Impact of forestry on soil quality in the UK (Vanguelova et al.)

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Introduction
Woodland in the UK covers 2.8 million hectares (Forestry Commission, 2005). Of this total, 1.3 million hectares (47%) is in Scotland, 1.1 million hectares (40%) is in England, 0.3 million hectares (10%) is in Wales and the remaining 0.1 million hectares (3%) is in Northern Ireland. The 2.8 million hectares of woodland in the UK represents 11.6% of the total land area, although this percentage ranges from 6.3% in Northern Ireland to 17.1% in Scotland. This proportion is amongst the lowest in Europe (only Ireland and the Netherlands have smaller percentages), but the productivity of Britain’s forests is substantially higher than much of Europe owing to our plantation-based forest estate and long growing season.

Soil quality is of significant importance for: (1) the productivity and sustainability of forest systems, (2) the conservation of soil and water resources, (3) the accumulation of persistent toxic substances, and (4) the contribution forested systems make to the global carbon cycle. Despite an embedded culture which acknowledges the importance of soil in the forest industry, it has been recognised that there is a need to monitor its ‘state’ so that forest practices can be modified should negative and irreversible changes begin to occur. The concept of ‘soil quality indicator’ has been put forward as an appropriate means to establish a baseline of soil quality and / or functional ability, and from which changes can be observed as a result of pressures exerted on the soil (Moffat and Kennedy, 2002).

Forest soil quality baseline
Historically, forest plantations have been located on comparatively infertile, poorly drained or thin soils in Britain. At a national scale a disproportionate amount are found on gleys and peats, but locally, individual forests tend to occur on the poorest soils in the region. In addition, many types have presented pedological impediments to deep rooting, especially the ironpan and fragipan soils. A consequence of this soil geography is that twentieth century forestry was dominated by the need to conquer the ground and bring it into a state fit for forest establishment, and promote economically satisfactory growth. Drainage was achieved principally by forming an open ditch network, and soil cultivation took place mainly by ploughing. Deep subsoiling was used to break up ironpans where necessary (Moffat and Kennedy, 2002). Cultivation affects soil conditions and functions such as effects on soil and air temperature, soil moisture, nutrients and bulk density (Paterson and Mason 1999). The effects above are regarded by foresters as beneficial and likely to improve tree survival, growth and stability, but cultivation can also promote negative effects such as erosion and nutrient loss. The soil’s ability to sequester carbon may also be compromised. The effects of these practices on the water environment were appreciated in the 1980s and current guidance (Forest and Water Guidelines, 2003) is far more restrictive in advocating minimal and shallow cultivation wherever possible.

Changes in forest soil quality through forest life cycle and forest practices
Using land for forestry gives little flexibility for changing the land use in short term compared to annual agricultural cropping systems. Changes to soil properties and functioning are also caused by the growth of trees themselves, notably in the first rotation after agriculture. Interception of precipitation by conifer canopies is larger than grass and most other agricultural crops. Thus, these soils tend to be at field capacity for a shorter time than those under agriculture. In peat soils and some gleys, tree crops may cause irreversible shrinkage and cracking, leading to altered hydrological behaviour (King et al., 1986). Chronosequence studies
develop our understanding of the natural tree growth cycle changes which are essential to enable the interpretation of any soil quality indicators (Pitman and Vanguelova, 2005).

Forest development influences soil properties with time, which is also highly dependent on the initial choice of tree species and the forest management practiced during the forest life cycle. Commercial forest practices in the UK developed predominantly within the plantation sylvicultural system, and management interventions to extract timber can be very disruptive (clear felling, whole tree harvesting practices) and can undoubtedly affect the quality of the forest soils (Wood et al., 2003). Practicing whole tree harvesting, for example, threatens the new rotation from soil nutrient extraction and reduced growth. Long-term experimental research has shown that even brash retention or subsequent fertilisation are sometime not adequate to sustain second rotation growth on whole tree harvesting sites on poor soils (Harrison, 2005). Wood extraction itself, if performed unprofessionally, can impact on the physical soil properties by causing compaction and rutting, especially on sensitive soil types (Hutchings et al., 2002).

Over one half (53%) of the total woodland area in Great Britain is made up of conifers although this proportion ranges from 31% in England to 72% in Scotland. Sitka spruce accounted for almost one half (49%) of the conifer area, followed by Scots pine (16%) and Lodgepole pine (10%). Amongst broadleaf species, oak covered 23% of the broadleaf area, followed by birch (16%) and ash (13%). Coniferous trees and their litter acidify the soil with time compared to most broadleaved trees. Increase in soil acidity is associated with changes in other soil processes and fluxes such as N and C cycling and pools, microbial activities and communities, organic matter, decomposition rate, Al and heavy metal mobilisation (Vanguelova, et al. 2005, Pitman and Vanguelova, 2005).

