# Importance of Soil Quality in Environment Protection

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## Summary

Soil quality can be characterised by the harmony between it's physical and biological state and the fertility. From the practical crop production viewpoint, some important contrasting factors of soil quality are: (1) soil looseness – compaction; (2) aggregation – clod and dust formation; friable structure – smeared or cracked structure; (3) organic material: conservation – decrease; (4) soil moisture: conservation – loss; water transmission – water-logging; (5) at least soil condition as a result of the long term effect of land use moderates or strengthens climatic harm. In our long-term research project practical soil quality factors were examined in arable field and experimental conditions. We state that prevention of the soil quality deterioration can be done by the developing and maintaining harmony between land use and environment. Elements of the soil quality conditions such as looseness, aggregation, workability, organic matter, water transport are examined and the improving methods are suggested. Tillage and production factors which can be adopted to alleviate the harmful climatic impacts are also summarised.

## Key words

land use, soil quality, soil physical and biological condition, climate impact

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## Introduction

In the classical Hungarian soil management literature the 'culture condition of soil' covered the term 'soil quality.' It is comprised of the harmony of physical, biological and chemical conditions of the soil, including favourable structure, bearing capacity, workability, air-, heat- and water management, referring optimal available nutrient supply and beneficial biological activity (Jolánkai et al., 1997). A soil, when it is in a culture condition represents a mellowed state, which is the most favourable interaction among the physical (structure, moisture, air, heat), the chemical (nutrients, pH), and the biological (activity of aerobe microorganisms and earthworms) soil factors. As stated many times the soil can be tilled with the best quality, least damage done and the energy in a mellowed condition. In the modern definition, the soil quality comprises physical, biological and chemical features of the soil, and together with level of quality indicates harmony or disharmony among the components (Dexter, 2004). Moreover, soil quality is considered as indicator of sustainable tillage practices (Karlen, 2004). In Hungarian relation, from 1800s till the 1970s, the main requirement of soil tillage was to provide suitable soil conditions for plant growth. During the last 20 years, traditional goal has been renewed because of deterioration of soil quality (Birkás, 2000). These tillage induced soil quality damages are as follows: (1) soil compaction and recompaction; (2) water-logging on compacted soils; (3) limiting water infiltration and increasing moisture loss; (4) clod or dust formation on dry soils, as well as smearing and puddling on wet soils; (5) water and wind erosion incidences; (6) deterioration of soil workability and trafficability; (7) inducing the water and wind erosion; (8) increasing the $CO_2$ emission and carbon loss; (9) destroying soil biological activity and living site of earthworms; (10) limiting soil mellowing. As Hungarian authors (Jolánkai et al., 1997; Várallyay, 1997; Birkás, et al., 2004) summarized the most important tasks for the next decade are: avoiding tillage-induced soil harm, conserving soil moisture and organic materials and managing stubble residues and using soil quality improving tillage.

## Material and methods

The Department of Soil Management of Szent István University initiated research to monitor the effects of tillage on soil physical quality in eight counties and 26 districts in 2000. This investigation covers 10,000 ha on 24 farms on different soils. Three methods were used to evaluate soil quality condition: (a) lifting, weighing and analysing soil monoliths to a depth of 50 cm, (b) sounding the soil to measure the thickness of the loosen layer, (c) measuring soil strength for each 20 mm increment with an electronic penetrometer (Daróczi and Lelkes, 1999), and (d) examining soil agronomical structure. Earthworms were hand-sorted from four 0-2 $m^3$ (1 $m^2$ area of soil to a depth of 20 cm) in May and in September. Earthworm burrows within the profile were counted to the depth of 30 cm.

