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Short-term changes in belowground C, N stocks in recently clear felled Sitka spruce plantations on podzolic soils of North Wales

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ABSTRACT

There is currently only limited understanding of the influence of conifer plantation management on soil carbon (C) and nitrogen (N) storage in maritime Europe. The study reported herein examined the effect of clear felling on belowground C and N stocks, and CO_2 effluxes at paired clear-felled, and standing plantation sites in North Wales. Clear-felled conifer stands were compared in three different time lapses (3, 5 and 8 years after harvesting). The O horizon (and associated C) was completely absent on the year 3 and year 8 clear-felled stands. There was no significant influence of clear-felling on mineral soil C and N at 0–10 cm depth between clear felled and unharvested sites, however, differences were observed in subsoil depths (10–20 cm and 20–50 cm). Clear-felled sites exhibited an initial gain in surface soil C and N through year 5 (likely due to incorporation of the O horizon into the mineral soil) after which the C stock decreased by year 8. Approximately 50 Mg C and 3 Mg N ha^{-1} yr^{-1}appear to have been lost from mineral soils 7 years after clear felling. Clear felling significantly ($p < 0.05$) increased soil CO_2 efflux and soil surface temperature. Total CO_2 emission from soils at clear felled sites was 148% higher than that of uncut plantations. Alternative harvest strategies should be considered that reduce C losses from plantations in North Wales.

1. Introduction

There is currently limited understanding of the influence of clear-felling forest plantations on total carbon (C) storage in maritime ecosystems of Europe. Protection of soil and land resources throughout the world is an important part of the campaign to reduce the occurrence of greenhouse gas (GHG) loading of the atmosphere and the subsequent effect on climate change. The Kyoto protocol and the Land Use, Land Use Change and Forestry (LULUCF) section in the United Nations Framework Convention on Climate Change (UNFCCC) aim to reduce the net GHG emission from forest ecosystems. These documents specifically discourage clear-felling and land clearing practices and promote forest management activities including uneven-age forest management, close to nature forestry, low thinning regimes, and extended length of rotation period (Jandl et al., 2007). Forest soil C emissions are aggravated by clear felling as a result of mechanical scarification during harvesting operation, exposing of mineral soils by removing or mixing of the O horizon with underlying layers, and faster decomposition of logging residues left on site after harvesting. These disturbances change the microclimate of soil and hasten the decomposition rate of soil organic matter due to increased temperature and moisture availability and result in a net release of C and nutrients at least for the first few years following harvesting (Johansson, 1994).

Timber harvesting by clear-felling system can be detrimental to the quality and health of forest soils (Wood et al., 2003). Clear-felling can change important soil physical characteristics like soil bulk density, porosity, aggregation, and infiltration capacity all of which are associated with certain other chemical and biological properties. The complete removal of the aboveground canopy renders the topsoil vulnerable to erosion. Clear-felling and whole tree harvesting also affect the newly planted stock in second rotation in harvested sites by impeding their nutrient extraction ability and hampering normal growth rates (Vanguelova et al., 2006). Long term research in plant growth in harvested sites has revealed that addition fertilization and brush retention are not always sufficient to meet the nutrient requirements for the subsequent rotation crop, therefore, establishment of another plantation in susceptible soils is often discouraged (Harrison, 2005).

Britain has a forest cover of approximately 2.8 million hectares, 11.6% of its total land area and the biomass contained in those forests contains 150 Mt C equivalents to 1 year CO_2 emission from fossil fuel burning and industrial activities in the UK (Broadmeadow and Matthews, 2003). This figure gives an idea of above ground biomass C in the UK, but under represents belowground biomass. A conservative estimate of belowground C stocks of UK forests is

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244 Mt and most of which lie in the peatbased soils of upland areas of Scotland and Wales (Broadmeadow and Matthews, 2003). Clear felling systems of harvesting are employed in the management of almost 90% of the plantation forests in Britain (Mason et al., 1999). Accordingly, total coniferous woodland area in Wales has gradually decreased from 168,000 ha in 2001 to 156,000 ha in 2009 as a result of recent harvesting activities (Forestry Commission, 2001, 2009). If the combined scenario of woodland area reduction and altered CO_2 emissions can be framed together, a better picture of the role of Welsh forest management and forest soils can be conceived in terms of global climate change and long-term productivity of these forest systems.

The purpose of the work reported was to determine the effect of clear felling operations on soil C and N stocks, and C flux in coniferous plantations of North Wales. Sitka spruce (*Picea sitchensis* (bong) carr.) plantation was selected because of its wider plantation practice in North Wales (Adam, 1999). Although intensive soil studies have been done in the UK (England, Scotland and Wales) covering different aspects of land management and their influence on total C storage (Stevens et al., 1995; Bellamy et al., 2005; Zerva and Mencuccini, 2005), very few have been performed in North Wales and few have focused on the impact of forest harvest practice (specially for exotic conifers) on mineral C and N of rocky brown podzolic and stagnopodzolic soils, typical in this region. There are only few similar soils in the mainland Europe and the previous focus has been to examine tree performance on these difficult soils rather than determining the impact of management activities (e.g. harvesting) on the soils (Hornung et al., 1987). The specific hypotheses tested were: (1) Soils in clear felled sites contain less C than uncut forests; (2) Soil C and N stocks decrease over time in clear felled sites; (3) Soil CO_2 flux is greater in clear felled sites than that of unharvested sites.

