cm^3$) C2 layer 60–100 cm ($1.34 g/cm^3$)	30 cm (A–layer)	no laboratory tests were performed according to the sampling protocol	K_A: no data loam	slightly crumbly	loose PD2	plowed layer, even root distribution, moderate earthworm activity
Post–investment state	strong mixing in the subsoil, reinstated humus layer ($1.47 g/cm^3$; $1.55 g/cm^3$; $1.35 g/cm^3$)	in the original depth of the layer	changed due to mixing	mixing, little change	structural disintegratio n in the whole profile	compaction, airlessness PD4	roots in cracks, earthworm activity decreased
Recultivated state	no further change ($1.32 g/cm^3$; $1.50 g/cm^3$; $1.34 g/cm^3$)	no further change	no further change	no further change	no visible change	turned with a disc harrow, compaction of topsoil improved PD3–PD4	more even distribution of roots, earthworm activity not improved

Table 6. Impact of anthropogenic layering (filling up) activity on selected sample plots (pre–investment state, post–investment state and recultivated condition)

	Stratification of soil (and bulk density)	Humic topsoil	Chemical properties in the humic topsoil	Texture of the humic topsoil	Structure revealed by spade test	Degree of compaction revealed by spade test	Roots/misc.
Pre–investment state	A–layer 0–30 cm ($1.28\ g/cm^3$) AC–layer 30–40 cm ($1.30\ g/cm^3$) C–layer 40–100 cm ($1.41\ g/cm^3$)	30 cm (A–layer)	pH: 8.21 humus: 1.0% total $CaCO_3$: 12.1% total salts dissolved in water: 0.02%	K_A: 27 sand	slightly granular	original soil was not disturbed PD2	even roots, moderate earthworm activity
Post–investment state	changed AH–layer 0–50 cm (anthropogenic layering) (–) A–layer 50–80 cm ($1.79\ g/cm^3$) C–layer 80–100 cm ($1.50\ g/cm^3$)	original fertile topsoil is buried	mixing, changed pH: 7.86 humus: 1.3% total $CaCO_3$: 15.3% total salts dissolved in water: <0.02%	mixing, changed K_A: 31 sandy loam	cannot be evaluated in the layering, did not change in the original soil	original soil is heavily compacted PD4	cannot be evaluated in the complete profile
Recultivated state	A–layer 0–30 cm ($1.75\ g/cm^3$) AC–layer 30–40 cm ($1.50\ g/cm^3$) C–layer 40–100 cm ($1.40\ g/cm^3$)	30 cm (A–layer)	pH: 8.11 humus: 1.0% total $CaCO_3$: 14.2% total salts dissolved in water: 0.02%	no further change in A–layer	granular	compacted PD4	few roots, few pores

Table 7. Impact of agricultural recycling activity on selected sample plots (pre–investment state, post–investment state and recultivated condition)

	Stratification of soil (and bulk density)	Humic topsoil	Chemical properties in the humic topsoil	Texture of the humic topsoil	Structure revealed by spade test	Degree of compaction revealed by spade test	Roots/misc.
Pre–investment state	A–layer 0–30 cm ($1.42\ g/cm^3$) AC–layer 30–40 cm ($1.45\ g/cm^3$) C–layer 40–100 cm ($1.35\ g/cm^3$)	30 cm (A–layer)	pH: 6.16 humus: 1.1% total $CaCO_3$: <0.1% total salts dissolved in water: <0.02%	K_A: 27 sand	slightly crumbly	slightly compacted topsoil PD3	even roots, poor earthworm activity
Post–investment state	the entire soil body was removed, A–layer was re–deposited ($1.48\ g/cm^3$)	missing	no soil to work with, new bedrock	no soil, new bedrock	none	heavily compacted topsoil PD4	no plants, no earthworm activity, ground water is close
Recultivated state	A_{antrop}–layer 0–50 cm ($1.54\ g/cm^3$) C–layer 50–100 cm ($1.42\ g/cm^3$)	laying humus (50 cm thick)	pH: 7.21 humus: 0.8% total $CaCO_3$: <0.1% total salts dissolved in water: <0.02%	K_A: 27 sand	none	heavily compacted topsoil PD4	no roots, no earthworm activity

