## 4. Soil Physical Damage: Summary of Issues

**Problem**
Soil structural degradation; compaction, poaching and erosion.

**Impact**

**Soil quality**
- increased incidence of surface ponding and waterlogging due to low infiltration rate.
- changes in soil chemistry under reducing conditions.
- reduction on rooting depth or even loss of surface horizon.

**Water quality**
- increased sediment load to rivers and alteration of stream bed conditions.
- increased load of nutrients, agrochemicals and faecal pathogens to rivers.

**Plant growth**
- reduced air-holding capacity and reduction of oxygen supply to roots.
- changes in major nutrient cycles due to altered soil chemistry.
- loss of seedbed contents or exposure of roots.

**Areas at Risk**

**Compaction:** intensive arable production on soils with high silt and clay contents. Higher risk for systems involving multiple passes of machinery under adverse soil conditions (i.e. at or close to field capacity) and systems where yield increases with late harvesting (e.g. root crops) or where multiple cropping takes place (e.g. intensive silage grass).

**Poaching:** animal production on imperfectly drained soils in the wetter areas in the west of Scotland. Livestock access to grazings on wet soils, direct access to river/streams for watering, application of slurries and wastes when soils are wet.

**Water-induced erosion:** is often associated with intensive arable production on sandy, coarse-textured soils in the East of Scotland.

**Wind-induced erosion:** in arable systems is commonly experienced on the sandy soils in Moray. However, it also occurs in extensive systems on the organic soils and peats of the hills and uplands, due to removal of plant cover by heavy grazing

**Practical Actions**

**Compaction and poaching** Soil strength decreases significantly with wetness and, thus, access for machinery and animals should be restricted when soil moisture content is at or close to field capacity. Remediation of severe subsoil compaction is costly and carries with it a risk of further damage because of the use of heavy machinery for soil loosening and deep ploughing. Natural regeneration of compacted topsoils can take up to 3 years. Avoidance of damage through sound land management is critical.

The use of engineering solutions such as low ground-pressure tyres, dual wheels and tracked vehicles may be justified in some cases to widen the operating window for land management. ‘Sacrificial’ systems such as ‘tramlines’ are now widely employed in cropping systems but may act as a point of initiation of erosion events during heavy rainfall events. In the longer term, liming and increasing soil organic matter contents in mineral soils can encourage the development of good soil structure.

Poaching damage by livestock is again amenable to good land management practices. Limiting access of stock to wet soils and fencing of sensitive areas, such as river banks, can all help at the farm level.

**Erosion** It is important to recognise that erosion is a natural process, which can be exacerbated by land use and management. It can then be considered as an off-site environmental hazard but only *in extremis* does it become a threat to the soil resource itself. It can be significantly reduced by the maintenance of plant cover throughout the year. Where this is not feasible, e.g. arable crop production, reducing the time interval where bare soil is present can help. The production of very fine seedbeds by power tools has been suggested as a cause of both erosion and ‘surface capping’ of seedbeds. To limit water erosion, associated with overland flow, contour ploughing is carried out in many countries throughout the world but to a much lesser extent in Scotland. For arable cropping in Scotland there are both technological and topographical limitations to the application of this approach.

The PEPFAA Code only addresses these issues briefly but the MAFF Soil Code contains a much fuller discussion with suggestions for avoiding damage. This reflects a difference in focus between the two with the MAFF Code addressing issues of resource management on farms whereas in Scotland the PEPFAA Code needs to be supplemented by land management information as bulletins and advisory notes (SAC).

**Linkages**

Nutrient transfers
Faecal pathogens.

**Research Gaps**

Development of simple field methods to assess structural stability, strength and degradation.

# 4. Soil Physical Damage: Critical Commentary

## 4.1. Introduction

The physical structure of soil has been intensively studied by soil scientists over many decades; indeed, a literature search, using the term ‘soil structure’, yielded over 1,600 references over the past twenty years. Restricting the time period to the last three years only reduced the number of articles to around 450. Clearly, early interest in the subject has not waned! Similarly, manifestations of physical damage to soils, from structural degradation to actual loss of the soil resource itself through erosion processes, holds a continuing interest for soil, environmental and agronomic scientists. However, much of the published work on soil structure is concerned with largely academic aspects of the subject area. Recently, there has been a particular focus on the way in which the physical architecture of the soil provides ‘a mosaic of microenvironments differing in their physical, chemical and biological properties’ (Ranjard and Richaume, 2001) and on the development of conceptual models of soil structure that attempt to identify ‘functional quantification of structure and its causal relationship to processes’ (Young *et al.*, 2001). An exception to this general statement may be found in the topics of tillage and soil compaction by machinery where a significant body of knowledge now exists on the impact of various farm operations associated with arable cropping (Ball *et al.*, 1997)

However, in a practical sense, it is probably more useful in a critical analysis to address a series of questions, such as:

- what is soil structure?
- why should farmers be interested in soil structure?
- what methods are available for the manipulation and improvement of soil structure?
- when is structural damage most likely to occur and how can it be averted?
- what can be done to remedy damage that has occurred?