In response to increasing environmental awareness from the public, forest policy is encouraging less intensive practices which increase species and structure diversity in existing even-aged plantation forestry to promote and provide multi-purpose benefits, for example Continuous Cover Forestry (CCF) practice. At a policy level CCF is expected to have a more benign impact on the environment compared to clearfelling due to the smaller-scale nature of the management operations. Nevertheless, there are some areas of concern, as one of the main threats is thought to be the potential increase in risk of soil compaction, rutting and erosion linked to more frequent machine access and lack of brash to protect routeways during wood extraction (Ireland et al., 2006). Plantations on Ancient Woodland Sites (PAWS), designated to convert coniferous plantations back to semi-ancient broadleaf woodland, will influence soil quality in different ways, depending on the technique coniferous brash is managed. If the brash is removed off site, a substantial amount of nutrients are removed with it. On the other hand, leaving conifer brash on sites being restored to broadleaved woodland could cause problems such as soil eutrophication due to increased rates of mineralisation and nitrification and also soil acidification due to the acidic nature of the brash.

Intensive agriculture and farming activities influence forest soil properties especially in small woodland patches, which are particularly common in England, through their effect on nitrogen deposition and nitrogen cycling which is enhanced at the forest edge (Sutton et al., 2001, Vanguelova, 2005).

**Impact of environmental drivers on forest soil quality**

In addition to forest management practices, changes in the environmental conditions due to human activities threaten the ability of soil to provide the necessary function for forests. Types of soil damage associated with atmospheric deposition, of particular concern in forests, include soil acidification, nutrient imbalance, nitrogen enrichment (eutrophication) and heavy metal contamination. Soil vulnerability is mostly based on soil characteristics such as soil chemical status, including pH, base saturation, Acid Neutralising Capacity (ANC), Cation Exchange Capacity (CEC), as well as the parent material. Several soil chemical indicators (e.g. soil pH,
Changes of climate will directly and indirectly affect forest soil quality and function. Rising temperatures can accelerate mineralisation rates and soil nutrient availability but nutrient and dissolved organic carbon leaching may also occur due to heavy winter rainfall. All effects will have implications for nutrient and carbon imbalances in forest soils. Soil moisture deficit may occur in sensitive areas following reduction in precipitation. Soil nutrient pools can be affected by changes in the amount and quality of tree litter production. Physical soil disturbances may occur as a result of winter waterlogging and windthrow as the size and proportion of storm events increases.

**Biodiversity**

The different physiochemical properties of forest soils compared with agricultural soils result in different patterns of biodiversity. In particular the tree rhizosphere population can be characterised by an extensive network of ectomycorrhiza which effectively extend the water and nutrient absorbency network of the tree root system although in the early stage of tree establishment endotrophic mycorrhiza, are also important (Lynch, 1990). These symbionts, together with the asymbiotic bacteria fungi and protozoa contribute to the net carbon and nutrient cycling in the soil ecosystem. As rhizodeposition to these populations can account for up to 40% of the carbon sequestered by the plant, the rhizosphere population becomes an important pool of the global carbon balance. Most of our knowledge of nitrogen and mineral cycling through the rhizosphere biota comes from studies of agricultural soils, but clearly it is important to assess those pathways in forest soils. Such assessments become crucial inputs to life cycle analysis of the plant production system in soil. Molecular methods are used increasingly to make these assessments (Lynch *et al*, 2004).

**Conclusion**

Forest soils differ from agricultural soils with: 1) well developed organic layers, 2) much higher acidity, 3) higher organic matter content, and 4) large spatial variability, 5) different biotic balances. These main differences need to be always considered when evaluating and selecting indicators to inform on the quality of forest soils. In order to determine the soil indicators and their thresholds to be used effectively in soil and forest management sustainable practices, some primary requirements need to be met as a) indicators should be sensitive to anthropogenic changes, b) indicators should be easy and cost effective to measure, c) they have been measured already or can be measured in most soil monitoring networks, d) indicators should provide a response to disturbances that is distinct from natural variation and e) indicators should be able to provide diagnostic and prognostic information and/or be able to be included in both aspects. Due to the variability and diversity of the forest ecosystems as well as the variability in environmental changes and forest management practices and their impacts on different soil quality, it is still not possible to state one or a single simple indicator to express the soil quality influenced by land use for forestry. Nevertheless, current and future research work is intended to improve our ability to use soil indicators as a means on influencing environmental and forestry policy and practice.
References


