10. Assessment of carbon fluxes in ploughed upland grasslands: a plot-scale experiment to detect the effect of cultivation on soil organic carbon (WP 2.6)

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10.1 Introduction

The UK LUCF Carbon Emission Inventory requires information on the fluxes arising in the transition between different land uses (Milne 2003). Grassland soils represent a substantial part of the terrestrial carbon stocks in the UK, and there are potentially large losses when these are cultivated, either for conversion to arable land or for improvement of pasture. Globally, it is estimated that around 50 Pg C have been emitted to the atmosphere from soils, following conversion of natural land to cultivated, agricultural land (Paustian *et al.*, 2000). The physical basis for this is that disturbance associated with soil tillage increases the turnover of soil aggregates and accelerates the decomposition of aggregate-associated soil organic matter (SOM). However, the number of experimental data quantifying this effect is rather small, and there are very few experimental data from the UK. Here, we describe a plot-scale experiment to detect the effect of cultivation on soil organic carbon content. Recent work (Smith *et al*. 2004) suggests that the increase in N_2O emissions in "no-till" agriculture outweighs the effect of carbon sequestration, in terms of Global Warming Potential (GWP). As a secondary aim, we include measurements of N_2O and CH_4 emission in this study, to obtain a more complete picture of the effect of cultivation on the greenhouse gas balance.

10.2 Methods

10.2.1 Field site and treatment

The experimental site chosen was on House O' Muir Farm near CEH Edinburgh (Figure 10-1), which is managed by the Scottish Agricultural College. The site is at an altitude of 290 m in an area which is used for rough grazing at a very low stocking density, but has received no improvement or cultivation. Nearby fields have been improved, and though the experimental site is similar, it is surrounded by steep slopes where improvement or cultivation using farm machinery would be impractical. The soil is relatively shallow (10-20 cm), but relatively high in organic matter (10 % carbon content).

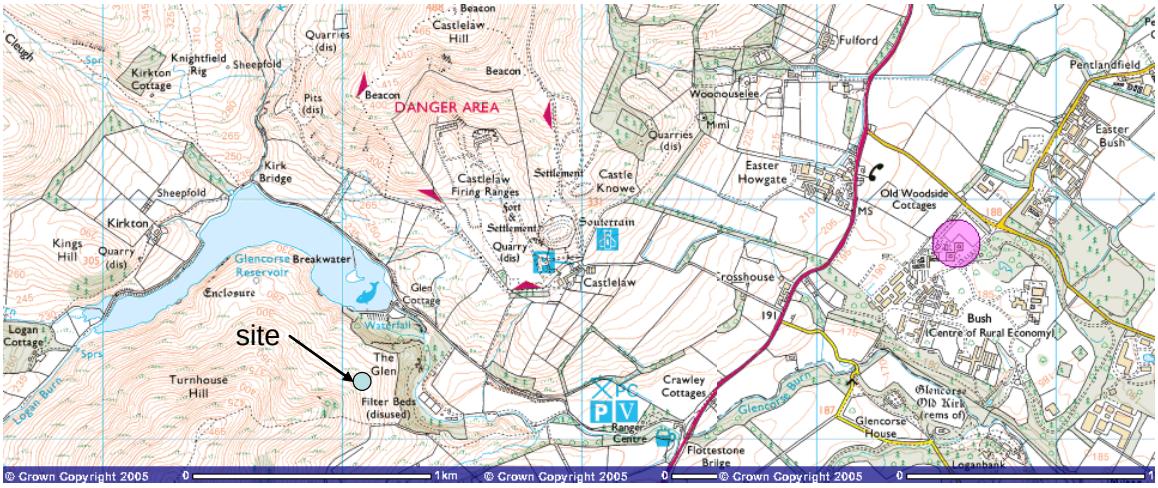

Figure 10-1: Location map of experimental site at House O' Muir Farm.

In June 2005, an 11 x 11 m area was fenced to exclude sheep. The vegetation within was cut to a height of 10 cm using a strimmer and the litter removed from the experimental area. Glyphosate herbicide ('Roundup') was applied on 8 July, with a further treatment on 14 July. This killed the remaining vegetation over a number of weeks, and the litter was removed by strimming and raking in August.

