Grower Summary

CP 062

Quantifying carbon (C) in UK apple orchards

Final 2013

Disclaimer

The results and conclusions in this report may be based on an investigation conducted over one year. Therefore, care must be taken with the interpretation of the results.

Use of pesticides

Only officially approved pesticides may be used in the UK. Approvals are normally granted only in relation to individual products and for specified uses. It is an offence to use non-approved products or to use approved products in a manner that does not comply with the statutory conditions of use, except where the crop or situation is the subject of an off-label extension of use.

Before using all pesticides check the approval status and conditions of use.

Read the label before use: use pesticides safely.

Further information

If you would like a copy of the full report, please email the HDC office (hdc@hdc.ahdb.org.uk), quoting your HDC number, alternatively contact the HDC at the address below.

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Headline

- Commercial orchards store significantly more carbon than arable crops.

Background and expected deliverables

Due to increasing concern over the changing climate, there is currently some interest in the effects of land use and management of ecosystems on carbon (C) storage. Temperate woody ecosystems are known to be potential C sinks. The aim of this study was to determine the amount of C stored within UK Bramley and Cox apple orchards of differing management types and comparing these with other habitats.

Research objectives

This study aimed to determine the C storage potential of orchards in relation to the management system, and to estimate the environmental value of C stored. This was achieved by focussing on several specific objectives:

- Determine the C stored in above and below-ground biomass and soils in different orchard management types;
- Determine the C sequestration of different orchard management types;
- Calculate the C footprint of different orchards, with standard management data on inputs and outputs for real orchard ecosystems.

These objectives were addressed by the following five tasks.

1. Quantifying carbon (C) in UK apple orchards
2. Soil carbon (C) fluxes in response to the grubbing-out management practices in UK apple orchards
3. Biochar-mediated changes in soil quality in a Bramley apple orchard pot trial
4. Evaluation of the cell wall properties and microstructure of *Malus*-derived biochar
5. Evaluation of environmental impacts of greenhouse gas emissions of apple production from UK apple orchard systems

Summary of the project and main conclusions

Task 1. Quantifying carbon (C) in UK apple orchards

Soil samples (n = 10 ha^{-1}) were collected to a 5 cm depth from both Cox and Bramley orchards of two age categories (< 15 and > 15 years old), traditional cider orchards (n = 3) and from various surrounding land uses for comparison. Soil was collected from one site to a depth of 100 cm to determine C content over the soil profile. Tree height and diameter at breast height (dbh) were recorded (n = 40 per orchard) and analysed by allometric equations to determine C in the above- and below-ground biomass. Significantly ($p < 0.001$) higher soil C was found between age categories, with means of 7.02, 12.63 and 16.21 t C ha^{-1} (< 15, > 15 and 35+ age groups respectively). The apple variety also influenced the amount of C stored, with Bramley soil having significantly higher ($p = 0.005$) C (mean < 15 = 8.86 t C ha^{-1}, mean > 15 = 14.33 t C ha^{-1}) than that found under Cox orchards (mean < 15 = 7.60 t C ha^{-1}, mean > 15 = 10.34 t C ha^{-1}). The tree and root C followed a similar pattern with significantly ($p < 0.001$) higher C content with increasing age and in that of Bramley orchards than that of Cox orchards (above-ground; $p < 0.001$, Bramley mean = 10.57 t C ha^{-1}, Cox mean = 4.99 t C ha^{-1}). Comparisons between orchards and surrounding habitats showed that orchards store significantly higher C than arable land but they store significantly less C than woodlands. This could be due to the smaller biomass of commercial orchard trees than those found in woodlands and that some of the C in orchard trees is attributed to fruit production. It is concluded that orchards have the potential to store large amounts of C depending on management type in comparison to other land uses, although this C store may be lost when the tree productivity declines and orchards are grubbed out.

