Subsoil Compaction:
A hidden form of
Soil Sealing in Europe

by:

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Abstract

There are two definitions of 'soil sealing': (I) 'covering (sealing) the soil surface by impervious materials, e.g. concrete, metal, glass, tarmac and plastic'; and (II) 'changing the nature of the soil such that it behaves as an impermeable medium, e.g. by compaction'. The main causes of soil sealing according to the first definition (I) are building development (e.g. industrial and residential premises) and transport (e.g. roads). Changing the nature of the soil such that it behaves as an impermeable medium (definition II) is an extension to include the potential effects of the passage of machinery (mostly agricultural) and the effects of heavy rainfall. Intensification of agriculture is now recognised as often having a detrimental effect on soils, not least the widespread development of compaction. The worst effects of compaction at the surface can be rectified relatively easily by cultivation but once subsoil compaction occurs, it can be extremely difficult and expensive to alleviate. It is now clear that the detrimental effects of subsoil compaction go far beyond agricultural concerns of a decrease in yield and increase in management costs. Environmental impacts include increased erosion risk, accelerated runoff and increased pollution. A preliminary attempt to assess the susceptibility of subsoils in Europe to compaction is presented here in the context of soil sealing. The resulting distribution is only the first stage in assessing the vulnerability of subsoils in Europe to compaction. The biggest problem with soil sealing as an environmental indicator is the difficulty of establishing the true extent at the regional and larger scales. However, subsoil compaction should not be ignored because it probably affects a larger area in Europe than urbanisation (land consumption) and in this respect it must be regarded as an important process of soil sealing.

Key words: *subsoil, compaction, soil, sealing, Europe*

Introduction

There are clearly two definitions of 'soil sealing'

I. 'covering (sealing) the soil surface by impervious materials … e.g. concrete, metal, glass, tarmac and plastic'
II. 'changing the nature of the soil such that it behaves as an impermeable medium e.g. by compaction'

The first definition (I) was adopted for the most recent initiatives on quality indicators for soil by the Organisation for Economic Cooperation and Development (OECD, 1993) and the European Environment Agency – EEA – (Gentile, 1999). The second (II) is proposed in this paper, as an extension to this concept of soil sealing, to fully take account of the effect of agriculture. Both types of 'soil sealing' involve human intervention, but the second (II) can also result from natural processes, for example crusting of bare soil surfaces by the impact of raindrops and the inherently compact nature of some clayey deposits.

The main causes of soil sealing according to the first definition (I) are building development (e.g. industrial and residential premises) and transport (e.g. roads), and these activities are driven largely by socio-economic pressures. Politics can also play a part through the planning process. Covering the land surface in this way often results in the destruction of the soil itself and may or may not be an irreversible process. It may be more correct to refer to this type of soil sealing as 'land consumption' (Dosch, pers comm.) or 'soil covering'.

Changing the nature of the soil such that it behaves as an impermeable medium (definition II) is an extension to include the potential effects of mechanical activity (mostly through the passage of agricultural machinery) and the effects of heavy rainfall on soils. Traditionally, soil scientists have understood these aspects to be sealing of the soil. Therefore, soil sealing *de facto* is a process that rearranges soil particles and/or soil structural units such that the soil surface behaves as though it is sealed directly rather than a process of mechanically covering the land with other (usually manmade) materials. This 'traditional' type of sealing takes the form of:

1. Surface and subsoil compaction
2. Surface crusting
3. Surface deformation by machinery and animals

In addition, agricultural activity *per se* can seal soil surfaces by (4) erection of glasshouses and (5) temporarily covering cultivated surfaces with polythene sheeting to conserve soil moisture.

However, the current indicators proposed by EEA (Gentile, 1999) for soil sealing only address or relate to:

1. Urbanisation
2. Environmental impacts e.g. flooding and landslide
3. Future trends e.g. changes in land use
4. Reversibility/irreversibility e.g. recycling/desealing of developed land.

