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| **Project title:** | Carbon storage in orchards and amenity plantings |
| **Project number:** | CP 62 |
| **Project leader:** | Professor Gareth Edwards-Jones, Bangor University |
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| **Key staff:** | Professor Douglas Godbold<br>Professor Davey Jones |
| **Location of project:** | Bangor University |
| **Industry Representative:** | N/A |
| **Date project commenced:** | 29 September 2008 |
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## DISCLAIMER:



The results and conclusions in this report are based on an investigation conducted over a one-year period. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

## AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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# Grower Summary

## Headline

Utilisation of post-grubbed orchard biomass is key to maximising carbon sequestration.

## Background and expected deliverables

Global warming and the rising levels of carbon dioxide ($CO_2$) in the atmosphere have various impacts on agricultural and horticultural processes and subsequent management practices. There are implications on production due to changing weather patterns and there is an increasing interest in balancing production with mitigation options. There is a large pool of carbon (C) stored in the soil, four times greater than the biotic C pool and as one of the five main global C pools, it plays a major role in climate change (Lal, 2004; Schlesinger, 2000; Scurlock and Hall, 1998). Terrestrial ecosystem carbon balance is maintained by a balance between two processes, above-ground vegetation photosynthesis and soil respiration (Pumpanen *et al.,* 2004; Valentini *et al*., 2000). Whether a system is a sink or source of atmospheric $CO_2$ is determined by the relationship between production and decomposition (Pumpanen *et al.,* 2004). The soil sink can remove part of the atmospheric $CO_2$ and sequester it as C, but some processes enable the soil to become a source and $CO_2$ can be lost back into the atmosphere (Ball *et al*., 1999; Gregorich *et al*., 1998).

Anthropogenic disturbance to the soil can cause the C store to lose $CO_2$. Disturbance increases the loss of $CO_2$ through soil respiration or by the decomposition of soil organic matter (SOM) (Schlesinger, 2000; Schlesinger and Andrews, 2000). There is dissolved $CO_2$ trapped in the soil solution, which can be released through a degassing process or $CO_2$ can leave the soil C store when the disturbance increases soil aeration, resulting in the oxidation of carbon stored (Calderón and Jackson, 2002; Gregorich *et al*., 1998; Schlesinger and Andrews, 2000).

In this second year of the project, the aim was to quantify the $CO_2$ lost from the orchard system and to compare it to the amount of soil organic carbon that is lost from other land management practices causing soil disturbance (West and Marland, 2002).

## Summary

Disturbance is observed within most commercial UK orchards as orchard fields are grubbed out when they become less productive. Grubbing out is the method where the roots and stumps are cleared and the field is left fallow for a year or two before replanting. In commercial orchards, this takes place when trees are between 15 and 35 years old. This practice has some implications for the potential of orchards as carbon stores in terms of the removal of woody biomass and the release of carbon dioxide from soil carbon stores due to the disturbance.

Measurements of $CO_2$ release from the soil were taken before, during and after grubbing out events. An infra-red gas analyzer (IRGA) based $CO_2$ analyzer was used to calculate soil $CO_2$ flux rates from the increase in $CO_2$ levels over time, the volume of the system and the surface area of the soil tested (Janssens *et al*., 2000). Measurements were taken at three sites. At site 1, two 4 year old cider trees were grubbed out, at site 2, 22 trees were sampled as a whole 22 year old Cox orchard was grubbed and site 3, 21 trees were sampled as a whole 30 year old Bramley orchard was grubbed out. Four measurements were taken at each tree and readings were taken at the same time of day and weather conditions were consistent to ensure that this did not have an effect on the respiration flux (Valentini *et al*., 2000).

It was found that on the day of grubbing, the soil $CO_2$ flux was significantly higher than the days before or after. Up to 0.8 g $CO_2$ $m^{-2}$ $h^{-1}$ was observed at site 1, up to 11 g $CO_2$ $m^{-2}$ $h^{-1}$ at site 2 and up to 20 g $CO_2$ $m^{-2}$ $h^{-1}$ at site 3. The $CO_2$ flux was affected by temperature and depth of disturbance, with higher release being observed during warmer seasons and on areas with higher levels of disturbance. It is also important to note that grubbing out events occur much less frequently than conventional tillage of land although the emissions may be higher.

It is unclear at this stage whether this is a true loss of soil carbon stocks or if the $CO_2$ that is trapped within air spaces in the soil is more easily able to diffuse out into the atmosphere (Bauer *et al*., 2006; Reicosky *et al*., 1999). A substrate Induced Respiration (SIR) experiment will be carried out to investigate this phenomenon and full carbon footprints of the orchard system will be calculated to determine overall C inputs and outputs.

