

Food Climate Research Network

Soil carbon sequestration workshop:

Summary of discussion



This paper summarises the presentations and discussions that took place at a workshop organised by the Food Climate Research Network and supported by Defra and the Committee on Climate Change on 21 January 2010. The workshop was held at Defra's headquarters in Nobel House.

1. Summary of presentations

a. Opportunities and risks of land management for soil carbon sequestration: Professor Pete Smith University of Aberdeen

Overview of potential

The UK Climate Change Act commits the UK to a 34% (or 42% if a global deal in emissions is reached) cut in CO₂eq emissions by 2020, rising to 80% by 2050. The Scottish government is committed to a 42% cut by 2020 and 80% by 2050, and the Welsh Assembly Government has committed to a 3% annual decrease from 2011 onwards. The targets cover emissions generated within national boundaries. Clearly radical changes in all sectors of society and the economy are needed. It has been estimated by the Stern Review on Climate Change that the global costs of taking the necessary action will amount to around 1% of world GDP by 2050.¹

There are three main approaches to sequestering carbon in soil: **a.** by increasing carbon inputs; **b.** by reducing carbon losses (for example by restoring farmed peatlands); or by **c.** reducing soil disturbance (such as through reduced tillage). A range of measures have been identified and listed elsewhere.²

An experiment at Rothamsted³ has shown that soils where manures were added in the years 1850-1870 still have elevated soil carbon levels today. Tropical peatland soils are one of the most significant sources of carbon losses today. The greatest soil carbon savings are likely to arise as a result of a focus on grazing and cropland management, particularly in degraded areas. Elsewhere, Smith et al estimate⁴ that 89% of the mitigation potential deliverable by the agricultural sector arises through soil carbon management.

The cost of carbon has a strong influence on the likelihood of uptake and effectiveness of different sequestration measures. Some carbon abatement is cost negative – that is, it could

¹ Stern, N. (2007) *The Economics of Climate Change: The Stern Review*, Cambridge University Press, Cambridge, UK

² Smith P. (2008). Land use change and soil organic carbon dynamics, *Nutr Cycl Agroecosyst* 81:169–178

³ Johnston, A. E., Poulton, P. R. & Coleman, K. (2009). Soil organic matter: its importance in sustainable agriculture and carbon dioxide fluxes. *Advances in Agronomy* 101, 1-57

⁴ Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes R, Sirotenko O. Agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA, eds. *Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*. New York: Cambridge University Press, 2007

yield financial gains, but initial investment may be needed. At low carbon prices (\$20/tonne), cropland management is the most effective route, as it is cheap to implement; cropland management includes improved agronomic practices (such as the use of new crop species and improved rotations), nutrient management, tillage, and residue management. As the price of carbon increases, the restoration of organic soils becomes more attractive. At low carbon prices, Smith estimates that only about a third of the total mitigation potential is likely to be realised.

Smith argues that, on balance, the mitigation potential in the agricultural sector compares favourably, from a cost perspective, with other mitigation measures in the energy, transport, industry and forestry sectors.

While soil carbon sequestration is no silver bullet (there aren't any silver bullets in any sector), it forms part of necessary spectrum of approaches to tackling climate changing emissions. We ignore it at our peril.

Risks and drawbacks

There are nevertheless significant drawbacks or trade-offs associated with reliance on soil carbon sequestration as a major contributor to the reduction of GHG emissions in the context of climate change mitigation. The four key ones relate to: sink saturation; permanence; leakage or displacement; verification and Smith discussed these in more detail:

a. Sink saturation: A switch from arable to grass, or from grass to forest will lead to carbon sequestration but after a time a new equilibrium is reached and carbon stops accruing in the soil or (in the case of trees) above ground biomass. Carbon sequestration is greatest in the first few years of the growth and development cycle, with the gains declining over time. Soils tend to become saturated after about 20-100 years.

b. Permanence: Carbon sequestration is easily reversible: planting trees will lead to carbon sequestration but those trees can then be cut down at a later time, releasing carbon and undoing any gain in carbon sequestration from when trees were planted. Therefore the forest must be maintained indefinitely in order permanently to maintain the sequestered carbon. The same applies in the case of soils.