Some of these indicators can be monitored given the availability of the appropriate statistics. Others such as flooding and landslides are also caused by a change in the nature of the soil.

This paper focuses on subsoil compaction as a form of soil sealing because this is probably the most extensive and the most persistent of those described above (1-3). In order to extrapolate from the research to policy arena, due attention must be paid to subsoil compaction as an on-going process of soil degradation that has significant environmental consequences.

Subsoil compaction

Intensification of agriculture is now recognised as often having a detrimental effect on soils, not least the widespread development of compaction. Compaction can occur at the surface or below in subsurface soil horizons. Knowledge concerning the vulnerability of subsoils to compaction in Europe is now an increasingly important requirement within agriculture and for planning environmental protection measures.

The worst effects of surface compaction can be rectified relatively easily by cultivation and hence it is perceived to be a less serious problem in the medium to long-term. On the contrary, once subsoil compaction occurs, it can be extremely difficult and expensive to alleviate. Furthermore, remedial treatments usually need to be repeated. The risk of subsoil compaction increases with the growth in farm size, increased mechanisation and equipment size, and the drive for greater productivity. The response of the engineering industry to the demands of agriculture has been impressive over the past 30 years. Larger and larger machines have been developed but, from the soil standpoint, the result has been a significant increase in axle loads not always matched by reductions in ground contact pressures to prevent or minimise compaction. (Renius, 1994; Tijink *et al*., 1995; Chamen *et al.*, 2001).

Research into the causes and effects of compaction in topsoils and subsoils in Europe has demonstrated the detrimental effects on the farming system (Hakansson, 1994). It is now clear, however, that the detrimental effects go far beyond agricultural concerns of a decrease in yield and increase in management costs.

The overall deterioration in soil structure that may result from compaction can also:

1. increase lateral seepage of excess water over and through the soil, accelerating the potential pollution of surface waters by organic wastes (slurry and sludge), pesticides, herbicides and other applied agrochemicals;
2. decrease the volume of the soil system available to act as a buffer and a filter for pollutants;
3. increase the risk of soil erosion and associated phosphorus losses on sloping land through the concentration of excess water above compacted layers;
4. accelerate effective runoff from and within catchments.
5. increase green house gas production and nitrogen losses through denitrification under wetter conditions.

Some of these effects are illustrated in Figure 1.