This paper comprises the most important results of the new field experiment that was initiated in 2002 in the district of Hatvan (47°42′N; 19°38′E). We have disposed soil quality data on this experimental field since 1983. The soil is loam, a Calcic Chernozem formed on loess. The trial included six methods of tillage: (a) root zone improving by loosening 40-45 cm (L), (b) soil layer inverting by ploughing 26-32 cm (P), (c) mulch-mixing by disking 16-20 cm (D), (d), mulching by heavy-duty cultivat 16-20 cm (C), and (e) mulch-sowing by direct drilling (DD). Two of the implements (plough, cultivator) were equipped with surface-preparing elements. In four of the variants (a-d) three traffics were used (stubble and primary tillage and seedbed preparation and plant). A till-plant machine was used for sowing since it is suitable for both normal and direct drilling. Cover percentages of the disturbed soil surface were ranked as: DD 80 % > C 35 % > D 30 % > L 25 % > P 0 %. The crop sequence included cash and catch crops: mustard (mulch, 2002), w. wheat (*Triticum aestivum* L., 2002/03) and maize (*Zea mays* L., 2003), rye (*Secale cereale* L., mulch 2003/04), pea (*Pisum sativum* L., mulch, 2004), w. wheat (2004/05), mustard (*Sinapis alba* L., mulch, 2005), w. wheat (2005/06). The trials were arranged in a randomized strip design. Plot size was 13 m x 158 m and each variant was replicated four times. The mean annual rainfall was around 580 mm, but during the last four-year period it fluctuated between 442 and 741 mm with extremes in distribution. The soil condition features were measured according to the accepted standards (Birkás and Gyuricza, 2004; Farkas, 2004). Our primary objective was to select some factors to assess soil quality, while the secondary aim was to summarize the possible steps for environment protection in national relation.

## Results

Soil condition indicators can be used to assess soil quality which may inform about climatic sensitivity of soils and through this may give preliminary information of the probable risks. There is a close correlation between the factors that are determined by the soil indicators. Factors that are more optimum can decrease, while more negative factors can increase the climatic sensitivity of soil.

*Soil condition*. Soil tillage throughout soil condition affects soil sensitivity to climatic impacts both in the short and long term. One reason why soil condition has become a more important soil management problem during the last years is the extensive water-logging that occurred on

**Table 1.** Connection between root zone looseness (at the depth of 0-50 cm) and soil sensitivity (results of field monitoring in Hungary, 2000-2005)

| In the given profile | Soil sensitivity | Climatic harm |
|---|---|---|
| no compaction; water transport is optimal | low | poor |
| no compacted layer, but soil is consolidated; water transport is slightly limited | medium | moderate |
| one or more compacted layer; water transport is strongly limited | high | strong |

**Table 2.** Occurrence frequency of the soil compaction in arable fields (results of field monitoring in Hungary, 2000-2005)

| In the given profile | Soil sensitivity | Climatic harm |
|---|---|---|
| below 40-45 cm | slight | poor |
| at 30-35 cm | slight | poor/moderate |
| at 22-26 cm | medium | moderate |
| at 16-20 cm | high | strong |
| from the top to deeper layers (e.g. 0-35 cm) | high | strong |

**Table 3.** Extension of the compacted layer (results of field monitoring in Hungary, 2000-2005)

| In the given profile | Soil sensitivity | Climatic harm |
|---|---|---|
| < 10 mm | slight | poor |
| 10-20 mm | medium | moderate |
| 30-60 mm | high | strong |
| > 100 mm | very high | very strong |