To reduce the impact of the grubbing out practice and thus horticulture's impact on the increasing levels of atmospheric $CO_2$, it is pertinent that mitigation options in terms of the grubbed out biomass are investigated. Most grubbed out wood is burnt on site. Producing biochar from the grubbed up apple trees could be an alternative method of producing a stable form of C from the above ground biomass that can be put back into the soil organic matter instead of converting it to $CO_2$ through charring.

An experiment using charred apple wood as a soil amendment, is being carried out to investigate apple tree productivity under varying levels of char application. Bramley apple trees have been planted in char pyrolysed from grubbed out apple trees at the following applications in 0 t $ha^{-1}$ (n = 5), 5 t $ha^{-1}$ (n = 4), 25 t $ha^{-1}$ (n = 4) and 50 t $ha^{-1}$ (n=4). The char was pyrolysed at temperatures up to 450°C for 11 hours, left to cool for 3 days and then ground into chips up to 4 mm in size. Results are due after the coming growing season.

## Financial benefits

No financial benefits have been identified to date.

## Action points for growers

- In order to enable greater C sequestration, alternative uses for the grubbed up wood in the system require investigation.
- Benefits are to be gained from reducing the $CO_2$ lost from the burning of wood at the field side.
- Biochar is currently being investigated to determine its viability as a management tool for incorporation into soil to enhance C storage.

# Science Section

## Introduction

This report documents work carried out on the effects of grubbing and biochar. Much of the soil C work reported in year 1 was completed in year 2.

Global climate change and mitigation options are becoming more prominent due to continual rising levels of carbon dioxide ($CO_2$) and in response to the Kyoto Protocol. $CO_2$ emissions have increased by 31% from 280 ppm in the 1700s to 380 ppm in 2005 at a progressively faster rate. Global $CO_2$ levels are currently at their highest concentration of the last 650,000 years (Canadell *et al*., 2007; Lal, 2004; Raupach *et al., 2007*). This rise is due to increasing fossil fuel combustion and land use change (Lal, 2004; West and Marland, 2002). The anthropogenic enrichment of atmospheric $CO_2$ has also led to an increase in land-surface precipitation in the Northern Hemisphere at a rate of 0.5-1%/decade and average global surface temperature has increased at a rate of 0.17 °C/decade, which is above the critical 0.1 °C/degrade rate (IPCC, 2001; Lal, 2004).

These changes in climate may have a negative effect on the stability of the soil organic carbon (SOC) pool, which comprises about 58% of the soil organic matter (SOM) and is an important store of carbon (C) (Lal, 2004). Emphasis remains on reducing the amount of $CO_2$ emitted into the atmosphere from the burning of fossil fuels, however, a potential mitigation option exists to sequester a portion of the atmospheric $CO_2$ into the terrestrial biosphere (West and Marland, 2002). Terrestrial soil and biota C pools are of great importance to the global C cycle, with emphasis being on the SOC pool estimated to contain 2500 billion tons to 2 m depth (Lal, 2011). The amount of organic C found in the soil is a balance between the C inputs and outputs and subsequently, reducing $CO_2$ soil emissions and increasing the soil C stored is of importance as an offset to implications of the changing climate (Gregorich *et al*., 1998). As one of the five main global C pools, the soil C pool plays a major role in climate change mitigation options as it is four times greater than the biotic C pool, with below-ground allocation of C to roots and SOM being significantly higher in C than the above-ground woody biomass (Lal, 2004; Schlesinger, 2000; Scurlock and Hall, 1998). Natural sinks, such as the soil fraction, remove part of the anthropogenic $CO_2$ from the atmosphere and sequester it (Canadell *et al*., 2007). However, organic C can be lost from the soil sink through the mineralization of SOM to $CO_2$ and minor losses can occur by soluble organic C leaching out of the system (Ball *et al*., 1999; Gregorich *et al*., 1998). The historic depletion of SOC has contributed 78 ± 12 Pg of C into the atmosphere (Lal, 2004).