Within the fenced area, the outermost 1 m was reserved as a buffer zone to reduce edge effects from surrounding vegetation. The inner 9 x 9 m was divided into 1 x 1 m plots. A Latin Square design of 81 experimental plots was laid out, with three treatments: an uncultivated control, a single cultivation, and bi-annual cultivation (Figure 10-2). The first cultivation treatment was applied in November 2005. Treatments 1 & 2 were cultivated to a depth of 10 cm using an edging tool and digging fork to cut out, turn over, and break up turfs. For treatment 2, this cultivation was repeated annually, in May 2006 and May 2007.

10.2.2 Soil carbon measurements

Immediately following cultivation in November 2005, soil samples were taken from all plots for analysis of carbon content. Cores were removed by inserting sections of plastic tubing into the soil, and then cutting these out with a knife. Cores were 8 cm deep x 3.8 cm diameter. Taking deeper cores proved impractical because of the limited soil depth. Samples were analysed at CEH Lancaster for total carbon by loss on ignition (LOI) and bulk density. A sub-sample of 18 cores were analysed using an Elemental Analyser for carbon and nitrogen content. These data were used to establish the following relationship between LOI and carbon content (C):

$$C\ (\%) = 3.1959 + 0.332 \cdot LOI\ (\%)$$

which was applied to the other samples to calculate carbon content.

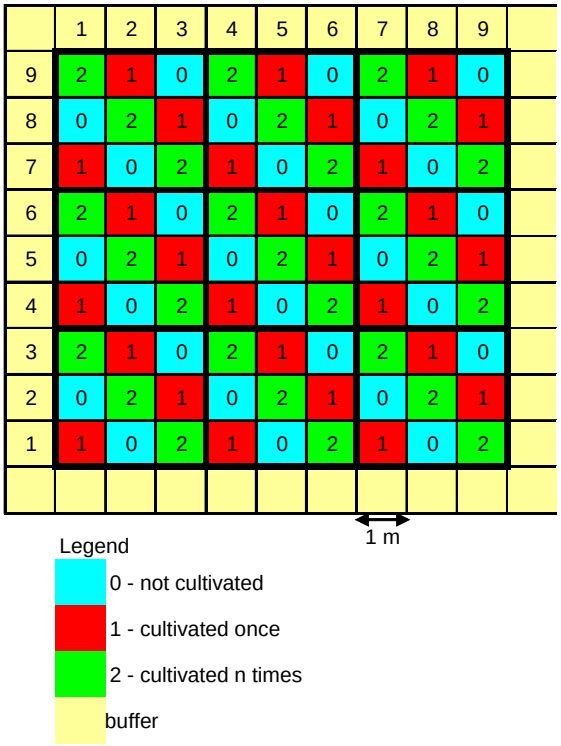

Figure 10-2: Replicated Latin Square experimental design, showing 11 x 11 m area with three treatments applied to 1 x 1 m plots in a 3 x 3 Latin Square, repeated 3 x 3 times.

10.2.3 Soil respiration measurements

A dynamic closed-chamber system (EGM-4, PP Systems, Hitchin, UK) was used to measure soil respiration on each of the 81 plots in October 2005, prior to the treatment being applied, and after 6, 12 and 18 months. An opaque chamber 10 cm in diameter and 15 cm in height was pressed into the soil. An internal fan provided mixing whilst air was pumped through the chamber and an infra-red gas analyser in a closed circuit. The chamber was left in position until a rise of 50 ppm CO_2 was measured, usually ~70 s. The soil respiration rate, *R*, from the soil was calculated as

$$R = \mathrm{d}CO_2/\mathrm{d}t \cdot w$$

where $\mathrm{d}CO_2/\mathrm{d}t$ is the rate of increase in CO_2 with time (μmol mol^{-1} s^{-1}), and *w* is the system volume: area ratio in units of mol air m^{-2}. Corrections to this equation, using polynomial functions of time to correct for effects of leaks were investigated but made little difference.