## 4.2. What is soil structure?

Soil structure has been defined as the ‘spatial heterogeneity of the different components or properties of soil’ (Dexter, 1988), although a simpler definition is the three-dimensional arrangement of particles and pores within the soil. This review identifies the importance of considering a hierarchy of structure – work which finds resonance in more recent work utilising the concepts of self similarity over a range of dimensions as expressed in fractal geometry (Young *et al.*, 2001).

## 4.3. Why should farmers be interested in soil structure?

The range of particle sizes found for the mineral and organic components of soil is enormous, ranging from fine clay particles, around $10^{-7}$m in diameter, through silt, sand, and gravel to stones up to several centimetres in diameter. If all of these fractions existed as independent particles then most of our soil resource could not be used for crop growth and agriculture, as we know it. It is only through the influence of soil structure that soils possess the qualities required for plant growth and agricultural production. These include a balanced supply of water and oxygen to the root system of the growing plant, the ability to form seedbeds, a mechanical anchorage for the root system, the capacity to buffer inputs of rainwater by infiltration, drainage and evaporation (Dexter, 1988). Many of these functions are critically dependent on soil porosity which also provides an environment in which soil microorganisms live and make their contribution to the turnover of carbon and some of the major nutrients (Ranjard and Richaume, 2001).

### 4.4. What methods are available for the manipulation and improvement of soil structure?

In response to this question two distinct approaches can be discerned in the literature. The first of these is concerned with the composition of the soil and the identification of specific soil components, which are found at higher concentrations in topsoils with greater structural stability. The most widely studied of these 'aggregating agents' is soil organic matter (Carter and Stewart, 1996) while some authors have focussed on the activity and role of specific components in soil organic matter (e.g. Ball *et al.*, 1996). The results from the many studies carried out in this area is that reductions in soil organic matter content by continuous cultivation can reduce organic matter content and hence increase the probability of structural degradation. However, despite the widespread acceptance of this advice, Loveland (2001) has shown that, in a review of over 1500 research papers, very few give sufficiently robust quantitative data whereby critical limits of organic matter content might be defined. However, he does conclude that organic matter levels should be maintained above 2% by weight. Another conditioning agent which has been widely studied for pH control is lime and, again, considerable information is available from SAC concerning its use.

The second approach is concerned with the impact of external pressures on the soil resource, i.e. the effects of mechanical tillage of the soil. Warkentin (2001) has recently published a thought-provoking review of the effects of tillage on sustaining soil functions. He concludes that the largest effects of tillage are increases in recycling rates, decreases in porosity and reduced habitat-biodiversity. Benefits include the destruction of competing plant species and largely temporary improvements in the water/air balance in seedbeds. Disbenefits are most clearly seen in relation to environmental concerns such as water quality, carbon and nitrogen storage and water partitioning. Mechanical working of soils is inevitably accompanied by mechanic loading of the soil and Ball and his co-workers (1996; 1997; 2000) at Scottish Agricultural College (SAC) have published a valuable series of papers summarising many years' work at SAC. It is also interesting to note that these papers contain references to methods by which the cost effectiveness of a number of ameliorative techniques, such as zero-tillage, conservation tillage and gantry systems, can be determined.

### 4.5. When is structural damage most likely to occur and how can it be averted?

Soil strength decreases with increasing wetness and the greatest risk of structural damage occurs when soils are at, or near, field capacity. This varies with soil type but data is available from the soil memoirs published by the Macaulay Institute. For generic, practical advice on land management procedures that can limit the extent and severity of structural damage, the Soil Code published by MAFF provides valuable advice. Engineering solutions suitable for high value crops in intensive systems are contained in advisory notes published by SAC.

One subject included under this topic heading is soil erosion, which can be considered as the ultimate in physical degradation i.e. the loss of the soil resource itself. Surveys on arable land in both Scotland and in England and Wales have shown that erosion should be considered a regional rather than a national problem (Chambers and Garwood, 2000; Speirs and Frost, 1988). Both the Soil Survey and Land Research Centre (1993) and the Macaulay Institute (Lilly *et al.*, 1999) have carried out assessments of the risk of soil erosion in mineral soils whilst Lilly *et al.* (1999) have extended their assessment to organic soils of the hills and uplands of Scotland. Grieve *et al.* (1995) have assessed the extent and severity of upland erosion in Scotland and have shown that 12% of the area sampled was eroded. The largest single component was peat erosion.

