Chapter 8

General Conclusions

Plantations of Sitka spruce represent a large part of the commercial forestry in Britain and are subject to intensive management. An area of about 315,000 ha of peaty gley soils have been drained, ploughed and planted since 1950s. This may have lead to large losses of carbon due to increased decomposition. Growth of trees leads to accumulation of carbon in the standing biomass as well as in the soil. When the forest stand reaches maturity (around 40 years old) it is clearfelled and then re-planting typically takes place after two or three years. Tree harvesting can have a great effect on soil C and on fluxes of the most important greenhouse gases: CO_2, N_2O and CH_4. Harwood forest is such a typical plantation managed over 40 year rotations, and the present research study was conducted in order to evaluate the long-term effects of afforestation and forest management of soil C storage and the short-term effects of clearfelling on soil CO_2, N_2O and CH_4 fluxes and the dependence of these gases on environmental factors (soil temperature, water content and water table depth) and how they can change after clearfelling.

The chronosequence approach was used to evaluate the long-term effects of afforestation on natural grassland and subsequent forest management on soil C stocks and C balance. It was concluded that the establishment of Sitka spruce forests on former grasslands on peaty gley soils lead to a decrease in soil C during the first rotation but also to net accumulation of soil carbon during a second rotation. C accumulation in the soil during the second rotation was probably caused by fairly high rates of C storage below ground, coupled to low rates of soil respiration. It was also estimated that by the age of clearfelling of the second rotation stands soil C stocks will have equalled those of the original unplanted grassland. However, at this stage it cannot be anticipated whether and for how long this accumulation will continue during a third rotation and a more intensive investigation of C efflux and storage in the chronosequence over a longer period is required to better understand the soil C balance of these forests.

Clearfelling of a Sitka spruce stand on peaty gley soil caused consequent changes in environmental variables during daytime. Air and soil temperatures increased in the CF compared to an uncut 40-yr stand and soil temperature exhibited higher fluctuations both in time and vertically in the soil profile. Clearfelling also caused an increase in soil water content and a rise of the water table.

Clearfelling also had a significant effect on soil CO_2 effluxes, and led to reduced effluxes compared to the uncut stand. For the first season following tree harvesting, the emissions of soil CO_2 in the CF were 30% lower than in the uncut 40-yr stand. However, CF was a net source of CO_2 to the atmosphere because there was no photosynthetic uptake from the trees in the clearfelled site, therefore the soil respiration equals the net CO_2 exchange with the atmosphere. It is expected (taking account of respiration by the harvest residues) that soil CO_2 efflux will increase together with photosynthetic uptake in the years following clearfelling, with the re-establishment of vegetation and trees and the soil microbial communities.

Clearfelling also affected the dependence of soil CO_2 efflux on soil temperature and water content. While soil temperature was a stronger predictor of soil CO_2 efflux in the mature stands compared to the water content, after clearfelling soil CO_2 became less dependent on soil temperature while soil water content became more important.

It cannot be said with certainty that clearfelling had a significant effect on soil N_2O fluxes since the two stands prior to clearfelling exhibited different patterns in soil N_2O fluxes. For the first ten months after clearfelling fluxes were much greater in the CF site than in the uncut 40-yr stand and it seems that clearfelling had some effect on soil N_2O fluxes, through their dependence on soil temperature and the higher availability of organic substrate.

Measurements of N_2O over several years would be required in order to get robust estimates of annual fluxes of N_2O and to be able to distinguish differences between different sites and the impact of a disturbance effect such as clearfelling.

Clearfelling had a much more distinct effect on soil CH_4 fluxes. It caused an increase in soil CH_4 emissions and turned the site from a net sink to a net source of CH_4. That can be attributed to the rise of the water table, as CH_4 is produced under anaerobic conditions, and thus higher emissions will result from wetter soils, as well as to the availability of more labile organic matter from log residues and small brash left in the site and dying roots. The change in the soil temperature did not seem to have any important effect on the soil CH_4 fluxes.

Statistical relationships of moderate strength were also observed between CO_2, N_2O and CH_4 fluxes in the CF site only, indicating that, overall, clearfelling had an effect on the emission of these trace gases. That happened by stimulating common factors influencing these trace gases, such as organic substrate availability and microbial activity, and their interactions with changes in the water table and temperature regimes.

