The effect of climate and land use change on soil respiratory fluxes

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Abstract
The effect of stand age on soil respiration has been studied at three locations at the Dooary forest,, County Laois, Ireland. This forest is located on a wet mineral soil and the chronosequence includes a semi-natural grassland (T_0), a 6 year old Sitka spruce and a 20 year old Sitka spruce stand. Different rates of total soil carbon dioxide (CO_2) efflux have been found among sites where soil CO_2 efflux decreased with forest age. In this study afforestation has been shown to decrease soil CO_2 emissions. Soil respiration has been shown to be driven by certain climatic parameters such as air temperature, precipitation and soil water status. Changing future climatic conditions may therefore change the observed rates of soil CO_2 efflux. In order to investigate the impacts of changing soil water content on rates of soil respiration, precipitation exclusion shelters have been installed at the chronosequence sites. The results show, in the short term, that the impacts of a reduction in precipitation on soil respiration differ between the different chronosequence sites with a significant reduction observed in the six year old forest stands and no significant differences observed at the other sites.

Key Words
Soil CO_2 fluxes, climate change, land use change, forest and wetland.

Introduction
Information on carbon (C) sequestration and greenhouse gas (GHG) emissions associated with land use, land use change and forestry (LULUCF) is required for reporting commitments under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto protocol. Forest ecosystems are significant, long-term carbon sinks (Valentini *et al.* 2003), and under Article 3.3 of the Kyoto protocol, C sequestered through afforestation, which has occurred since 1990, may contribute towards a reduction in the national GHG emission inventory of a signatory country. Due to the rapid growth of the Irish economy over the past decade current GHG emissions are approximately 23.5% above the 1990 level (EPA 2007). During the same period Ireland's forestry sector has developed rapidly: afforestation in Ireland increased by ~186,000 ha between 1990 and 2000 (Joyce and O'Carroll 2002) and it is estimated that it will contribute to a reduction of 11 Mt carbon dioxide (CO_2) equivalents per year from the national GHG inventory (Black and Farrell 2006). Within terrestrial ecosystems the efflux from the soil is one of the largest carbon flux components, contributing between 20-40% of the total annual input of CO_2 into the atmosphere (Lankreijer *et al*. 2003). The accurate measurement of soil respiration is therefore necessary for a thorough understanding of forest carbon cycling and belowground metabolic activity.

Forest ecosystems can act as a sink or a source of atmospheric CO_2 on the basis of the net difference between the two fluxes of photosynthesis and respiration. The impact of afforestation of formerly arable land on ecosystem C dynamics needs to be better understood in order to maximize sequestration of atmospheric C (Saiz *et al.* 2006). Whilst there are some information on forest stand age effects on soil respiration (Ewel *et al.* 1986a; Irvine and Law 2002; Klopatek 2002; Saiz *et al.* 2006), there are significant gaps in scientific research on the impact of climate change. In particular the modification of water availability through changing seasonal drying and wetting cycles due to changes in climate and disturbances associated with forestry operations. Particular emphasis has recently been placed on the prediction of drier summers in Ireland resulting from climate change and the impact that this will have on vegetation and water resources (ICARUS 2008; c4i 2008). In addition little is known regarding the consequence of these changes for soil's sequestration potential. It is also important to consider the change in C source/sink capacity associated with afforestation as the vegetation changes from grassland to a forest canopy. This study investigates the impacts of land use change on soil respiration by measuring soil CO_2 emissions on a grassland and two different aged Sitka spruce (*Picea sitchensi*) forest stands. Moreover it will attempt to determine the effects of a projected reduction in the Irish summertime precipitation on soil respiration by using an ecosystem scale manipulation experiment that reduces the quantity of rainfall on experimental plots at the chronosequence sites.

Methods

Soil CO_2 flux measurements and the experimental design

A series of sites were selected to represent the typical land use change to forestry. This chronosequence included a semi-natural grassland (T_0), a 6-year-old and a 20-year-old Sitka spruce (*Picea sitchensi*).
The three sites were selected at Dooary, County Laois, and were close to one another to ensure the soil type (a surface water gley –representative of the typical post 1990 afforestation site) was as similar as possible. Regular measurements of soil respiration have been taken using an EGM PP Systems Infrared gas analyser with soil respiration chamber. Associated measurements including soil temperature and soil moisture content have been taken in conjunction with soil respiration measurements. The climate manipulation aspect of the experiment was achieved by installing precipitation exclusion zones at each chronosequences stage prior to the summer of 2009. The exclusion zones consisted of a shelter constructed using transparent plastic sheeting over a wooden frame, covering an area of 25 m^2. The polyethene sheeting was chosen so to reduce the absorption of radiation, ensuring that changes in respiration were due to water availability and not due to a reduction in root exudates. The roofs of the shelters were ~ 1.5 m above the ground and had sloping sides that did not reach the ground, thereby not increasing the ambient air temperature or obstructing air movements. There were four independent experimental plots at each site.