c. Linkage and displacement: If more manure is added to a particular soil, more sequestration occurs. However if the manure being used would otherwise have been applied to soil on another farm or field, then no net sequestration occurs, but simply a shifting around of the sequestration. Similarly, when peatlands are taken out of agricultural production and restored, while sequestration may occur on these lands, the knock on effects also need to be considered. In order to produce the same amount of food, land elsewhere may be ploughed up for agricultural production, so leading to soil carbon losses and perhaps outweighing the gains from peatland restoration.

d. Verification: It takes tens of years to monitor change, so a long term approach to demonstrating change is required. Some projects implemented under the Clean Development Mechanism have proved to be uneconomic since the costs of demonstrating and verifying increases in soil carbon are greater than the value of the carbon credit obtained.

Conclusions

Smith pointed out that it took 300 million years to make the fossil fuels and it is not going to be possible to lock up all the carbon we have released in a few short years. Overall it is

better to emit less than to emit as usual and try to sequester carbon later, or, by analogy 'better to keep the marbles in the jar than to spill them all and then try to pick them up.'

Smith emphasised that soil carbon sequestration is no substitute for seeking to reduce greenhouse gas (GHG) emissions across the board. This said, at a global level it offers significant, and cost-competitive mitigation potential. It can be seen as a useful approach to meeting short and medium term targets and can also yield co-benefits, such as improvements in the fertility, workability, and water-holding capacity of soils. However, its limitations need to be borne in mind as does the importance of recognising that it does not replace genuine emissions reduction.

b. The potential for soil carbon sequestration, including the role of nitrogen **Professor Keith Goulding. Rothamsted Research**

For carbon sequestration to help mitigate climate change, there needs to be a net drawdown from atmosphere, not just a movement of carbon within the landscape. Goulding emphasised the following points that need to be borne in mind when considering the benefits of soil carbon sequestration approaches (some of which reinforced those made by Smith):

- Equilibrium: a new carbon equilibrium in soils is reached within 20-30 years
- There are permanence issues, as sequestration is reversible
- Other GHGs are involved, not just carbon dioxide.

He also pointed out the potential win-wins; the incorporation of carbon rich material into the soil improves the fertility. It also makes the soil easier to work and as such, less energy is needed for inversion ploughing.

Goulding addressed the following issues in turn:

- relationship with the nitrogen cycle;
- the role of crop residues;
- the role of manure;
- biochar.

Goulding first discussed the relationship between nitrogen fertilisation and carbon sequestration. He highlighted a study published in *Nature*⁵ that nitrogen produced as a result of human activities (such as car driving) and deposited onto soils led to significant increases in the carbon sequestered since the nitrogen had a fertilisation effect. Other studies, however, have shown that the effects are variable (apparent in temperate but not tropical regions) and that while there is an important relationship between nitrogen and carbon, the overall effects on carbon sequestration are small. Moreover, woodland close to sources of nitrogen, such as ammonia from farms or NO_x from vehicles and central heating, scavenge a great deal of this nitrogen from the air (because of the large surface area of trees). While some of the nitrogen stimulates growth, most of this nitrogen cannot be used by the trees so the excess is liable to be leached as nitrate into waters or converted to nitrous oxide gas by soil organisms, so contributing to climate change. There are considerable gaps in our knowledge regarding the carbon-nitrogen interactions in woodlands and a need for more research in this area (see below).

Goulding highlighted a range of land management approaches that could help sequester carbon, including the incorporation of crop residues, paper waste or 'crumble,' manures and

⁵ Magnani, F; Mencuccini, M; Borghetti, M, et al. (2007) The human footprint in the carbon cycle of temperate and boreal forests. *Nature*, 447, Issue 7146, Pages: 848-850.

biosolids; the application of nitrogen fertilisers to increase biomass production, a shift from ploughing to reduced tillage, the conversion of arable land to forest, biochar and subsoil carbon.