It has already been mentioned that the concentrations of CO_2, N_2O and CH_4 in the atmosphere are increasing and this can contribute to the greenhouse effect and climate change. CO_2 is the most abundant greenhouse gas and because of its long atmospheric residence time (100 years) its contribution to greenhouse warming is about 50%. N_2O and CH_4 contribute less to the greenhouse effect, with N_2O having a residence time between 100-200 years and a contribution to greenhouse warming of about 4%, while CH_4 has a residence time of 8-12 years and a contribution to greenhouse warming of about 19% (Bouwman, 1990). In order to estimate the total impact of greenhouse gases to the atmosphere, the Global Warming Potential (GWP) is calculated. The GWP describes how much an emitted amount of a greenhouse gas perturbs the atmospheric balance over a 20 to a 500 years period. The relevant time horizon depends on the policy application (Houghton *et al*., 1997). The time most commonly used is 100 years because it approximates the lifetime of CO_2, the dominant climate forcing agent. By this, the emission of 1 kg of N_2O to the atmosphere is 296 times more effective than 1 kg of CO_2, while 1 kg of CH_4 is 23 times more effective than 1 kg of CO_2 (Houghton *et al*., 2001).

The GWP of these gases was calculated for the first ten months after clearfelling for the CF site and the 40-yr stand, in order to estimate the contribution to the atmosphere and the effect that clearfelling had on them (Table 1). Soil CO_2 efflux was the largest flux to the atmosphere from both sites, and clearfelling caused a reduction by 30% (21,227 ± 1,890 and 15,126 ± 3,670 kg ha^{-1} in the 40-yr stand and the CF, respectively). The N_2O-CO_2 equivalent emissions were 290% higher in the CF than the 40-yr stand (532.8 ± 108.6 and 183.5 ± 89 kg ha^{-1}, respectively), and the CH_4-CO_2 equivalent emissions were 1650% higher in the CF than the 40-yr stand (151.8 ± 108.1 and 9.2 ± 4.6 kg ha^{-1}, respectively). The total emissions equivalent to CO_2 were 21,420 kg ha^{-1} from the 40-yr stand and 15,811 kg ha^{-1} from the CF site. However, it cannot be concluded the clearfelled site contributed to the atmosphere less than the uncut stand in soil greenhouse gas emissions because of lack of C sequestration by the vegetation in the clearfell. Although clearfelling increased significantly the emissions of N_2O and CH_4, CO_2 remained the dominant greenhouse gas from this site.

Table 1: Comparison of the GWP of soil emissions of CO_2, N_2O and CH_4 (kg ha^{-1}) for the first ten moths after clearfelling (March to December 2002), in the 40-yr stand and the CF in Harwood. The GWP of CO2 is 1, while for CH_4 is 23 times that of CO_2 and for N_2O is 296. The numbers in the brackets indicate the standard error of the mean.

site	CO_2 (DC) (kg ha^{-1})	N_2O-CO_2 equiv. (kg ha^{-1})	CH_4-CO_2 equiv. (kg ha^{-1})	Total (kg ha^{-1})
40-yr	21,227 (1,890)	183.5 (8.9)	9.2 (4.6)	21,420
CF	15,126 (3,670)	532.8 (108.6)	151.8 (108.1)	15,811

In this study the spatial variability of soil CO_2 efflux was also investigated in the mature stands (CF_{before} and 40-yr) by using geostatistical analysis. Both stands appeared to be relatively homogenous, however geostatistical analysis indicated that spatial variability of soil CO_2 fluxes is very high, although the spatial scale of this variability is small. The variation in microtopography resulting from the ploughing that had taken place before tree planting 40 years ago (ridge, furrow and plain ground) had no significant effect on the soil CO_2 efflux. Clearfelling of the trees and disturbance of the soil by harvesting machines increases spatial variability of soil CO_2 efflux, which was indicated by much higher coefficients of variation. Finally, the number of sampling points required to accurately sample soil CO_2 efflux within 20% of the population mean is not constant and changes in relation to the flux itself. In a mature undisturbed stand fewer samples are required for periods of high soil CO_2 efflux.

Finally, the two methods used to measure soil CO_2 efflux, the dynamic closed chamber (DC) and the static closed chamber (SC), were further investigated because the DC method was giving generally higher fluxes than the SC method. After a series of laboratory experiments and measurements of soil CO_2 concentration and CO_2 fluxes in a soil monolith, it was concluded that the use of the closed static chamber method can lead to lateral diffusion of soil CO_2 outside the chamber and that results in lower CO_2 flux estimation. The effect is more pronounced at high temperatures, when CO_2 flux is higher, and water content lower. However, the CO_2 efflux value given by the closed dynamic chamber was strongly related to the value given by the closed static chamber and that suggests that the latter method, that is the main method for measuring other trace gases such CH_4 and N_2O, can be also used for the measurement of soil CO_2, provided that it is calibrated and corrected against an accepted closed dynamic chamber method.