It is known that anthropogenic perturbations to the soil cause a decline in organic matter and has the potential to have a diluting effect on the soil C because the disturbance mixes subsoil with relatively low organic matter, with surface soil of high organic matter content (Gregorich *et al*., 1998). Disturbance increases the loss of $CO_2$ through soil respiration or by the decomposition of SOM (Schlesinger, 2000; Schlesinger and Andrews, 2000). There is a short-term $CO_2$ efflux to the atmosphere following cultivation practices involving disturbance to the soil, partially to do with the degassing of dissolved $CO_2$ from the soil solution (Cadlerón and Jackson, 2002). Soil respiration is the primary path by which $CO_2$ leaves the soil surface and returns to the atmosphere after being fixed by plants (Schlesinger and Andrews, 2000). Land management activities including deforestation, biomass burning, shifting cultivation, tillage and ploughing are known to disturb soil structure and enhance the mineralization of SOC, thereby increasing $CO_2$ emissions into the atmosphere (Ball *et al*., 1999; Calderón and Jackson, 2002; Lal, 2004; Lal, 2011). Currently estimated at approximately 75 x $10^{15}$ g C $yr^{-1}$ this flux is expected to increase due to soil disturbance activities (Schlesinger and Andrews, 2000). The disturbance to the ground brings crop residue into more favourable decomposition conditions with increased soil aeration, moisture content and an increase in contact with microbes, leading to greater rates of soil respiration (Gregorich *et al*., 1998; Schlesinger and Andrews, 2000). Losses of C from soil due to cultivation may be as large as 0.8 x $10^{15}$ g C $yr^{-1}$ and as $CO_2$ efflux via soil respiration is recognised as one of the largest fluxes in the global C cycle, small changes could have a large effect on atmospheric $CO_2$ concentrations (Schlesinger and Andrews, 2000). There has been a loss of one-half to two-thirds of the original SOC from some cultivated soils (Lal, 2004). Therefore, land use change is a potential cause of $CO_2$ being returned back into the atmosphere, with more C being lost from soil stores through this manner and soil cultivation than from the combustion of fossil fuels up until the 1950s (Lal, 2004).

There have been few integrated studies on the quantities of $CO_2$ emissions following tillage practices in the UK (Ball *et al*., 1999). Ball *et al*., (1999) carried out a greenhouse gas (GHG) flux study on a cambisol and a gleysol soil under spring barley in Scotland with a cool moist climate using closed chamber automatic gas sampling methods. It was determined that reduced or no tillage systems had less $CO_2$ emissions than conventional tillage, with emissions peaking between 0.14-0.15 g C $m^{-2}$ $h^{-1}$ for sites with no tillage, peaks of 0.225 g C $m^{-2}$ $h^{-1}$ for sites ploughed to a depth of 200 mm and peaks of 0.36 g C $m^{-2}$ $h^{-1}$ for sites ploughed to a depth of 300 mm (Ball *et al*., 1999). Measurements on southeastern USA conventional tillage plots during four seasons (Summer, Autumn, Spring and Summer) in 2003 and 2004 measured soil $CO_2$ flux to be approximately 22-23 g $m^{-2}$ $h^{-1}$, 4 g $m^{-2}$ $h^{-1}$, 11 g $m^{-2}$ $h^{-1}$ and 18 g $m^{-2}$ $h^{-1}$, with variation being due to the time of year (Bauer *et al*., 2006). Temperature and depth of cultivation are major factors in the amount of $CO_2$ released during tillage practices (Ball *et al*., 1999; Bauer *et al*., 2006). The understanding of land use and soil management of terrestrial ecosystems is therefore vital in terms of offsetting anthropogenic $CO_2$ emissions and for the global C budget (Lal, 2004). Improvement in management practices and land use change for European soils has the potential to be a net sink for 0.8% of the world's fossil fuel combustion $CO_2$ emission (Schlesinger and Andrews, 2000).

Disturbance to the ground is observed within UK orchards as it is common practice to grub whole orchard fields when they become less productive. Grubbing is the method where the canopy framework, trunk and roots are cleared and burnt in situ and the field is left fallow for a year or two before replanting. In commercial orchards grubbing takes place when trees are between 15 and 35 years old. The implications of this practice on UK orchards and their capacity for carbon storage are twofold. Firstly, there is the removal of the C stored within the woody biomass and secondly, the release of carbon dioxide from soil carbon stores due to the disturbance. Grubbing apple trees, like the removal of crop residues, will leave soil unprotected, which even for short periods of time increases the risk of accelerated erosion, depletion of the SOC pool, disruption in nutrient cycling, decline in soil fauna and flora activity and species diversity, decline in water retention capacity and put the sustainable use of soil resources in jeopardy (Lal, 2008).