2. Materials and methods

2.1. Site description

Three forest plantations managed by UK Forestry Commission were selected in North Wales viz. Abergwyngregyn, Bethesda, and Beddgelert (Table 1). Each site was composed of a mature, unharvested Sitka spruce plantation paired with an adjacent clear felled site both of which were planted at the same time. Each site, however, represented a different stand age and different time since clear felling (Fig. 1). Soil types in these sites are under Manod and Hafren association according to Welsh soil classification system. Manod is characterized as well-drained fine loamy or silty soils over unconsolidated colluvial deposits (typical brown podzolic soil) and Hafren as loamy permeable soils over rock with a wet peaty surface and a bleached subsurface horizon (ferric stagnopodzols) (Stevens et al., 1995; National Soil Resource Institute, 2010). All these soils are very acidic, base-poor in the mineral horizons and the main exchange complex is aluminum base (Hornung et al., 1987). Location, topography, vegetation and site specific soil information of the study areas are given in Table 1 and Table 2. The technique used for the harvesting operation was mechanical clear felling by harvester forwarder leaving stump, branches and logging residues on site (stem harvesting). No fertilization was reported in these areas. The study was carried out in the spring and summer of 2010. Mean temperature ranged between 14 and 16 °C and precipitation varied from 0.11 mm to 0.45 mm during the study period.

2.2. Soil sampling

A plot of 30 m × 30 m was established in both unharvested and harvested stands at each site (Fig. 2). The starting point of the plot and direction of transect was selected arbitrarily giving much attention to avoid any edge effect. Four (4) transects were run in each plot with an interval of 10 m between transects. Computer generated random numbers were used to fix three sampling points along each of the four transects. At each point, O horizon samples were collected using a 15 cm diameter PVC ring, all contents down to the mineral soil were collected and placed into a sample bag (the same samples were also used for bulk density measurement). Soil pits with an opening of 15–20 cm diameter were created down to 50 cm by using a shovel and auger at each sampling point. Mineral soil samples were collected from three different depths (0–10, 10–20, and 20–50 cm). A total of 12 pits were dug per plot and altogether 72 pits (12 × 6 plot) were dug each of 50 cm depth in all the sites. A total of 36 samples were collected from each plot (3 replications × 3 depths × 4 transects). The three replicate samples in each transect were mixed to create one composite sample (Fig. 2) which resulted a total sample size of 72 (12 composite × 6 sites). Mineral soil bulk density (BD) samples were collected by using a bulk density core (5 cm × 5 cm). High coarse fragments in subsurface layers precluded collection of BD cores beyond 5 cm depth. Surface BD was used in combination with subsurface CF contents when determining total C and N per unit area. Four (4) BD samples were collected from each plot (1 per transect) in a systematic pattern around the sampling points. The first soil

Table 1
Description of study areas of the current research with different topographical and geospatial characteristics along with their land management history on Sitka spruce plantations in North Wales.

Site name	Land cover	Aspect (°)	Slope (%)	Slope shape	Coordinates (Lat-Long)	Elevation (m)	Ground vegetation[b]	Year of establishment	Year of harvesting
Abergwyngregyn	[a]PF (AU)	NW (340)	36	Concave	53°13′09.19″N 003°58′56.16″W	263	Moss	1961	–
	Harvested (AH)	NW (340)	27	Concave	53°13′17.04″N 003°59′18.42″W	254	Grass, Sedge, Bramble, Moss	1961	2007
Bethesda	PF (BU)	W (270)	6	Plane	53°10′06.52″N 004°02′41.81″W	324	Moss, Bracken	1955	–
	Harvested (BH)	W (270)	13	Concave	53°10′04.64″N 004°02′38.38″W	338	Grass, Bracken, Gorse	1955	2005
Beddgelert	PF (BtU)	NE (30)	30	Straight	53°00′52.97″N 004°07′55.92″W	270	Moss	1936	–
	Harvested (BtH)	NE (30)	26	Straight	53°00′54.95″N 004°07′54.09″W	253	Grass, Moss	1936	2002

[a] PF = Plantation forest; within bracket codes in column 2 are the short form of study sites and will be referred like this in the next sections of manuscript.
[b] Ground vegetation = Grasses (*Molinia caerulea*, *Holcus mollis*, *Fescue* sp., *Deschampsia* sp., *Juncus* sp.), brambles (*Rubus* sp.), sedges (*Carex* sp.), bracken (*Pteridium* sp.), gorse (*Ulex* sp.).