Task 2. Soil carbon (C) fluxes in response to the grubbing-out management practices in UK apple orchards

In response to rising levels of atmospheric carbon dioxide (CO_2), it is important to investigate carbon (C) sinks and their stability. The soil organic C (SOC) pool is an important store of terrestrial C, containing an estimated 2500 billion tons to 2 m depth, making it a significant C sink. Natural exchange of C in the form of CO_2 occurs between the air environment and the terrestrial biosphere. However, disturbance to the ground may exacerbate this exchange, leading to a release in CO_2 from the soil. As disturbance has this effect, it is important to understand the implications of land management decisions. In the context of UK orchards, a grubbing-out process occurs once the orchard field reaches the end of its productive lifespan. The process removes the tree stumps and roots causing disturbance to the soil. The effect of this disturbance was quantified by measuring the amount of CO_2 lost from the system before, during and after the grubbing out event using an infra-red gas analyzer. The CO_2 leaving the system was subsequently partitioned to determine the effects of the management practice on the soil C store. It was found that the majority of the CO_2 (ca. 95%) leaving the orchard system was due to the abiotic release of trapped CO_2 in the soil pore spaces. It was determined that this process lasted for approximately 30 minutes after the disturbance event before soil respiration returned to a new steady state which was lower than when trees were present. The grubbing-out process liberated approximately 0.01 t C ha^{-1} from the soil, which is a very small amount compared to the C loss from removal of

standing biomass (in commercial orchards) of up to 25 t C ha^{-1} and that held in the soil (ca.80 t C ha^{-1}).

Task 3. Biochar-mediated changes in soil quality in a Bramley apple orchard pot trial

The production and application of biochar creates the potential to reduce greenhouse gas (GHG) emissions and mitigate climate change through carbon (C) sequestration in soil. In UK orchards where the apple trees are grubbed out (complete removal including roots and stump) at the end of their productive life, there is potential to pyrolyse the waste biomass and incorporate it back into the soil. In this study, an experimental pot trial consisting of Bramley maiden whips (n = 17) was set up with four levels of biochar treatment (0, 5, 25 and 50 t ha^{-1}) for two growing seasons. Soil respiration, tree height and dbh were measured at regular intervals, while soil samples were collected and analysed in June 2011 and January 2013. There was found to be no significant differences in tree height growth ($p = 0.88$), in dbh increase ($p = 0.497$), electrical conductivity ($p = 0.450$), bulk density ($p = 0.393$) and moisture ($p = 0.954$) between biochar treatments. There were significant differences found in pH ($p = 0.005$) and organic C ($p = 0.004$), with the 50 t ha^{-1} treatment having a pH with 0.88 units higher and containing twice as much total C than the control.There were significantly different levels of PO_4, NO_3 and NH_4 between the treatments (p = 0.011, 0.001 and 0.005 respectively), but no significant difference in exchangeable Na ($p = 0.886$). There was a significantly higher amount of available K in the highest level of biochar treatment than in the lower treatments ($p = 0.013$), although it was not significantly different to the control. There were no significant differences in available Ca ($p = 0.10$) or in terms of soil respiration ($p = 0.606$), although there was a strong positive correlation between treatments for soil respiration ($r^2 = 0.92$).

Task 4. Evaluation of the cell wall properties and microstructure of Malus-derived biochar

With growing concern over the environmental impact of climate change, there is an emphasis on the delivery of mitigation options. One potential solution is the use of biochar; pyrolyzed organic matter, being used as a soil amendment to sequester carbon (C) in the terrestrial biosphere. This study investigated the production and characterization of biochar derived from *Malus* wood. Cubes of wood from a large *Malus* trunk were either left as wood (n = 27) or charred (n = 27) at 450°C for 15 minutes. A second set of samples (n = 3 for each treatment) were charred for varying lengths of time at 450°C from 3, 6, 9, 12 and 15 minutes to determine what effect, if any, length of charring time had on the physical properties of the biochar. Mean cell wall density was the same for both the wood and char samples (1.45g cm^{-3}), with higher variation being displayed in the char sample set. The Brunauer, Emmett and Teller (BET) surface area was significantly higher in the charcoal samples (mean for wood samples = 0.97 $m^2\ g^{-1}$, mean for the char samples = 5.27 $m^2\ g^{-1}$). As charring time increased, the mean density increases (p = 0.016) and with charring times exceeding 9 minutes, the surface area significantly increases. The charring process has an effect on the materials pore size and the pore size distribution, with the char product resulting in much fewer large pores than the equivalent wood sample. The equilibrium moisture content (EMC) at 95% relative humidity (RH) of the char (7, 15 and 9%) is lower than that of wood samples (21%), with the moisture adsorption isotherms displaying different characteristics. Very little hysteresis occurs in the char samples. It is concluded that the charring process has an effect on the physical properties and chemical composition of the wood feedstock.