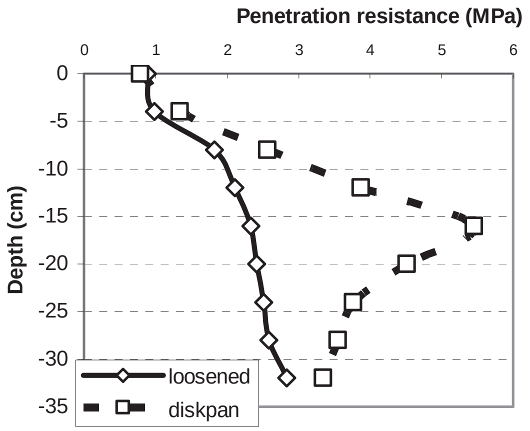

**Figure 1.** Penetration resistance curves of a loosened and a diskpan compacted soil

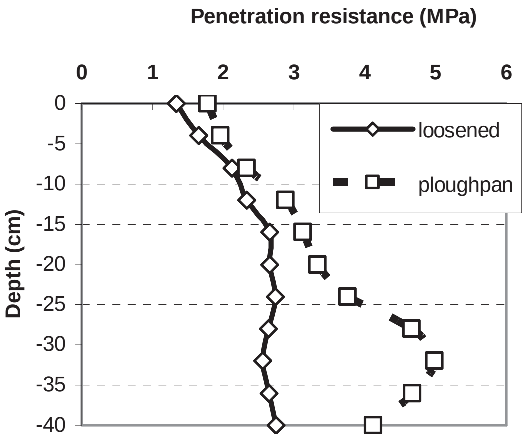

**Figure 2.** Penetration resistance curves of a loosened and a ploughpan compacted soil

nearly 420,000 ha of arable land in 2006 and the severe drought that occurred in 2000 and 2003. Both of these stresses resulted in decreased crop yields, presumably because of the increasing soil structure damage associated with the tillage-pan compaction. Results of the long-term examination have proved that the root zone looseness, which is a soil state at the depth of 0-50 cm, may refer to soil sensitivity under alterable climatic conditions. Absence or presence of the compacted layer in the root zone may refer to a possible water transport in the soil (Table 1). It can be stated that the disking and regularly used ploughing and often on wet soils, can be considered the primary cause of tillage-pan formation (Figure 1, 2). Location of the compacted layer gives information about the tillage and/or traffic induced faults. On the other hand, the occurrence frequency of the compacted layers in arable soils provides information of the soil sensitivity level and of the probable risk (Table 2). The third important factor is the extension of the compacted layer in a soil. The soil in the compacted layer has a penetration resistance of 3.0-5.0 MPa (in a well-loosened soil the mean value is about 1.0-2.5 MPa). This soil state refers both to degree of the deterioration and to the expected risk under dry and rainy seasons (Table 3).

*Agronomical structure.* Agronomical structure which is the rate of the clod, aggregate and dust in the cultivated soil, forms by natural and tillage induced processes. During the field monitoring we found some primary factors to cause clod or dust formation and to deteriorate the aggregation. These factors are: (1) soil compaction and recompaction; (2) soil drying after harvest; (3) over aeration of soils during primary tillage; (4) soil drying at primary tillage (before seedbed preparation). It can be stated that structure deterioration may extent by the use of water and carbon loss tillage in a long-term. In the experimental conditions five main factors had beneficial impacts on the aggregation and

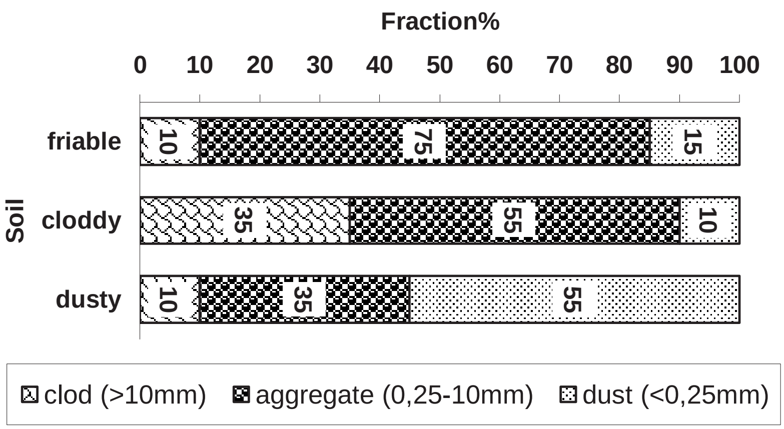

**Figure 3.**
Clod:aggregate:dust rate in a friable, cloddy and dusty soil (Hatvan, 2002-2005)

they are soil structure conservation tillage, surface mulching (after harvest), moderate surface drying, plant rooting, and earthworm activity. Prevention of clod and dust formation should be a further requirement for tillage in agricultural soils. Possible requirements that were found on the bases of field monitoring and trials are: (1) avoidance and alleviation of soil compaction; (2) avoidance of mechanical stresses on dry and wet soils; (3) decrease of soil disturbance and over-aeration; (4) usage of structure conserving tillage operations; (5) loosening of dry soils carefully.; (6) growth of deep rooting crops or crops that leaves big biomass; (7) incorporation and/or mulching of the crop residues. It is concluded that prevention of the aggregate deterioration and improvement of the friability may give a chance to decrease the soil sensitivity to climatic extremes (Figure 3).