Emissions from land are generated from three sources: machinery, production and application of fertilisers and pesticides, and the oxidisation of SOC following disturbance (West and Marland, 2002). The extent of the disturbance is determined by the management practice, such as conventional tillage, reduced tillage and conservation tillage, where less than 15%, between 15-30% and greater than 30% crop residues are left behind respectively (Bauer *et al.*, 2006; West and Marland, 2002). Understanding the effects of the grubbing out process on the SOC is crucial to developing management systems to enhance soil C sequestration. The aim is to quantify the $CO_2$ lost from the orchard system and to compare it to the amount of soil organic carbon that is lost from other land management practices causing soil disturbance (West and Marland, 2002).

Another important factor to consider is the destination of the wood that is grubbed out of the orchard. Currently it is observed that it is mostly burnt on site and an investigation is being undertaken to determine whether the incorporation of biochar (charcoal used as a soil amendment) produced from the grubbed out apple trees offers growers the opportunity to enhance carbon storage.

Biochar is produced as a by-product of the pyrolysis of biomass with high carbon content such as wood (Demirbas, 2004). This method of converting biomass, which has removed $CO_2$ from the atmosphere through photosynthesis, into a long-lived store of carbon produces a potential long-term carbon sink (McHenry, 2009). The addition of charcoal is a source of stable C and has high persistence as it is relatively recalcitrant and has a long residence time in soil (Lal, 2008; Steiner *et al.*, 2007). Preliminary results show that in addition to sequestering carbon, the presence of 20g of biochar per kg of soil may reduce nitrous oxide and methane emissions by 80 and 100% respectively (Lehmann, 2007). Potential benefits include a positive effect on fertility, leading to an increase in agricultural productivity while providing farmers with a mechanism of participating in carbon markets by directly applying carbon into the soil (Marris, 2006; McHenry, 2009). It can contain three times as much phosphorous and nitrogen and a higher amount of carbon than the surrounding soils (Marris, 2006). The mass of biochar is 70-80% less than the original biomass (McHenry, 2009).

## Materials and methods

### Site description

Site 1 (Light loam; 53°3′ N 4°16′ W) a 4 year old cider orchard where two Kingston Black cider trees were grubbed. Measurements were taken at both grubbed trees and a third tree, which was not disturbed in any way for comparison.

Site 2 (Upper Greensand; 52°5′ N 53°18′ W), a 22 year old Cox orchard (n = 22).

Site 3 (Upper Greensand; 52°5′ N 53°18′ W), a 30 year old Bramley orchard (n = 21).

### Measurement of soil $CO_2$ efflux

To measure the $CO_2$ efflux of the orchard system during the management practice of grubbing, an infra-red gas analyzer (IRGA) based $CO_2$ analyzer, the PP Systems EGM 4 with a SRC-1 chamber (PP Systems, Hitchin, Herts, UK), was used at three separate grubbing events. The EGM 4 IRGA calculates soil $CO_2$ flux rates from the increase in $CO_2$ levels over time, the volume of the system and the surface area of the soil tested (Janssens *et al*., 2000).

Soil respiration was determined at each grubbing event using a closed chamber EGM 4 IRGA equipped with a SRC-1 gas chamber with an internal volume of 1964 $cm^3$ and area exposed to the soil of 78 $cm^2$ (PP Systems, Hitchin, Herts, UK). The IRGA used a 124 s enclosure time to log the $CO_2$ concentration, a 15 s purge time to lower the $CO_2$ concentration inside the chamber to ambient levels and a 15 s equilibration time. At the end of each measurement, a linear regression is computed between the soil $CO_2$ respiration and the $CO_2$ concentration within the chamber (La Scala Jr *et al*., 2000).

At site 1, measurements were taken before (day 1), during (day 4) and after the grubbing event to monitor the $CO_2$ respiration from the soil and its' return to baseline levels. The day of grubbing for sites 2 and 3 was day 2. Measurements were taken sequentially throughout the orchard. Four replicates at each tree were taken following north, east, south and west directions. All readings were taken at the same time of day and the weather conditions were consistent, to ensure that the temperature flux was not the cause of the respiration flux (Valentini *et al*., 2000).

**Data analysis**

Analysis was completed using a one-way ANOVA and a post-hoc Tukey test, with tree as the factor. A random effects model was then run with the factor level of day. Statistical procedures were carried out using the statistical package SPSS PC version 14 (SPSS Inc. Chicago, USA), with p = 0.05 used as the upper limit for statistical significance.

**Biochar pot trial**

Grubbed apple (*Malus*) wood was collected from a local Anglesey orchard (53°11′ N 4°15′ W) and from Abergwyngregyn, Gwynedd, North Wales (53°14′ N 4°01′ W). It was left to air dry for 2 – 3 months to 25% or less moisture level. The wood was charred in a traditional rotund kiln for 10 hours at temperatures up to 450°C. The char was left to cool for three days and then removed from the kiln before being ground by hand into chips approximately 4 mm in size. Samples of char were dried, ground to less than 2mm and weighed out into 5 mm x 9 mm aluminium cups for analysis in a LECO TruSpec CN analyser to determine C content of the char.