Task 5. Evaluation of environmental impacts of greenhouse gas emissions of apple production from UK apple orchard systems

As atmospheric levels of greenhouse gases (GHGs) continue to rise, it is important to consider the practices which contribute to this. Whilst it is known that the food supply chain accounts for one fifth of all UK emissions, little is known about the contribution of the horticulture sector. This study investigated the GHG impact of UK apple orchards, with a particular focus on Cox and Bramley varieties; Rubens and Gala varieties were also considered to a lesser extent. Apple orchard owners completed a specific questionnaire; the data was then run in the model developed between Bangor University and Footprints 4 Food Ltd to calculate PAS 2050 compliant carbon footprints. The system boundary was cradle-to- farm gate, focussing on apple production and harvest; no post-harvest stages were considered in order to make each orchard comparable. A sensitivity analysis was carried out to explore the impact of potential management changes. The calculations showed the mean carbon footprint for Bramley, Cox and the remaining varieties (Rubens and Gala) to be 0.06, 0.11 and 0.12 kg CO_2e per kg of apples produced. Bramley orchards had significantly lower

emissions (p = 0.007) than Cox orchards. No significant differences (p = 0.911) were found between the traditional and trellis planting methods or between the different tree ages; over 15 and under 15 years old ($p = 0.561$). There was moderate correlation between the carbon footprint and energy use ($r^2 = 0.33$) and a strong positive correlation between carbon footprint and fertiliser use ($r^2 = 0.75$), showing that fertiliser usage was the highest GHG contributor (ranging from 26.55 to 53.81%). In conclusion, while UK apple orchard carbon footprints are comparatively low, there is potential to lower emissions through a change in management practice.

General discussion and conclusion

This study aimed to determine the carbon (C) storage potential of UK apple orchards with particular focus on the most widely planted commercial varieties Bramley and Cox (Defra, 2007; English Apples and Pears, 2012). Apple production within the UK had declined by 3% in 2007 from 2004 figures, however orchard area had increased by 1.7% in 2009 (Defra, 2010a). According to research carried out by the Horticultural Development Company (Beckenham, 2009), there was a total of 152,900 ha of fruit and vegetable production area with 13.6% of that being commercial orchards, which produce 284,000 tonnes of orchard fruit per annum. While UK fruit self-sufficiency, number of registered apple growers and production area have steadily declined in recent years, the volume produced has actually increased due to improved yields, new technololgy and a more efficient planting method (Beckenham, 2009; Borrie and Potter, 2005).

Throughout the study, it has been shown that the longer apple trees are allowed to stand and accrue biomass, the higher the C storage will be. However, in a world, where efficiency and being cost-effective are the driving forces of industry, orchard trees are grubbed-out at the end of their productive life. The emphasis should be on working alongside orchard owners to help them achieve the highest possible yields in the most C saving efficient manner and quantifying the C inputs and outputs to determine just how much C is being stored within UK orchards. In the current climate, it is becoming more important to encourage orchard owners to produce high quality fruit yields whilst the UK government sanctions schemes to encourage a healthier lifestyle and diet by increasing the consumption of fresh fruit and vegetables (Beckenham, 2009; Food Standards Agency, 2006; Fresh Produce Consortium, 2008). There is a drive to boost UK industry, with particular groups promoting local produce, such as English Apple and Pears (2012) who represent England at the World Apple and Pear Association (WAPA; 2012).