4. DISCUSSIONS

In connection with all the investments and industrial activities on agricultural land that we examined, it should be emphasized that the humus content has become less favorable as a result of changes in the chemical properties of the soil. However, the most significant change occurred in soil compaction – in some cases (e.g. during investments and activities where the humus is removed, deposited and then reapplied, often trampled by heavy machinery) it resulted in the disintegration of soil structure. Therefore, the recommended recultivation steps, namely organic fertilization and loosening, are indeed necessary, but in our experience performing them once is not enough. Improvements in structure, increased earthworm activity, and a lasting reduction in compaction can only be expected as a result of farming that takes into account the ecological functions of the soil. Adverse changes caused by temporary use of the land for alternative purposes can only be eliminated by consistent soil improvement by the farmer (work that is repeated for several years in succession – applying more organic fertilizer and green manure; minimizing compaction and disturbance in order to increase earthworm activity; covering soil, mulching, occasional loosening, etc.).

Following some investments and industrial activities that involve or affect the use of land, the change in soil condition can be summarized as follows:

Before establishing service roads and access roads in connection with road construction, in order to protect it, the humus layer was extracted and deposited to the depth determined by the soil expert. This operation caused a slight mixing and deterioration of the structure in the removed topsoil. With regard to chemical properties, a slight decrease in the humus content occurred. As a consequence of road construction, the movement of vehicles and heavy machinery exerted a strong compaction effect on the removed surfaces (from PD3 to PD5), and there was a significant physical change in the structure of the topsoil. With the cessation of the activity, the humus layer was restored, and organic fertilization and soil loosening were also required as a way of recultivating the area. A single, well–timed soil loosening has improved the compacted soil layer (illustrated by bulk density (1.31 g/cm^3) and PD values (PD3–PD4)), but regaining the initial, good soil conditions requires multiple loosenings of the soil (carried out for several years). The same applies for the stabilization of the organic matter stock and structure. We can conclude that the recultivation proposed after the investment has no significant effect on the earthworm activity, as the restoration of the biological life of the soil can be be achieved by persistent, continuous and thoughtful farming work.

As for deposition–type activities (humus repository and stockpile), soil compaction (PD4) was detected under the repository. Note here that the storage and removal of external material (building debris, gravel, building materials, etc.) is never perfect enough to eliminate all the external material from the surface of the soil. Thus, after the repository was demolished, it is absolutely necessary to remove external matter. We also found that no significant chemical change was caused by the activity. In the process of recultivation, soil biology was improved by organic fertilizers, while compaction was reduced by soil loosening, but a single intervention, although measurable, was not sufficient to restore the soil to its original condition.

In the case of underground cable laying, the humus layer was removed separately, after which the lower layers of soil were also affected by earthwork. In this way, soil disturbance is the most significant effect, causing both chemical and physical changes. It was found that the structural degradation of soil is not sufficiently improved by a single organic fertilization during recultivation, and compaction caused by earthmoving equipment is only slightly improved (from PD4 to PD3–PD4) by a single soil loosening. Thus, no improvement was observed in structure, compaction (bulk density and PD), or in earthworm and root activity immediately after recultivation.

With regard to anthropogenic layering and filling, changes similar to the deposition were observed, with slight chemical changes but significant compaction (PD4) depending on the nature of the applied material. Note here that in the case of structured soils, although the soil structure may remain stable, compaction occurs inevitably. Therefore the most important task is to eliminate compaction. This requires consistent soil improvement over several years, as well as the restoration and enhancement of biological life in the soil.