Agricultural top soil, from the Henfaes research station, was used in the pot trial. This was chosen as it was similar to the soil type used in an orchard. Char was mixed with the soil using the pot surface area calculation at the following char application levels, 0, 5, 25 and 50 t $ha^{-1}$. Mixing of soil and char was carried out by hand and placed into 35 litre pots. The tree variety chosen for the trial was Bramley as this is widely grown in the UK. 1 year old Bramley maiden whips were potted up in the char/soil mix at the following char rates; 0 t $ha^{-1}$ = 5, 5 t $ha^{-1}$ = 4, 25 t $ha^{-1}$ = 4, 50 t $ha^{-1}$ = 4. N and P resin capsules were buried in the pot for future retrieval and testing. Tree productivity and the effects of the char amendment on the soil will be monitored over the coming year.

## Results

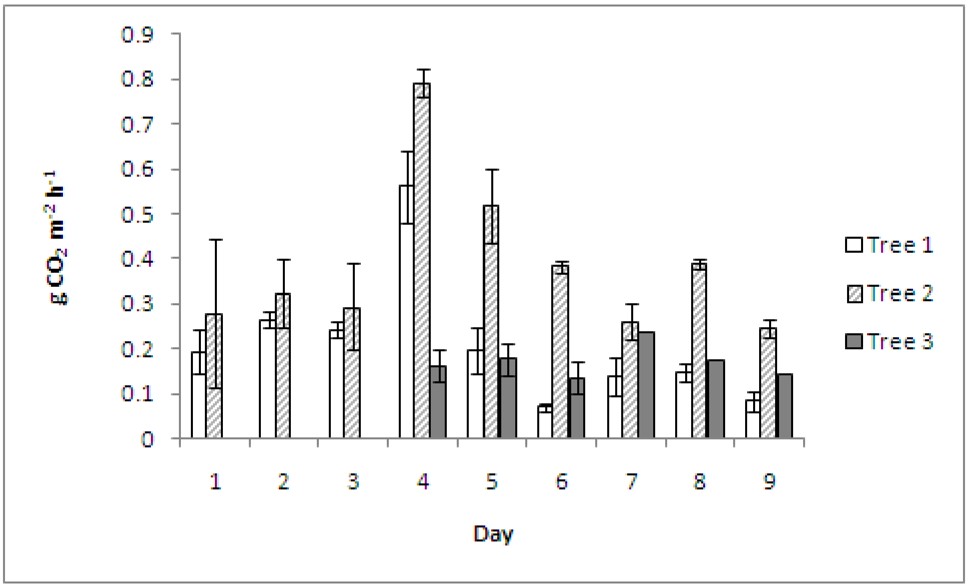


**Fig. 1.** Carbon dioxide (g $CO_2$ $m^{-2}$ $h^{-1}$) efflux from cider orchard soil before (days 1-3), during (day 4) and after (days 5-9) a grubbing out event of orchard trees at site 1, with trees 1 and 2 being treatment trees and tree 3 the control

At site 1 (Fig. 1), tree 1 showed a significant difference on day 4, the grubbing event, to all other days ($p < 0.01$).

Tree 2 showed a significant difference on day 4 to all other days ($p < 0.05$) except day 5, which didn't reach baseline levels again until day 6.

Tree 3 showed no significant difference. The day of the grubbing event (day 4) was significantly different to all the other days ($p < 0.01$).

Site 2 (Fig. 2) had a significantly higher ($p < 0.05$) $CO_2$ efflux when trees 7 and 17 were grubbed than all the other trees tested in the orchard. Significant differences in mean soil respiration for the day of grubbing were observed ($p < 0.01$), with a mean loss of 4.43 g $CO_2$ $m^{-2}$ $h^{-1}$ per tree on the day of grubbing (maximum of 10.13 g $CO_2$ $m^{-2}$ $h^{-1}$ per tree and a minimum of 2.01 g $CO_2$ $m^{-2}$ $h^{-1}$ per tree) compared to baseline mean (n = 22) of 0.37 g $CO_2$ $m^{-2}$ $h^{-1}$ per tree on the previous day. The mean $CO_2$ lost per tree on the day following grubbing fell to 0.25 g $CO_2$ $m^{-2}$ $h^{-1}$ per tree.

