Soil Tillage Needs a Radical Change for Sustainability

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Summary

In Central Europe, the challenge in soil tillage throughout the last century can be characterized as a fight against extreme climatic and economic situations. From 1800s till the 1970s, the main requirement of soil tillage was to provide suitable soil conditions for plant growth (moreover with fine structure). Both climatic and economic difficulties were beneficial in establishing new tillage trends, however overestimation of the crop demands have presumably been promoted by the deterioration in soil quality. From the end of the 1990s, new requirements have also been introduced because of the rise in energy prices and because of the need to cut production costs. The reduced tillage in Central European region showed some advantages, e.g. less soil disturbance and traffic however, that resulted in new soil condition defects (e.g. top- and subsoil compaction, structure degradation). The ideas of sustainability offered a better solution that is to conserve soil resources and to protect the environment. A new problem, the global climate change, and the importance of the adaptability fasten to the original sustainable goals. In this paper the features of soil quality deteriorating tillage (conventional, over-reduced) are summarised, the steps of improvement are demonstrated, and factors affecting sustainable soil tillage are formulated.

Key words

soil, soil quality, tillage, sustainability, climate change

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Introduction

In Central Europe, from 1800s till the 1970s, the main requirement of soil tillage was to provide suitable soil conditions for plant growth, moreover with fine structure (Table 1). The plant requirements have often been overestimated by farmers and the consequences had been decreasing effects on yield by means of compacted pans or creation water-impenetrable layers (Birkás et al., 2000, 2004a,b). In other hand in the tillage practice there were beliefs or bad use in number those have had their time, such as deep and black stubble tillage, cloddy winter ploughing (to catch snow), deep summer ploughing (for soil disinfection by sun), and fine-aggregated seedbed for more crops (Birkás, 2006). During the last decades, these traditional goals were forced to change due to the deterioration of soil quality (Basic et al., 2002; Lipiec et al., 2003; Sabo et al., 2006; Farkas et al., 2007). While close correlation is found between soil quality deterioration and climatic harms (e.g. water-logging, severe drought) the authors were induced to elaborate variable and effectual harm-alleviation technique in due time (Birkás et al., 2004b). From the end of the 1980s, the ideas of sustainability have been offered a new challenge, evolving toward greater efficiency of resource use, and developing and maintaining a harmony between crop production technologies and soil environment (Várallyay, 1997; Zugec et al., 2000). By now, a new problem, the global climate change, and the importance of the adaptability call attention to develop the original sustainable goals. Consequently, it is final time to step forward in behalf of soil tillage and to instruct the climate-harm alleviation methods in arable fields.

Materials and methods

This paper is based on soil condition monitoring and measuring that started 20 years ago in Hungary by Department of Soil Management at Szent István University Gödöllő, and in Croatia by Department of General Agronomy, Faculty of Agriculture, University of Zagreb, and by Department of Crop Production, Faculty of Agriculture at J.J. Strossmayer University in Osijek. The soil condition monitoring was focused on evaluation of soil quality factors conventionally tilled (e.g. compaction and/or looseness state; level of aggregation at different land use; consequences of water and wind erosion; drought and water-logging situations). While the preliminary results were published both by Hungarian (Bencsik et al., 2007; Birkás et al., 2002; 2006; Birkás and Kalmár et al., 2006; 2007) and Croatian relation (Basic et al., 2002; Jug and Stipesevic, 2006a,b; 2007; Kisic et al., 2003; 2004; 2005; 2006; Sabo et al., 2007), in this paper the important facts are only listed. The soil consequences of reduced and over-reduced tillage practice are also presented. We used next points for monitoring: 1) tillage goal, method and tools; 2) depth of primary tillage; 3) energy demand of system; 4) surface features; 5) stubble residues handling; 6) impacts on OM condition; 7) adaptability on different soils; 8; impacts on soil state and plants and soil loss and 9) long-term impacts. The ideas and the adaptable methods of sustainable soil tillage have been elaborated for last years depending on our new research results. By this means the objectives of this study are: 1) to summarise the risk factors of conventional soil tillage; 2) to compare the soil consequences of reduced and the over-reduced tillage and 3) to characterize of the bases of sustainable soil tillage completing the adaptable methods.