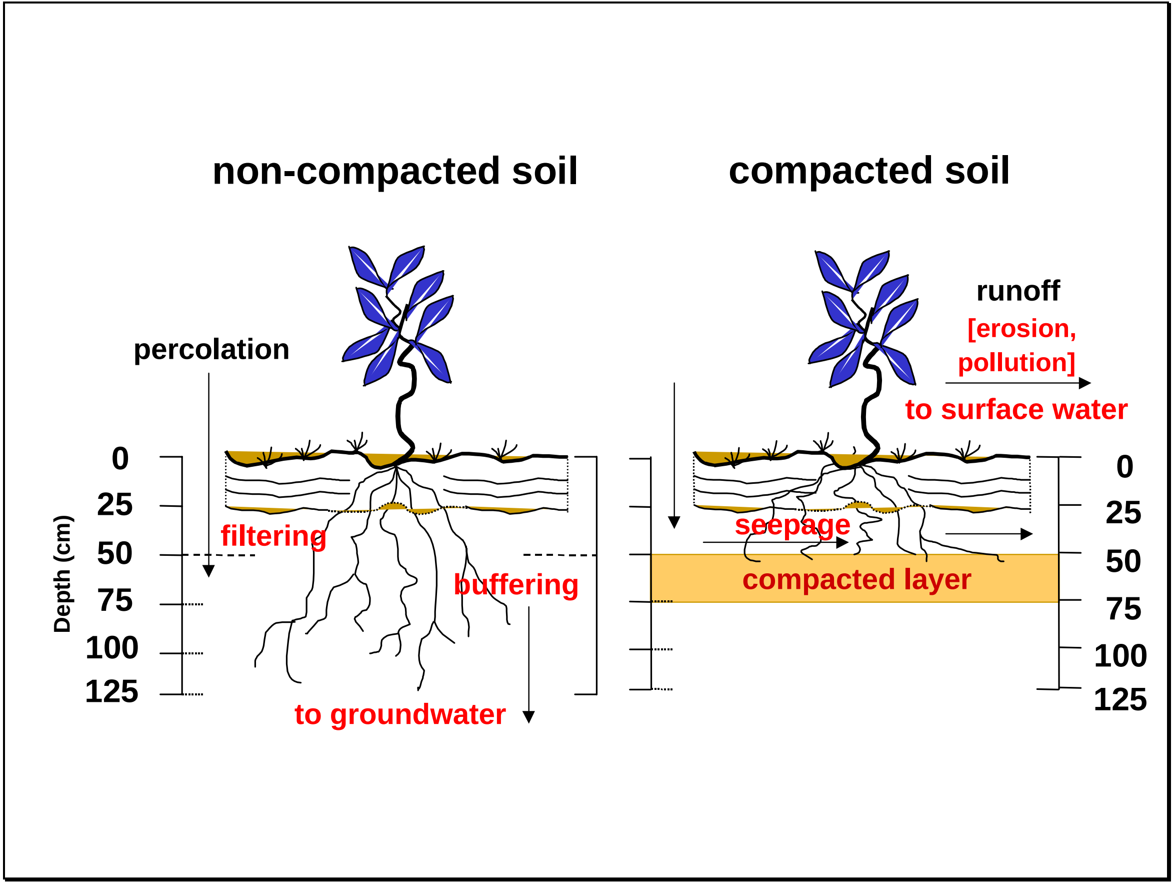

Figure 1 The Impacts of subsoil compaction

Subsoil compaction has been the subject of a recent Concerted Action (Akker, 1999), supported financially by the European Commission under the FAIR Programme. A parallel network covering eastern Europe is being supported under the INCO-COPERNICUS programme (Akker and Canarache, 2000). The European Soil Bureau has been associated with the collection of data on subsoil compaction in the both the FAIR and INCO-COPERNICUS programmes with a view to incorporating new soil data in the European Soil Database.

With respect to sealing, 'changing the nature of the soil' such that it behaves as an impermeable medium, essentially means increasing the bulk density above the threshold when downward percolation of water ceases. Rock materials generally have densities between 2.55 and 2.65 t m^{-3} (g cm^{-3}) whereas soils generally have densities in the range 0.8 to 1.6 t m^{-3}. However, many soil materials with a bulk density in excess of 1.75 t m^{-3} effectively behave as though they are impervious to downward water movement (Hall et al. 1977).

Subsoil compaction is a manifestation of increased bulk density and can therefore be related directly to soil properties. External aspects such as land use and the use of machinery also play an important part in the occurrence and distribution of compacted subsoils.

Under the FAIR Programme, Jones *et al.* (2000a, 2000b, and 2001) have made a preliminary attempt to assess the susceptibility of subsoils in Europe to compaction. Using this scheme, the susceptibility classification (Table 1) has been applied to the European Soil Database (Heineke *et al.*, 1998) and a preliminary map (Figure 2) produced, showing the susceptibility of subsoils to compaction.