Results

Rates of soil CO_2 efflux were measured at each site from 30^{th} April until 15^{th} October 2009. The results show that the highest soil CO_2 emissions were measured in the grassland and were lower in the 6 followed by the 20 year-old forest stands. Emissions ranged between 0.4-1.7 g/m^2/h in the grassland; 0.4-1.2 g/m^2/h in the six years old forest and only 0.2-0.6 g/m^2/h in the twenty years old forest (Figure 1). The differences in fluxes between the grassland and the 20-year-old sites were found to be highly significant ($P < 0.001$).

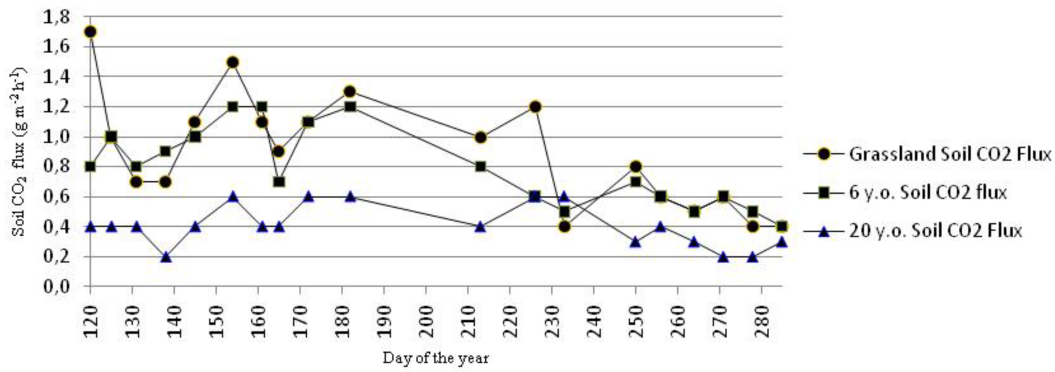

Figure 1. Mean soil CO_2 efflux at the Dooary forest chronosequence.

Soil temperature and soil moisture are driving forces in the production and emission of soil CO_2 (Raich & Schlesinger, 1992; Kirschbaum, 1995; Davidson *et al.* 1998). Measurements of soil temperature and soil moisture content were taken in conjunction with each soil CO_2 flux measurement and the relationship between soil CO_2 efflux and temperature and moisture content was analysed (Table 1).

Table 1. Relationship between soil CO_2 flux rates and soil moisture and temperature for the three chronosequence sites.

	Grassland	6 year old Sitka spruce	20 year old Sitka spruce
Soil Moisture	r^2= 0.1163 y = -0,0355x + 2,8963	r^2= 0.0033 y = 0,9169x + 53,744	r^2= 0.0208 y = 6,4785x + 38,834
Soil Temperature	r^2= 0.0475 y = 0,0328x + 0,4497	r^2= 0.0171 y = 1,2909x + 12,07	r^2= 0.4486 y = 10,418x + 8,169

As a result of the climate manipulation, soil CO_2 fluxes were generally higher inside the exclusion shelters at all sites (Figures 2-4). “In” and “Out” indicate the soil CO_2 efflux measurements taken inside and outside the rain out shelters respectively.

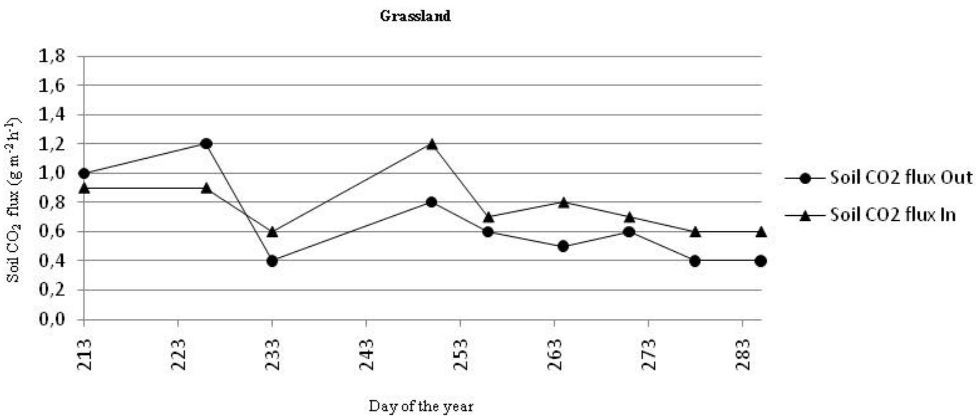

Figure 2. CO_2 fluxes (g/m^2/h) inside and outside the shelter on the grassland site.