Results and discussion

Risk factors of conventional tillage

While this subject has been published widely in the last decades, in this paper the main risk factors of the conventional tillage are only summarised (Table 2).

A compaction process occurs in soils by repeated pressing of the same tools at the same depth, and the dense layer extending to the top- and subsoil restricts the rooting depth and increases plant sensitivity to the drought. Number of the secondary processes is usually great, thus the recompaction process can occur prior to planting.

A compacted layer, through the water infiltration restriction, promotes the water-logging harms significant-

Table 1. Requirements and consequences of soil tillage in Central European region

Period	Requirements	Consequences
1800s-1970s	Suitable soil conditions for plant growth: create fine structure, form clean surface, use deep and black stubble tillage ('for sun disinfection'), use cloddy winter ploughing ('for snow')	Soil quality deterioration: compacted pans (creation of water-impenetrable layers), dust formation, soil water and wind erosion loss ↓ yield decrease
1980s-	Ideas of sustainability – new challenge, evolving toward greater efficiency of resource use	Developing and maintaining a harmony between crop production technologies and soil environment
2000s-	Mitigation of climatic harms by use of climate-harm alleviation methods	Less tillage defects = better water transport = stabilised crop production

Table 2. Risk factors of conventional tillage

Tillage damages	Consequences
Compaction - by repeated pressing of same tools at same depth	Restricts rooting depth and increases plant sensitivity to drought
Dense layer extending to the top- and subsoil	Recompaction process prior to planting
Great number of the secondary processes	Promotes water-logging harms
Restricted water infiltration	Decomposition of stubble residues and nutrients is retarded in compacted and recompacted layers
Limited water and air penetration	Clodding (during primary tillage) and dust formation (by multitraffic, secondary tillage)
Less adoption to soil moisture	Water and wind erosion
Dust formation of soils	Sludging, crusting, cracking, capping
Mechanical stresses (bad ploughing, clod/dust formation)	Cut of biological mellowing, destroy habits of earthworms
Deep and repeated soil disturbance	CO_2 emission increases into atmosphere – contributing to global warming and reduces OM
CO_2-C, OM loss	No friable state - declined/limited workability, trafficability and loading capacity
Clean surface	Higher soil structure vulnerability and soil sensitivity to climatic extremes

ly. While the water and air penetration is greatly limited, thus decomposition of the stubble residues and nutrients is also retarded in the airless, compacted and recompacted layers of soil.

In conventional practice the adoption to soil moisture content is lower, therefore the clodding, during the primary tillage and the dust formation, by the multitraffic, are very typical secondary processes. A pulverized soil is moved by the water and wind (erosion), and other harmful processes are also stimulated (e.g. sludging, crusting, cracking and capping).

Soil biological mellowing can be cut or neglected due to repeated mechanical stresses. Habits of the earthworms are usually destroyed by annual ploughing. The strong clod formation on dry soils and the smearing and puddling on wet soils also restrict their activity.

A soil disturbed deeply and repeatedly increases the emission of CO_2 into the atmosphere contributing to global warming and reduces organic materials. In a soil disturbed frequently, organic material content has also been decreased, thus the workability, and the loading capacity are also declined. A soil, becoming poor in organic materials and in friable state is workable in a narrower moisture range, thus the trafficability is also limited.

A clean surface is a great requirement in conventional viewpoint. However this fact promotes both the soil structure vulnerability and the soil sensitivity to climatic extremes.

Most of the negative consequences listed above and discussed widely (Birkás et al., 2004; Várallyay, 1997; Zugec et al., 2000; Birkás and Dexter et al., 2006) are exactly originated from the multi-traffic conventional soil tillage practice (number of traffics was often occurred from 6 to 12). In other hand, the conventional tillage characterised by the tillage of the whole surface, and uses one way ploughing. The soil condition fitting to the imagined crop requirements is obtained using more time than is reasonable, and with higher energy costs. However the possibility that tillage-induced harms might mostly be prevented and may improve by the use of an adequate tillage, gives the chance to reduce the risks and to improve soil condition.