Table 1 Susceptibility to compaction from texture and density

Texture		Packing density t m^{-3}		
		Low	Medium	High
Code	Class	< 1.40	1.40 – 1.75	> 1.75
1	Coarse	VH	H	M[1]
2	Medium	H	M	M
3	Medium fine	M(H)	M	L[3]
4	Fine	M[2]	L[4]	L[3]
5	Very fine	M[2]	L[4]	L[3]
9	Organic	VH	H	

Susceptibility classes: L low, M medium, H high, VH very high
Texture classes are those of FAO-UNESCO (1974)

[1] *except for naturally compacted or cemented coarse (sandy) materials that have very low (L) susceptibility.*
[2] *these packing densities are usually found only in recent alluvial soils with bulk densities of 0.8 to 1.0 t m^{-3} or in topsoils with >5% organiccarbon.*
[3] *these soils are already compact.*
[4] *Fluvisols in these categories have moderate susceptibility*

As emphasised above, this is only the first stage in assessing the vulnerability of subsoils in Europe to compaction and as it does not take into account land use or the interaction of climate.

Spatial analysis based on Figure 2 has revealed the following proportions for the 4 susceptibility classes: low 20%; moderate 44%; high 28; very high 9%. Thus more than a third of European subsoils are classified as having high or very high susceptibility to compaction and more than 75% moderate or high susceptibility.

The impacts of subsoil compaction can be assessed according to the DPSIR framework proposed by OECD (1983) and adopted by the EEA for environmental auditing purposes. This is illustrated in Figure 3 and it provides a suitable mechanism for identifying appropriate responses.

Discussion and conclusions

In order to provide reliable estimates of areas affected by subsoil compaction, climatic data must be overlaid on the soil data (Figure 2) preferably incorporating land use information. A suitable source of climatic data for Europe is the MARS project database (Vossen and Meyer-Roux, 1995) which contains agroclimatic parameters interpolated on a 50km x 50km grid for Europe. Land use data can be extracted from the CORINE database.

Compaction can also be caused by the passage of non-agricultural traffic. Hence in the north of Scotland and in northern Finland, the organic rich soils are not at risk from agricultural machinery because they are not under cultivation, but forestry or construction machinery will have a devastating effect on soil structure.

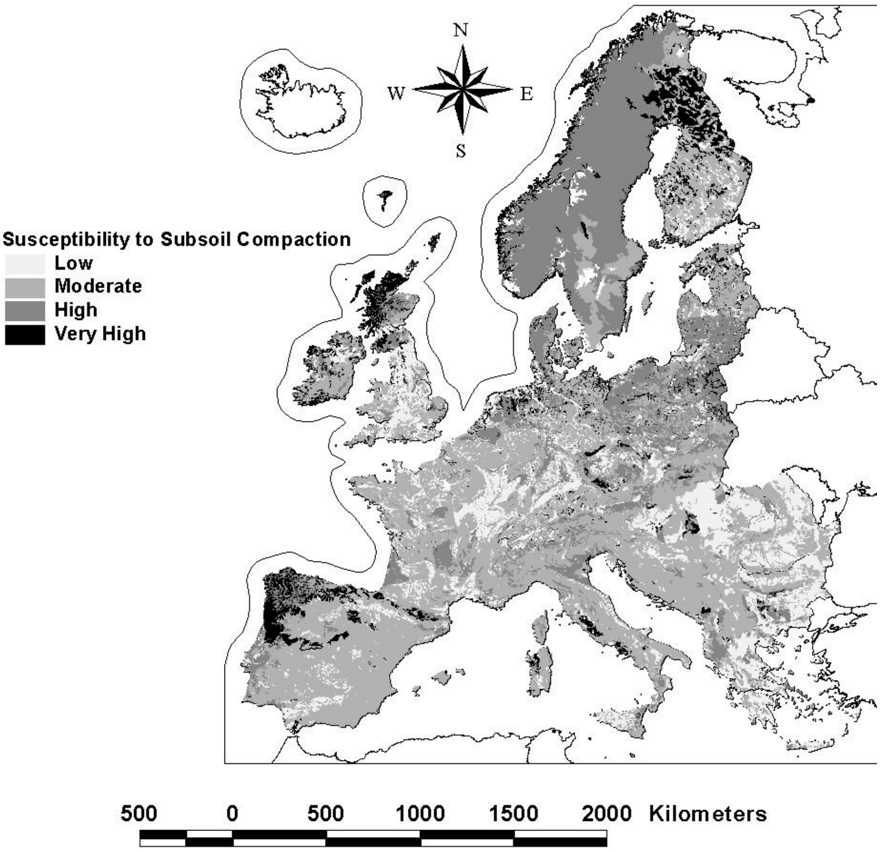

Figure 2 Susceptibility to subsoil compaction
[This assessment does not take into account land use or the interaction of climate]