Task 1 of this study quantified the C in UK orchards by determining soil C, above- and below-ground biomass, determining the amount of C stored over a 100 cm deep soil profile for one UK orchard and comparing the top 5 cm soil C to that of surrounding land uses. The work showed that orchards have a greater potential for C storage than other land uses such as arable farming but that they store less C than woodlands do. Orchard fields are subjected to much less disturbance (approximately once every 15-35 years) than arable crop areas, which undergo annual ploughing. The C stored within the soil and biomass of the orchards varied depending on their age category, which is an indicator of management practice. For orchards older than 15 years old, they represent the more traditional method of planting, with a lower number of trees per ha that are allowed to accumulate a high amount of woody biomass. A new planting method is seen in the trees under 15 years, where there is a vast increase in stand density and the trees are grown along a trellis network, ensuring that most C is directed to fruit production and not woody biomass. The orchards > 15 years old had significantly more C storage than those in the < 15 category, but those younger orchards still had significantly more C stored in the top 5 cm of soil than the arable fields.

The management practice of grubbing-out whole orchards was explored (Task 2) to determine actual C loss from an orchard during the process. Although the total biomass of the tree is being removed (up to approximately 25 t C ha^{-1} for the above-ground biomass and approximately 5 t C ha^{-1} for the below-ground biomass), only 0.01 t C ha^{-1} was calculated to leave the soil during the event. Compared to the amount of soil C that accumulates over the orchards growing period, the majority will remain sequestered in the soil and accumulate over time.

In Task 3, investigations were made into the hypothesis that the biomass removed from the orchard during the grubbing-out events could be used to produce biochar, which can be used as a C rich (approximately 80%) soil amendment to return a proportion of the biomass C back into the orchard field. In accordance with other UK studies, it was found that while the biochar addition to the soil did not have any adverse effects on soil quality and tree growth, it did increase the total soil C by 25% (25 t ha^{-1} treatment) and 102% (50 t ha^{-1} treatment). Using biochar as a soil amendment needs further investigation with longer-term field trials to determine the full effects that it has on an ecosystem before being incorporated on a large- scale. Full environmental risk assessment must be carried out as the amendment is permanent once added into the soil.

Task 4 further investigated the sorption properties of the *Malus*-derived biochar as they play a significant role in determining the effect that biochar will have on the soil-nutrient interactions and the effect of biochar on herbicide and fertiliser applications (Lehmann *et al*., 2011). The study found that the charring process had a significant effect on the surface area of the material, with the resulting biochar having significantly higher surface area due to having fewer large pores than the original apple wood. It was also determined that charring time had an effect on the physical properties of the biochar. There was a much lower equilibrium moisture content (EMC) for charred samples and the moisture adsorption isotherms displayed different characteristics. Definite physical changes occurred during the charring process upon the wood cell components. This area now needs to be explored to determine exactly which changes occur. The determination of the compositional change may lead to a greater understanding of how the biochar will interact with nutrients and other compounds within the soil ecosystem.

C footprints of 16 UK apple orchards were calculated to determine the impact of producing apples in the UK upon GHG emissions. The system boundary was cradle to farm-gate and did not include post-harvest or retail stages for comparison purposes. Significant differences were again found between apple variety, with Cox having a significantly higher C footprint (mean = 0.11 kg CO_2e per kg apples produced) than Bramley (mean = 0.06 kg CO_2e per kg apples produced). Interestingly, there were no significant differences in terms of GHG emissions between the planting method. Orchards < 15 had a C footprint of 0.09 kg CO_2e per kg apples produced, while orchards > 15 were found to have a C footprint of 0.08 kg CO_2e per kg apples produced.

Financial benefits

- This study did not identify any financial benefits for UK apple growers.

Action points for growers

- Although there are no direct action points from this work, growers should be aware that orchards do offer significant carbon sinks which store more carbon than any form of arable crop production.