The CO_2 emissions found inside and outside the shelters were not significantly different ($P>0.05$) and the soil water content measured inside and outside the shelters was not significantly different ($P>0.05$).
The grassland site is the most exposed of the chronosequence sites and the strong winds and the heavy rain may have compromised the efficiency of the rain-out shelters and the experiment. During the next months new shelters will be built and new measurements will be taken.

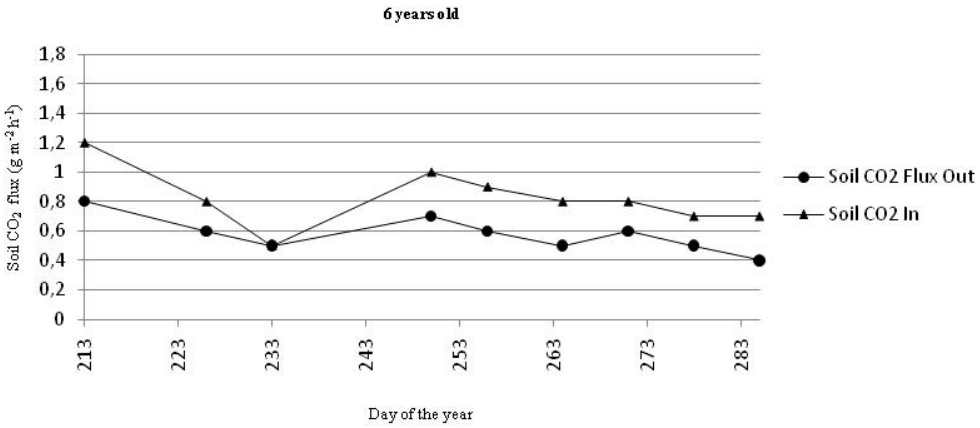

Figure 3. CO_2 fluxes (g/m^2/h) inside and outside the shelter on the 6 year old forest site.

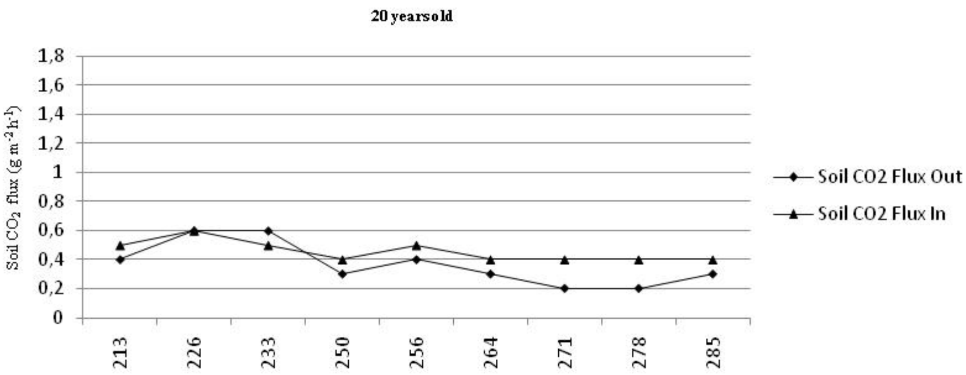

Figure 4. CO_2 fluxes (g/m^2/h) inside and outside the shelter on the 20 year old forest site.

The CO_2 emissions measured inside and outside the shelters were significantly different ($P<0.01$) in addition the soil water content measured inside and outside the shelters at the 6 year-old forest was highly significant ($P<0.001$). These results suggest that soil water content plays an important role on soil CO_2 production and emission. The CO_2 emissions found inside and outside the shelters were not significantly different ($P>0.05$) however the measured soil water content inside and outside of the shelters was significantly different ($P<0.01$). These results suggest that at this site the reduction in soil water content did not have a significant impact on rates of soil CO_2 efflux. The differences observed between the six and twenty year old Sitka spruce sites could be due, in part, to the differences in the composition of the understory vegetation at the two sites. Due to canopy closure at the twenty year old site understory vegetation is no longer present at the forest floor which may have reduced rates of soil CO_2 efflux due to changes in the autotrophic contribution to total soil CO_2 efflux. In order to test this assumption root exclusion cores have been installed inside and outside of the precipitation exclusion shelters at each site, which will allow total soil CO_2 efflux to be partitioned into its autotrophic and heterotrophic parts.

Conclusions

Afforestation results in a decrease in soil respiration although the reasons for this are not clear, as there is only a significant relationship with temperature in the oldest stand examined. Reductions in rainfall are predicted to have the greatest impact on older forest stands although perhaps surprisingly this may result in an increase in soil respiration. Overall these results indicate a complex relationship between soil respiration, afforestation and climate change that may depend on the climatic and site specific factors.

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