We also studied an agricultural recycling area where formerly a clay mining site had been operating. Here, as a result of soil removal and clay extraction, all of the original soil disappeared and, by reapplying the previously removed humus layer, on the new soil layers – which are generally deeper (and hence closer to groundwater) – , a new, A– and C–level, compacted (PD4) subsoil was created. For this reason, of course, recultivation also included organic fertilization and soil loosening steps, but the achieved soil conditions were no longer comparable land to the original ones, in this case the aim was to create the best possible soil condition and fertility.

Based on the above, we can conclude that recultivation – although the initial steps taken during the first phase of recultivation can be considered effective in all cases examined by us – is a time–consuming process that results in a land use that is in harmony with the natural environment only if it is accompanied by a patient farming attitude.

5. CONCLUSIONS

Having evaluated the research results of the pre–investment baseline conditions, as well as post–investment and post–recultivation conditions, we have come to unbiased conclusions regarding recultivation that help investors and farmers to achieve objective soil protection. Articles 43 (2) and (3) of Law 2007/CXXIX merely refer in general to soil protection requirements, namely (2) During the realization of the investments, the investor is obliged to save and utilize the humus layer. And (3) During construction and operation, it must be ensured that the environmental impacts do not adversely affect the quality of the affected and the surrounding agricultural land.

Based on the investigation of the surface and spade tests we carried out, detrimental soil compaction can be detected, the primary signs of which are soil degradation, a decrease in earthworm activity, and a sparse root zone. The task is to eliminate harmful soil compaction (eventually soil compaction itself).

According to soil compaction tests results, we gained insight into the problems that make farming difficult after the recultivation of agricultural land that had been temporarily used for alternative purposes. Specifically, we managed to point out the importance of keeping to the goals of the recultivation plan, and – when these goals were successfully kept to – the efficacy of recultivation, as well as the longer time span it requires. In this manner, the criteria for reducing/eliminating harmful soil compaction or for active soil protection can be defined as follows:

- Considering that humus layer was damaged by all investments and activities, while soil structure deterioration and harmful compaction were also frequent, (with decreased or missing earthworm activity and decreased rooting capacity), recultivation was recommended for all cases, with correct recultivation steps and repeated application crucial for effectiveness.
- Retaining or further improving the condition achieved by recultivation (the goal is "at least" achieving the original conditions, but more desirably achieving conditions that are appropriate for the type of soil) was possible by repeated and timely soil loosening, and by avoiding additional compaction and rotation. Also applying organic matter and mulching to stimulate biological (earthworm) activity (note here that the latter also has beneficial effects on organic matter supply).
- Similar to forming soil structure, repairing and restoring degraded structure was very slow, but facilitated and promoted by regular organic fertilization (e.g., farmyard manure, green manure, compost, etc.) and, for lime–free soils, liming may also be practiced.
- Organic fertilizers were beneficial for organic matter (humus) content, as well.
- Combined application of these criteria are considered highly effective (reduced harmful compaction accompanied by the restoration and enhancement of biological life through earthworm activity (since earthworms are sensitive to the physiological parameters of soil and thus an excellent biological indicator of soil). Moreover, rooting capacity and fertility are improved, with the appearance of a root layer entailing favorable porosity and structure.

Through the selected and presented, it can be concluded that after investments in conventional technologies and techniques, recultivation is always necessary (repeated soil loosening, organic fertilization, etc.); this however, is time consuming, costly and has no immediate effect. Investments and industrial activities with as little soil disturbance as possible, followed by possible recultivation with as few re–cultivation steps as possible, are considered to be the right direction.

Ideally, there would be no need for re–cultivation if the investment and industrial activities were carried out with innovative soil–saving technologies and other agricultural engineering solutions (e.g. drainage technology without disturbance, etc.) that would leave little or no "soil wound" requiring recultivation. Last but not least, this soil–centered approach is an integral part of environmental mentoring because the main objective is preserving the character of agrarian landscapes.

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