10.2.4 N_2O and CH_4 flux measurements

N_2O and CH_4 fluxes were measured in May 2006 using static closed chambers (Clayton *et al*., 1994). One chamber (volume 25120 cm^3, area 1256 cm^2) was located in each of the plots. The chambers were closed for 60 min with an aluminum lid and gas samples were collected in portable evacuated aluminium vials (Scott *et al*., 1999). Samples were analyzed for N_2O by electron capture and for CH_4 by flame injection gas chromatography.

10.3 Results and Discussion

The previous report (Levy *et al*. 2006) showed that there were no significant differences in soil carbon or respiration rates between the plots allocated to the different treatments, prior to cultivation. CO_2 emission rates measured in May 2006

were less than half those measured in October 2005, showing a clear effect of the removal of the vegetation and the root respiration component. The results here suggest that CO_2 emissions were higher in the uncultivated treatment (Figure 10-3), and this is close to significant levels (p = 0.07, Table 10-1a). The most likely explanation is that the effect on decomposition was very rapid immediately following cultivation, with the labile pools of carbon being respired within six months, such that substrate levels and thus respiration rates were lower than in the control by May 2006. Without the measurements of soil carbon loss originally planned for year 3, we cannot draw definite conclusions about this.

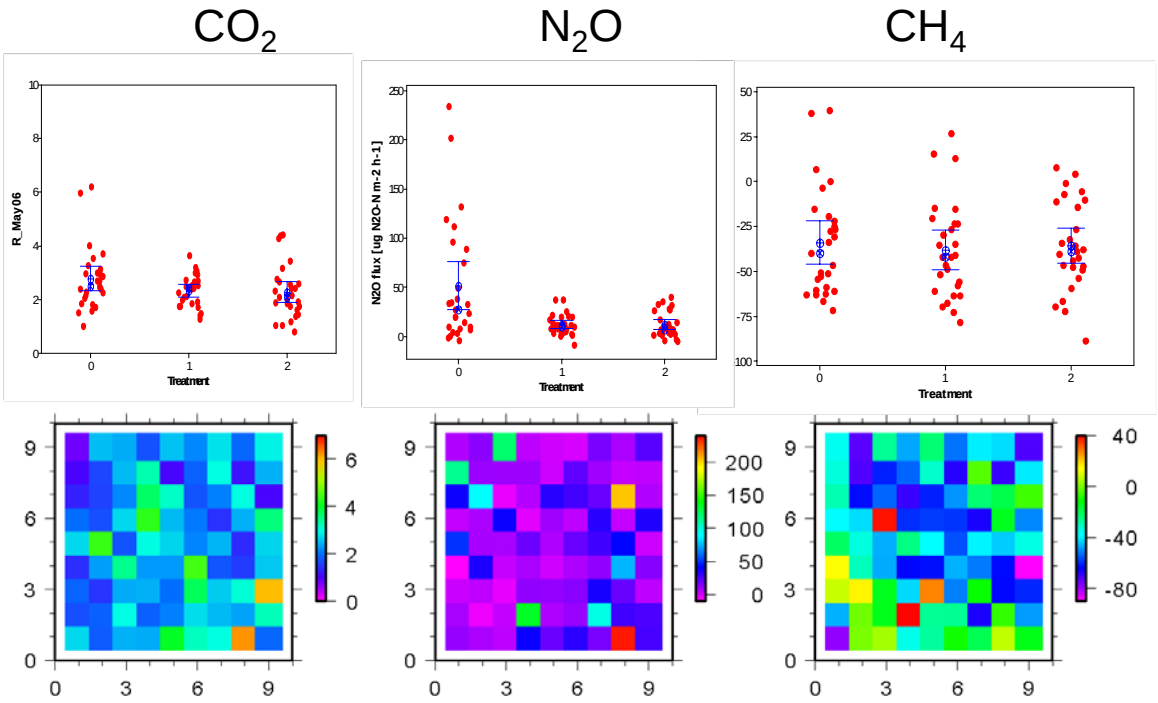

Figure 10-3: Upper row: interval plots showing the fluxes of CO_2, N_2O, and CH_4 by treatment, measured in May 2006, six months after the first cultivation. Treatments are: 0 – uncultivated control; 1 – cultivated once; 2- cultivated annually. Error bars show 95 % confidence intervals. Only N_2O fluxes show differences significant at the 95 % level. Lower row: Spatial distribution of the above data. X- and y- axes are the spatial position within the experimental area, in metres. The origin is the NE corner of the area.