Reduced and over-reduced tillage

Tillage might be optimally reduced, if the soil condition which met the demands of the crop to be grown was obtained with minimum number of tillage operations considering the soil conditions (Birkás, 2006). Both in Hungarian and Croatian relations, the trend of reduced tillage is based on the recognition of disadvantages of conventional one, including high costs. The 'Hungarian reasonable tillage' strategy, promoted by Cserháti at the end of the 1800s was aimed at reducing tillage without increasing the risk in arable fields (Birkás et al., 2004a). However, the first steps to reduce tillage traffics were taken in the 1970s due to increasing of the fuels price. As authors (Birkás et al., 2004b; Jug et al., 2006a,b) stated, the tillage might be optimally reduced, if the soil condition which met the demands of the crop to be grown was obtained with minimum number of tillage operations considering the soil conditions. On the one hand, reduced tillage was applied successfully in arable fields, but on the other hand, as the field monitoring was stated, that was used exaggeratedly. The main problem was the shallow primary tillage by disk, using repeatedly at the same depth year by year. According to the concerning field measuring, 48% of the total monitored area (1860 ha) was deteriorated by

Table 3. Comparison of three soil tillage practices in Hungary and in Croatia in the 2000s

Factors	Conventional	Over-reduced	Sustainable
Tillage goal	Plant demand	Low costs	Soil quality improvement
Method	Inverting	Disking	Rational
Tools	One way plough and simple equipment	Disk and simple equipment	Cultivator, subsoiler, plough (as required)
Depth of primary tillage	Deeper as required	Shallow	As soil condition requires
Energy demand	High	Low/high	Real
Surface	Clean	Clean	Covered by mulch
Stubble residues	Tillage limiting matter	Causing diseases	Valuable matter
OM	Decreasing	Decreasing	Conserving
Adaptability on different soils	Doubtful	Constrained	Well
Impacts on soil state	Changeable	Dangerous	Conservation, regeneration
Impacts on soil loss	Promoting	Promoting	Decreasing
Impacts on plants	Favourable in short-term	Unfavourable	Favourable in long-term
C-CO_2 flux kg ha^{-1} day^{-1}*	105-260	44-86	15-35
Long-term impacts	Climate sensitivity	High climate sensitivity	Decrease of climate harms

*Source: Birkás M., Jolánkai M., Stingli A., Bottlik L. 2007. Az alkalmazkodó művelés jelentősége a talaj- és klímavédelemben. „KLÍMA-21" Füzetek, 51. 34-47.

Table 4. The surface cover and the probable results in arable fields

		Cover % of the surface		
< 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 seasons; In average seasons decreases moisture loss slightly	Sufficient in dry and average seasons; Moderates soil water loss, and promotes soil mellowing	Effectual in water conservation and soil mellowing in dry and droughty seasons	Effectual in water conservation both in dry and droughty seasons	Effectual, but total cover of the soil is not recommended in arable fields.
		Aggregate conservation in rainy seasons		
insufficient	adequate	favourable	favourable	favourable

conventional disk. There are considerable differences between tillage systems above-mentioned and the sustainable one (Table 3).

The most important features of the normal reduced tillage is the energy saving and the adaptability to real condition of soil. The number of traffic is rationally less due to modern tillage technique. This system is suitable for soil quality improvement. However it requires a perfect level of knowledge.

The over-reduced tillage is forced to save energy and tillage traffic because of the lack of capital and appropriate equipment. A greater problem both in Hungary and Croatia is the imperfect level of knowledge. Deterioration in soil physical (diskpan compaction and/or the dustiness of topsoil) and biological state is typical.

Both the conventional and over-reduced way throughout of the soil quality deterioration has not been suitable to mitigate the climate harms. This situation requires establishment and realization of the new soil quality improving program.