*Organic material*. Studying of organic material content in soils, including its response to land use, is one of the oldest questions in agronomy. On soils which were originally rich in SOM we found five influencing factors (Figure 4), e.g.: (1) number and extent of soil disturbance (affecting $CO_2$ emission); (2) crop residue mass and handling (incorporate, mulch, or mix as recycle); (3) soil moisture storage or loss (affecting soil disturbance); (4) correct/incorrect-timing of primary tillage; (5) depth and method

**Table 4.** Soil disturbance impacts on organic matter loss and storage (Hatvan, 1983, 2002-2005)

| Negative impacts by | Positive impacts by |
|---|---|
| deep and rough disturbance of soil or clean-till or termination of conservation way or inverting virgin soils | soil condition improvement and maintenance or less intensity with adequate residue management |
| Stimulates soil OM loss | Promotes OM accumulation |
| - periodical disruption of soil structure | - aggregate conservation |
| - exposes new aggregates to microbial attack | - physical protection from biodegradation |
| - accelerates respiration of $CO_2$ by organisms | - maintain humid, non-dried soil condition during summer (mulch the surface) |
| - accelerates oxidation and thus aerobe microbial activity | |
| - dilutes soil C by mixing subsoil with topsoil | - managing soil microbial activity |
| - exposes soil surface to erosive forces | - mitigates the effect of increasing atmospheric $CO_2$ |

**Table 5.** The surface cover and the probable results (results of field monitoring in Hungary, 2000-2005)

| Percentage of the surface cover (%) | | | | |
|---|---|---|---|---|
| < 10 | 25-30 | 45-50 | 70-75 | 95-100 |
| Level of the decrease in soil moisture loss | | | | |
| slight | good | good | very good | very good |
| insufficient in dry season; in average season decrease the moisture loss slightly | sufficient in dry and average seasons; moderates soil water loss; promotes soil mellowing and sprouting weed and volunteer plants | effectual in water conservation and soil mellowing both in dry and droughty seasons | effectual in dry seasons; others: sprouting weed and volunteer plants are retarded; 20-25% of residues may mix into the soil promoting decomposition processes | total cover of soil is not recommended in the arable fields; half of residues required mixing into the soil; residue decomposition may be promoted by N-fertilization. |
| Aggregate conservation in rainy season | | | | |
| insufficient | adequate | favourable | favourable | favourable |

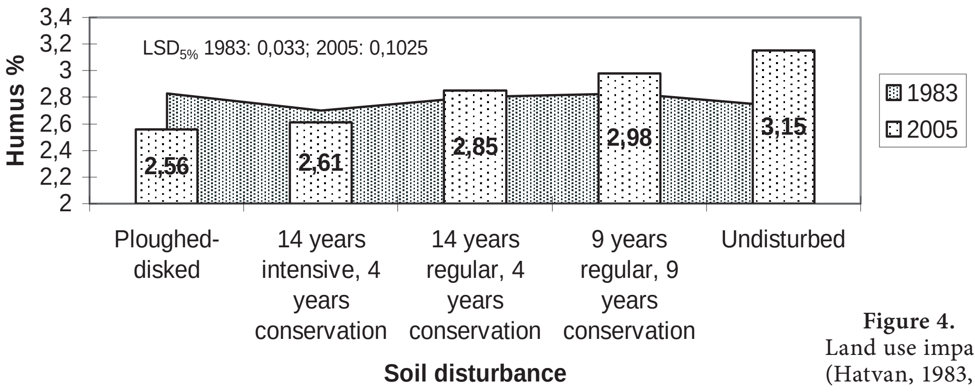

**Figure 4.**
Land use impacts on humus content of soil (Hatvan, 1983, 2005)

of soil disturbance in summer (affecting $CO_2$ emission). Other main features related to tillage impacts are listed in Table 4. Results obtained both in experimental and field relations reconfirmed that less (optimal) soil disturbance should be applied to conserve organic matters effectively, and that frequent disturbance promotes the loss of humus in a long-term.

*Soil moisture management*. Data of the field monitoring confirmed that depth and quality of the tillage have great influence on soil moisture management. In the growing season both depth of the loosened layer and the surface state (friability, cover) are the most important factors (Table 5).