No significant differences ($p > 0.05$) between trees grubbed were observed within site 3 (Fig. 3). The disturbance event did have a significant effect ($p < 0.01$) on the amount of $CO_2$ released from the soil, with a mean loss of 7.14 g $CO_2$ $m^{-2}$ $h^{-1}$ per tree (maximum of 18.08 g $CO_2$ $m^{-2}$ $h^{-1}$ per tree and a minimum of 2.31 g $CO_2$ $m^{-2}$ $h^{-1}$ per tree) compared to baseline mean (n = 21) of 0.18 g $CO_2$ $m^{-2}$ $h^{-1}$ per tree on the previous day. The mean $CO_2$ lost per tree on the day following grubbing fell to 0.05 g $CO_2$ $m^{-2}$ $h^{-1}$ per tree.

Alongside, the loss of $CO_2$ from the soil, up to 15 t $ha^{-1}$ C of standing biomass per tree is removed from the system by grubbing it out of the ground for an orchard field of approximately 30 years old.

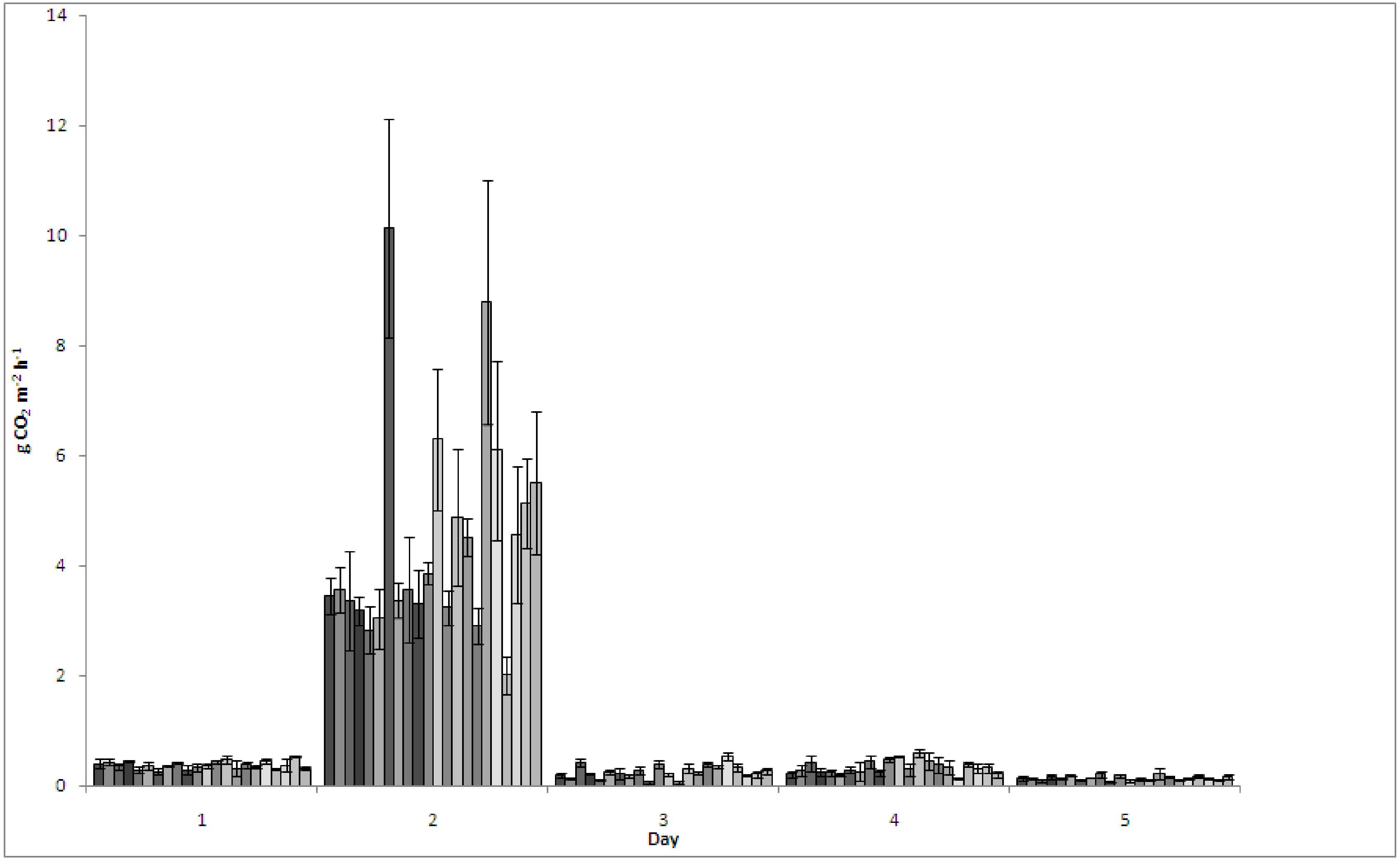


**Fig. 2.** The $CO_2$ efflux before (day 1), during (day 2) and after (days 3-5) the grubbing out event of a cox orchard at site 2, where one bar represents each tree over the 5 day measurement period