Features of the sustainable soil tillage

Fundamental factors characterising the sustainable soil tillage have close correlation with the environmental requirements. We elaborated and summarised the most important tasks as follows:

1. Avoiding the tillage-induced soil harms e.g. occurrence and extension of soil compaction; soil structure degradation; water and wind erosion; CO_2 emission; organic material loss; deterioration in soil biological activity.
2. Maintaining a favourable loosen soil condition to decrease soil susceptibility to the climate harms (drought, water-logging).
3. Combine the soil conservation tillage, the defensive surface and the long-term plant cover to prevent and to decrease the erosion harms on sloped soils.
4. Soil moisture management. Improving the water infiltration and storage in wet years and decreasing the moisture loss in dry and average seasons.
5. Using adaptable tillage processes to improve the water infiltration through alleviation of the compacted status

Table 5. Considerations between conventional and sustainable soil tillage

Factors	Conventional system	Sustainable system
1. Time and labour	much (-)	reduced (+)
2. Fuel consumption	much (-)	reduced (+)
3. Special technique	no (+)	required (-)
4. Pests and disease	manageable (+)	manageable (+)
5. Herbicide dependence	acceptable (+ -)	acceptable (+ -)
6. Soil and environment conservation	doubtful (-)	effectual (+)
7. Compaction harm (traffics)	extended (-)	reduced (+)
8. Soil moisture loss	high (-)	low (+)
9. Stubble residues handling	acceptable (+ -)	acceptable (+ -)
10. Adaptability to	.	.
• heavy soil	possible (+)	possible (+)
• dry soil	possible (+)	low risk (+)
• wet soil	doubtful (-)	manageable (+)
• compacted subsoil	requires subsoiling (-)	requires subsoiling (-)
11. Impact on soil structure	unfavourable (-)	conserving (+)
12. Improving effect on degraded soil	dubious (-)	effectual (+)
13. Impact on soil biological life	generally unfavourable (-)	favourable (+)
14. Establishment of crop production	depends on climatic factors (+ -)	effectual (+)
15. Requires improved management	rarely (-)	yes (+)
16. Popularity (now)	great (-)	low (-)
17. Prognosis (future)	declining (+)	progressive (+)
Advantages : Disadvantages	35:65	77:23

Legend: (+): advantageous; (-): disadvantageous; (+ -): alterable for farming

(soil loosening, subsoiling) and to moderate the moisture loss (surface preparation, mulching).

6. Stubble residue management. Incorporating and mulching with stubble residues in the fields aims to improve the organic matter balance, to decrease the soil moisture loss, promoting and maintaining the favourable biological activity in soils thus improving the soil workability trough the mellowing process in dry years (Table 4).
7. Organic material management to increase the stability of the structure, the water-holding capacity, the soil loading capacity and the workability and to decrease the soil compactibility and vulnerability.
8. Using energy saving tillage. Utilizing the possible machinery (tractor, mass of tool, running gear, working speed, energetic relation between tractor and tool, state and construction of tillage tool) and arable site factors to reduce the energy consumption thus to decrease the environmental load.
9. Fulfilling the soil sustainability ideas, that is supposed a real knowledge in soil characters and soil condition level. Referring to sustainability, a great chance would be followed a soil quality maintaining and improving tillage.
10. Using soil loading alleviation crop rotation. The sequence of the cash crops may follow an optimal change in growing seasons in order to produce different patterns of root proliferation throughout of the soil matrix (fibre root vs. tap root crops). Also, different cover crops can be used to prevent erosion, to conserve soil water and to improve soil structure and bearing capacity for traffic.

We may offer solutions in the spirit of sustainability, e.g. shallow stubble-mulch tillage in summer to decrease high water loss and prevent the structure deterioration. We have elaborated adequate variants of primary tillage (e.g. improved ploughing systems, loosening systems, system based on heavy-duty cultivator use, and systems to improve soil aggregation and mellowing). We state that the sustainable management based on the soil improving and maintaining tillage offers the real solution (Table 5).

Conclusions

At the end of the obtained results of measuring and monitoring can be summarised in the following way.

1. The tillage tendencies that are conventional, reduced, over-reduced (designed to reduce specific constraints) and sustainable can be considered by the reason of their impact on soil and environment condition.
2. The conventional tillage by the multi-traffics and the over-reduced by the soil compaction harms contribute to the environmental risks, however the sustainable one through the improvement and maintenance of soil condition offers a long-term solution.

3. Ten fundamental requirements were selected to summarise the sustainable tillage features filling the sustainable soil tillage strategy that can establish a harmony between environment conservation and the demands of crop production.

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