The most important factors in the occurrence of erosion are slope, texture and the lack of vegetative cover. In arable systems it is thought that increased erosion results from the increased use of winter crops while Speirs and Frost consider that high energy inputs in the preparation of very fine seed beds can initiate erosion events. Grieve *et al*. (1995) have discussed the factors that contribute in upland situations including damage to vegetation cover through heavy grazing, and treading near footpaths.

Compaction and poaching by grazing animals are both subject to control by suitable management practices. The key factor is to control access to wet soils. Internationally, where erosion can seriously impact on the sustainability of agriculture, many techniques and approaches have been developed to control erosion, including the maintenance of continuous plant cover and the use of contour ploughing. The latter technique has not been widely used in the UK but, as suggested in the MAFF Soil Code there are technical issues in relation to cropping machinery as well as the very complex topography in agricultural fields in the UK.

### 4.6. What can be done to remedy damage that has already occurred?

Damage to arable soils through compaction can be remedied through deep-ploughing but there is a risk of further damage if conditions are not suitable. Ball *et al.* (1997) cite data which suggests that natural recovery can occur in a period of three years. Erosion damage in semi-natural ecosystems is very difficult to remedy and normally involves the re-establishment of some form of plant cover. In all cases, it is fair to say that avoidance is by far the preferable option in relation to physical degradation. Topsoil takes many years to form but only a short time to lose.

## 4.7. References


Ball, B.C., Campbell, D.J., Douglas, J.T., Henshall, J.K. and O'Sullivan, M.F. (1997). Soil structural quality, compaction and land management. *Journal of Soil Science*, **48**, 593-601.

Ball, B.C., Campbell, D.J. and Hunter, E.A. (2000). Soil compactibility in relation to physical and organic properties at 156 sites in the UK. *Soil and Tillage Research, **57**(1-2), 83-91.*

Ball, B.C., Cheshire, M.V., Robertson, E.A.G. and Hunter, E.A. (1996). Carbohydrate composition in relation to structural stability, compactibility and plasticity of two soils in a long-term experiment*. Soil and Tillage Research, **39**(3-4), 143-160.*

Chambers, B.J. and Garwood, T.W.D. (2000). Monitoring of water erosion on arable farms in England. *Soil Use and Management*, **16**, 93-99.

Carter, M.R. and Stewart, B.A. (eds) (1996). Structure and Organic Matter Storage in Agricultural Soils. CRC Press, Boca Raton, Fla., USA. 477pp

Dexter, A.R. (1988). Advances in characterization of soil structure. *Soils and Tillage Research*, **11**, 199-238.

Grieve, I.C., Davidson, D.A. and *Gordon, J.E*. (1995). Nature, extent and severity of soil-erosion in upland Scotland (1995). *Land Degradation and Rehabilitation*, **6**, 41-55.

Lilly, A.., Hudson, G., Birnie, R.V. and Horne, P.L. (1999). The inherent geomorphological risk of soil erosion by overland flow in Scotland. Contract Report to SNH. R/AC1/BAT/99/53

Loveland, P.J. (2001). Critical Levels of Soil Organic Matter. Final Report to MAFF (project code SP0306).

Ministry of Agriculture Fisheries and Food (1998). Code of Good Agricultural Practice for the Protection of Soil. MAFF Publications, London SW1A 2XX.

Ranjard, L. and Richaume, A.S. (2001). Quantitative and qualitative microscale distribution of bacteria in soil. *J. Res. Microbiol.*, **152**, 707-716.

Soil Survey and Land Research Centre (1993). Risk of soil erosion in England and Wales by water on land under winter cereal cropping.1:625,000 scale map. SSLRC, Silsoe.

Speirs, R.B. and Frost, C.A. (1988). The increasing incidence of accelerated soil water erosion on arable land in east of Scotland. *Research and Development in Agriculture*, **2**, 161-167.

Warkentin, B.P. (2001). The tillage effect in sustaining soil functions. *J. Plant Nutr. Soil Sci*., **164**, 345-350.

Young, I.M., Crawford, J.W. and Rappolt, C. (2001). New methods and models for characterising structural heterogeneity of soil. *Soil and Tillage Research*, **61**, 33-45.

**Please see Appendix 2 for selected bibliography on soil erosion**