*Land use impacts*. Data of the field monitoring proved close correlation between land use influence on soils (conservation, deterioration) and climatic harm. A harmony between soil tillage, crop sequence, fertilization, and crop protection may promote structure, biological life, water, and carbon conservation. This practice gives a real chance to alleviate any harm caused by climate extremes. However a long-term disharmony between soil tillage, crop sequence, fertilization, and crop protection causes deterioration of soil quality factors and the probability of a strong climatic harm. Summarising the factors decreasing climatic harm we found seven points: (1) protecting soil physical and biological condition and soil regeneration capacity; (2) protecting and improving soil quality factors (e.g. organic matter, aggregate, aggregation process, loose structure, moisture transport) by the soil-quality-maintaining-land-use methods; (3) preventing land use situations are promoting degradation processes (e.g. compaction, dust/clod formation), and apply harm-improving processes if they are needed; (4) improving biological effects of the crops by soil conservation tillage; (5) improving the root zone and forming the surface to adapt climatic conditions in the given years (alleviation of harm and maintanence of the crop production stability); (6) protecting the soil biological life by achieving harmony between tillage, crops, and fertilization; (7) using integrated crop protection harmonizing with soil disturbance, mulching and crop sequence.

## Discussion

Authors (Dexter, 2004; Karlen, 2004) agreed that soil quality depends on dynamic soil processes and properties that cause plant production risks even in the long term. Goals connected with soil quality, namely improvement, conservation, and maintenance, corresponded with the aims of sustainable management (Kisic et al., 2006; Zugec et al., 2006). Importance of the soil quality research, as authors outline, is multilateral, and it is: (1) to recognize soil degradation and it's consequences (deterioration in workability, trafficability, declining of soil biological processes, increasing of production costs, yield and farming losses) on time; (2) to prove that there is relation between soil quality and climatic harm; (3) to elaborate new methods for soil condition improvement; (4) to decrease economical pressures; (5) to determine the goals for soil and environment protection. There is also a number of soil quality indicators. On one hand they reflect the point of view of the authors and on the other hand they are based on the soil physics traditions. The new research results have been widened not only the number of methods but the possible factors as well. In this paper some practical indicators are presented.

In Hungary the tillage-induced soil compaction (diskpan- and ploughpan) occurs on 2.0 million ha of arable land (Birkás, 2004), that is on soils that are sensitive to compaction. However, the ratio of the vulnerable soils is higher; it covers 63% of arable land. Long-term field monitoring and trials showed that annual disking and ploughing causes subsoil compaction at the depth of tillage within 2-3 years. Both occurrence and consequences of the soil compaction were fairly discussed (Birkás, 2000, Birkás et al., 2004). However the frequent climatic extremes and the yield loss recalled to attention the need to solve the most serious compaction problems on the fields. In the next decade two important tasks are stressed: prevention of tillage-induced compaction and the necessity of the improvement of soil condition. The decrease of the climate induced harm also needs new requirements for tillage. These are to improve and/or to maintain a loosen condition. The agronomical structure of the soil including ratio of aggregates and water-resistant aggregates is related to environmental (climate, soil) and human (land use) factors. As Dexter and Birkás (2004) stressed, aggregation can be improved by long-term soil conservation management. As authors (Birkás, 2000; Gyuricza, 2000; Kisic et al., 2006) stated soil tillage is a primary technological process, which may improve the physical and biological condition of the soil. On the other hand it may also induce severe agro-ecological and soil degradation problems (Jolánkai et al., 1997). Consequently, soil tillage should be done with the consideration of the impacts on soil and environment condition and on farm management. It is well known that tillage operations modify soil structure both directly and indirectly (Zugec et al., 2006). Results of our trial reconfirmed that less soil disturbance can be applied to conserve organic matters effectively, however, to disturb the soil frequently promotes the loss of humus in a long-term. Similar consequences were summarized by Paustian et al. (1998) and ECAF (1999).

## Conclusion

Soil tillage impacts on soil condition often do not fulfill the environmental demands. Less environmental harm might be induced if agronomical demands corresponded to the environmental ones. In Hungary, consequences of climatic extremes on the fields call to attention the need to reassess the quality level of arable soils. Mitigation of the harmful climatic impacts on crop production requires establishment and realization of a soil quality improving program. In the farm management viewpoint the most important steps are: (1) prevention of the tillage induced harm including soil compaction and structure degradation; (2) conservation of optimal soil physical and biological condition and fertility; (3) usage of soil structure conservation tillage in humid, dry and wet conditions; (4) improvement of soil loading capacity connected with organic matter conservation; (5) reasonable management of soil organic materials; (6) rational utilization of stubble residues; (7) maintaining an optimal water management in soils by improving soil condition and avoiding the harm. Our research results give data to review the recent situation and may help to extend and to realize a soil quality improving program in the next decade.

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