The biggest problem with soil sealing remains the difficulty of establishing accurately its extent at the regional and larger scales, because reliable estimates that can be compared with what is actually happening are rare. Subsoil compaction, resulting from the passage of agricultural machinery, has so far been ignored as a manifestation of soil sealing yet undoubtedly, it is on the increase because of the intensification of agriculture. Subsoil compaction is now believed to affect large areas in intensively farmed regions, particularly in Eastern Europe, contributing to increased runoff and to an increased risk of flooding.

In reality, subsoil compaction probably affects a larger area in Europe than urbanisation and in this respect the extent of susceptible soils is impressively large. However, for subsoil compaction to be recognised by the policy making sector as an on-going process of soil degradation that contributes significantly to soil sealing, more consideration needs to be given to the pressures and possible responses (Figure 3).

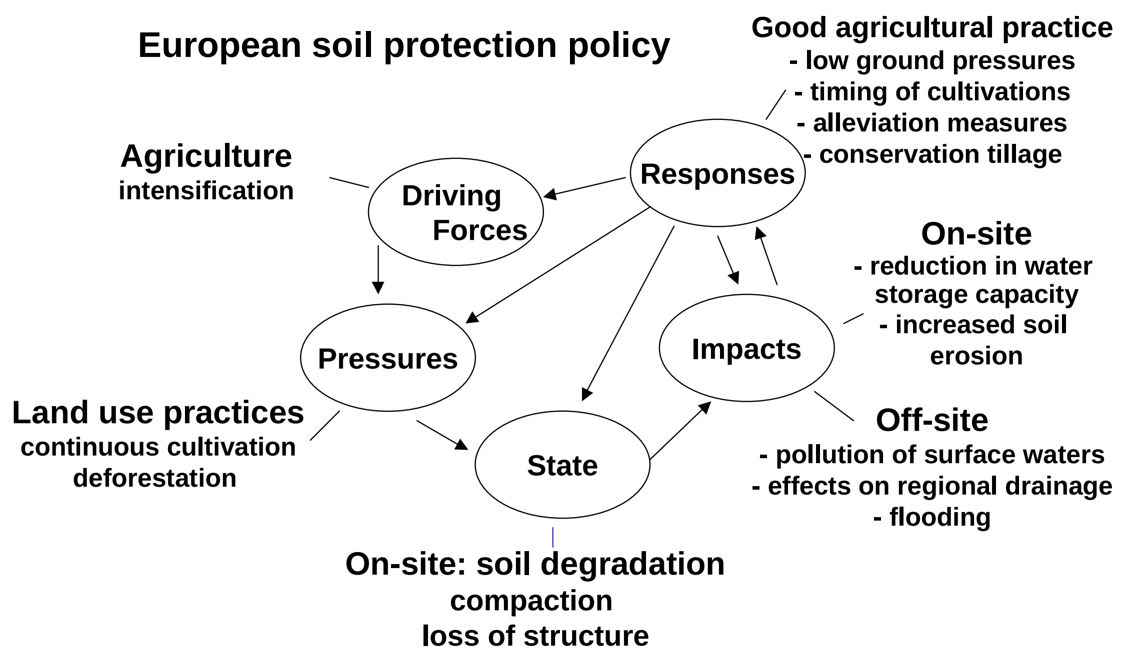

Figure 3 The DPSIR Framework applied to subsoil compaction

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