Figure 10-3 and Table 10-1b show that N_2O emissions were significantly lower in the cultivated treatments (p<0.001). N_2O production in soils is complex, as it occurs as a consequence of both the oxidative process of nitrification and the reductive process of denitrification (Granli and Bøckmann, 1994). Low soil moisture and coarse soil texture generally promote nitrification, whereas high soil moisture, fine soil texture and high organic C content promote denitrification, although both processes may go on simultaneously within soils (Davidson, 1991). Although the negative effect of cultivation on denitrification may to some extent be counter-balanced by a positive effect on nitrification, the net effect is generally a reduction in N_2O production, and this is seen here. Figure 10-3 also shows that these soils were generally sinks for CH_4, as expected in aerobic soils, where CH_4 is taken up through oxidation by methanotrophic bacteria. This sink might be expected to be larger in the more aerobic, cultivated plots, but Table 10-1c shows no significant differences in CH_4 fluxes.

Table 10-1: Analysis of Variance tables for differences between treatments in the fluxes of CO_2, N_2O, and CH_4, accounting for the spatial variation by blocking according to the 3x3 m Latin square in which the plot occurs (thick black lines in Figure 10-2).

(a) Analysis of Variance for CO_2 flux

Source	DF	SS	MS	F	P
Treatment	2	4.1968	2.0984	2.73	0.072
Block	8	16.6198	2.0775	2.70	0.012
Error	70	53.8974	0.7700		
Total	80	74.7140			

(b) Analysis of Variance for N_2O flux

Source	DF	SS	MS	F	P
Treatment	2	28320	14160	11.26	0.000
Block	8	21005	2626	2.09	0.048
Error	70	88009	1257		
Total	80	137334			

(c) Analysis of Variance for CH_4 flux

Source	DF	SS	MS	F	P
Treatment	2	220.0	110.0	0.18	0.834
Block	8	16989.8	2123.7	3.51	0.002
Error	70	42372.6	605.3		
Total	80	59582.4			

As a preliminary attempt to estimate the impact of cultivation on the overall greenhouse gas balance, we calculate the total greenhouse warming potential (GWP). GWP is calculated by adding changes to the N_2O and CH_4 fluxes to the change in soil carbon stock, weighted by their relative effects on radiative forcing (297 and 23, respectively). Here we calculate the change in GWP relative to the control. Because it has not yet been measured, we estimate the change in soil carbon assuming it is proportional to the change in soil respiration. This is likely to overestimate the change, as respiration will be more sensitive to the change in the labile pool, but serves to illustrate the method. Using this assumption, the cultivated treatments lost 214 g CO_2 m^{-2} more than the control over the first six months of the experiement. Assuming the N_2O fluxes can be applied over the whole six month period, the cultivated treatments emitted 0.54 g N_2O m^{-2} less than the control. Differences in CH_4 emissions can be ignored as there were no significant differences. Using a global warming potential for N_2O of 297 relative to CO_2 gives

$$GWP = 214 – (0.54 \times 297) = +54 \text{ g } CO_2 \text{ } m^{-2}.$$

Thus, the loss of soil carbon outweighs the reduction in N_2O emission at this point. We note that the two effects are of similar magnitude and the sign of the balance could be changed when this is calculated over a longer period, and when the measured change in soil carbon is used, rather than estimates. We note also that the spatial blocking term is highly significant in Table 10-1a-c, indicating that spatial variation is important and needs to be accounted for in the analysis. Our experimental design lends itself to more complex spatial analysis, e.g. spatial REML, and this will be pursued if necessary. An attempt to measure the ^{14}C component in respired CO_2 was made in November 2006 but failed to capture enough CO_2 for ^{14}C analysis. A modification to the method to increase the capture of CO_2 is currently being tested (May 2007) and will be reported on in the next report.

10.4 References

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10.5 Acknowledgements

We acknowledge the co-operation and assistance provided by Alex Moir of the Scottish Agricultural College, Bush Estate.