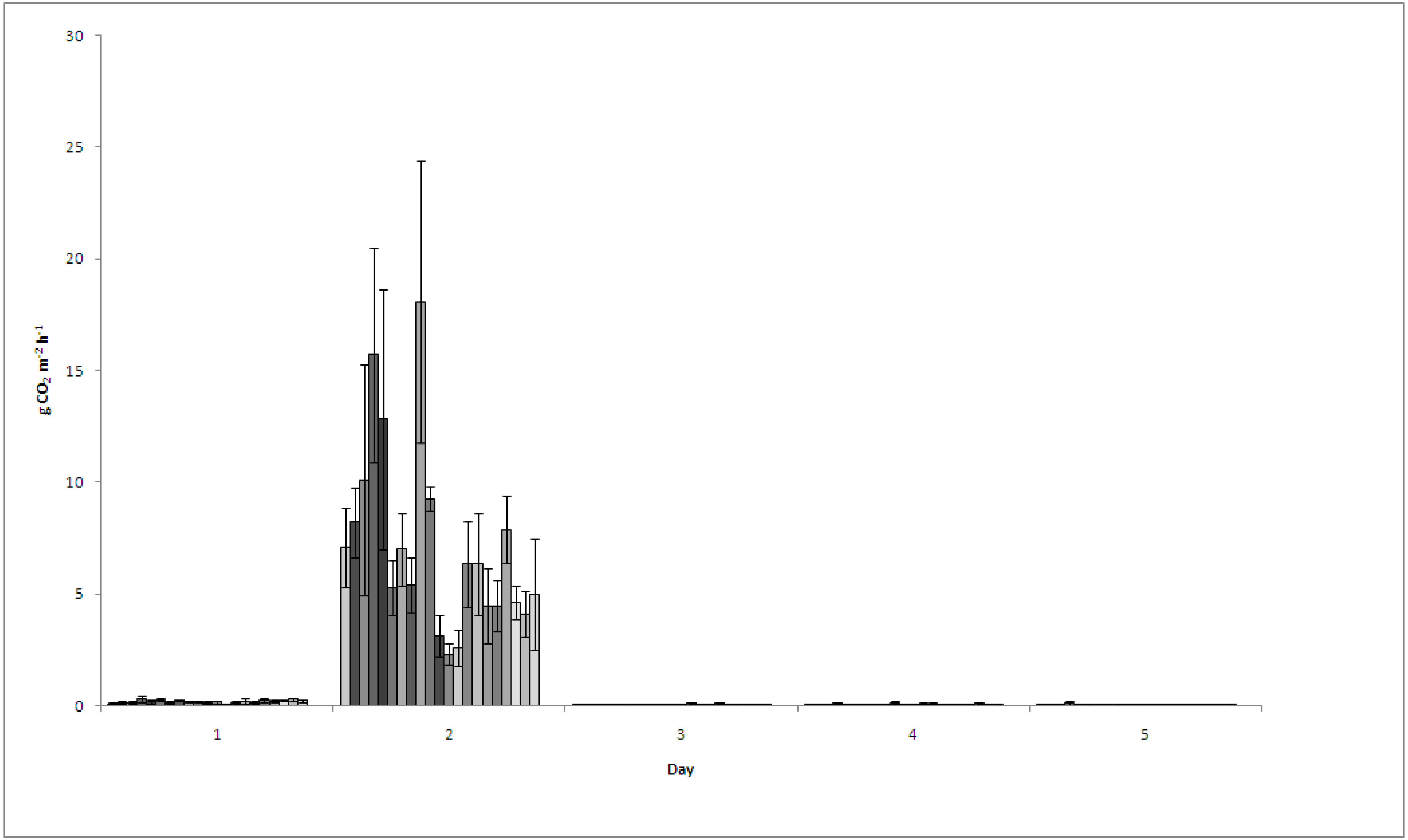


**Fig. 3.** The $CO_2$ efflux before (day 1), during (day 2) and after (days 3-5) the grubbing out event of a bramley orchard at Site 3, where one bar represents each tree over the 5 day measurement period

## Discussion

### Soil respiration

There are three main sources of $CO_2$ emissions in agriculture:

- machinery used for cultivation
- the production and application of fertilisers
- loss of C from the SOC when it is oxidised during disturbance (West and Morland, 2002)

The work carried out at all three sites shows that there was significantly more $CO_2$ released from the soil immediately after the *Malus* trees were grubbed, before $CO_2$ flux returned to baseline levels. Site 3 showed no significant difference ($p > 0.05$) between tree treatments, however, at site 2, trees 7 and 17 released significantly higher amounts of $CO_2$ ($p < 0.05$). Using the location map and site observation, it was shown that these two trees were at the end of the rows near the area of high disturbance where all the grubbed out trees were discarded, therefore these two trees had an increased level of disturbance over the other trees tested.

It is unclear from the experiment whether this was a true loss from the soil C store or a short-term $CO_2$ flux due to the rapid release of $CO_2$ trapped in soil air spaces (Bauer *et al*., 2006). A substrate induced respiration (SIR) experiment will be done to determine the availability of microbial biomass C (MBC) that is readily oxidised, thus enabling the determination of how much C is lost from the soil C store and its' impact on the C sequestration (Martens, 1995).

The time of year, and consequent ambient temperatures are likely to have an effect on the $CO_2$ emitted from the soil as temperature will affect soil respiration (Bauer *et al*., 2006). This is supported by the variation observed by our data, where site 2 displayed lower $CO_2$ flux than site 3 as they were measured in Autumn and Spring respectively (Bauer *et al*., 2006). Site 2 was measured in Autumn, while site 3 was measured at the end of Winter/beginning of Spring. The depth of disturbance also plays a role in the $CO_2$ flux observed (Ball *et al*., 1999). The grubbing of relatively large 22 and 30 year old trees (creating a disturbance at each tree position of approximately 1 m and 1.5 m in radius and 30 cm and 40 cm deep respectively) disturbs an area much larger than the greatest ploughing depth of 30 cm measured by Ball *et al*., (1999), which could be why the flux from our data is larger.

Conventional tillage and disturbance to the soil does cause a depletion of the SOC pool (Lal, 2004; Smith *et al*., 2000). A change in management practice from plough till to less intensive or conservation tillage can result in the soil becoming a C sink by enhancing C sequestration and reducing $CO_2$ emissions (Ball *et al*., 1999; Lal, 2004; Schlesinger, 2000; West and Marland, 2002). While this may be a viable option within agriculture, it is more than likely not a possible scenario for orchards. It is important to remember that although the $CO_2$ flux from the grubbed orchards was greater than the flux from the tillage of spring barley (Ball *et al*., 1999), the grubbing events occur on a much less frequent basis than conventional tilling.

While disturbances to the soil and the grubbing practice release $CO_2$ efflux from the soil, a full carbon analysis is required to determine the total amount of C leaving and entering the orchard system. This will be calculated by including the estimation of crop production, energy use, C emissions for primary fuels, fertilizer and pesticide use, lime treatment, irrigation, electricity consumption and farm machinery (West and Marland, 2002). Full carbon footprints will be calculated for apple orchards in the coming months, this will enable direct comparison to many studies, which include fertilizer production and application along with machinery and fuel costs.

## Conclusion

The grubbing practice, where orchard trees are removed from the orchard by the roots, released carbon dioxide ($CO_2$) from the soil on the day of grubbing (up to 20 g $CO_2$ $m^{-2}$ $h^{-1}$) and led to a loss of C in terms of biomass (up to 15 t $ha^{-2}$ C). It is unclear at this stage whether the $CO_2$ emitted was loss from soil carbon stocks or from the degassing associated with disturbance. A substrate induced respiration (SIR) experiment using a respirometer will be carried out to determine the $CO_2$ saturation point of the soil and full carbon footprints will be calculated to determine the total amount of C entering and leaving the system.

The impact of biochar amendments on tree productivity is unknown. An experiment has been established to monitor the productivity of Bramley apple trees in varying levels of biochar amendment (0, 5, 25 and 50 t $ha^{-1}$). Measurements will be taken to monitor the soil respiration, tree growth (height, diameter, branch length, branch number, leaf number, leaf area, leaf respiration, photosynthesis and the number of apples produced) and nutrient analysis will be carried out on the soil to determine any positive or negative effects of the char on the system.

## Knowledge and Technology Transfer

Use of the infra-red gas analyser (IRGA)
Kiln to make char from apple wood

## Glossary

**Biochar** - char from biomass used a soil amendment to sequester C

**Grubbing -** the method where the roots and stumps are cleared and the field is left fallow for a year or two before replanting

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