Regarding crop residues, around 22% of the carbon in crop residues added to the soil is retained, the rest being released to air. As adding crop residues, such as straw stubble to the soil, is now standard practice in the UK, on the whole there is little scope for net benefit arising – more may be applied in one place at the expense of applications elsewhere. Goulding cited research⁶ finding that a greater GHG benefit can be achieved by first incinerating the straw to capture the energy and then applying the ash to the soil as a fertiliser. However (later in the Q&A session) one questioner asked whether the gains in terms of soil quality and texture are better if straw is applied as opposed to ash, and Goulding confirmed that straw is indeed better. In which case, the questioner commented, from a long term perspective of soil sustainability then might not the application of straw be preferable? Goulding replied that this was arguably so.

On manures and biosolids, 23% of the carbon in farmyard manure and 56% in digested sludge is retained in the topsoil. Goulding stressed that best use should be made of this resource. Digested sludge is retained better in the soil than raw manure, but most in any case goes to land now so there is no net benefit. Adding manure also leads to the release of nitrous oxide emissions, so good judgement in how and at what rate it is applied is important. Goulding also referred to research showing that the incorporation of paper crumble can have benefits for soil carbon.⁷

Fertilisers increase crop production, and hence the soils capture more carbon if the plant residues are then incorporated into the soil. As such there is a potential mitigation benefit. However, since GHG emissions are generated during the course of producing and applying the fertiliser, the precise balance is critical. A balance needs to be struck between production, land use change and soil carbon sequestration, and emissions.

Research findings on reduced tillage are mixed. There is evidence of some gain in the accumulation of carbon in the top layer of soil (down to 15cm) but less research into the impacts at greater depths (at around 30cm). There are also greater emissions of N₂O, particularly in dense wet soils. Furthermore if the land is later ploughed (and it does need to be ploughed every so often) then the retained carbon will be released to the atmosphere, leading to no gains. This said, reduced tillage can improve soil quality and as such may be worth practising in its own right.

Goulding only touched upon subsoil carbon as this is an area where significantly more research is needed. Subsoil carbon is carbon that moves down into the soil below the layer ploughed – that is, below about 25 cm. It might be leached down in dissolved form or put there by plant roots. Because there is less microbial activity in the uncultivated lower soil layers, there is likely to be slower decomposition and release of carbon dioxide. However, this is supposition and more research is needed here.

⁶ Powlson D S, Riche A B, Coleman K, Glendinig M J, Whitmore A P. (2008). Carbon sequestration in European soils through straw incorporation: Limitations and alternatives
Waste Management 28 741–746

⁷ Bhogal A, Chambers B J, Whitmore A P and Powlson D S. (2009) *The effects of reduced tillage practices and organic material additions on the carbon content of arable soils*. Scientific Report for Defra Project SP0561.

Goulding emphasised that most agricultural systems will inevitably lead to net emissions of greenhouse gases. Genuine overall emission reduction can be achieved through a shift from food production to forest land. However, if (given the global land constraints we face) afforestation displaces food production to land elsewhere than overall effects may not be beneficial.

Great claims have been made for biochar. Biochar is produced through the combustion of wood materials that are partially burned in limited oxygen (pyrolised). Its purported (but as yet unverified) benefits include: a near permanent increase in soil carbon (biochar does not break down easily); a greater stabilisation of other soil carbon; the suppression of other greenhouse gas emissions; enhanced fertiliser use efficiency; improvements in the soil's physical properties, enhanced crop performance and greater soil biodiversity. However, while a great number of review papers have been written, there has been very little experimental work to test these ideas. There is also the risk that the pyrolysis process may lead to the production of polyaromatic hydrocarbons and other persistent organic pollutants (POPs), which may present a local health issue near the production plant and a wider issue when the biochar is applied to soil.

To conclude, Goulding highlighted the range of approaches that could lead to soil carbon sequestration. However, in order to avoid perverse effects (for example displacement of food production to other parts of the world, or application of manure on one area of land at the expense of application on another where it was previously applied), an integrated approach based on life cycle analysis is needed. Single issue thinking can be dangerous; to illustrate the point Goulding highlighted research which investigated the impacts of measures adopted by a farm to reduce nitrogen leaching in response to regulatory requirements. The research found that while leaching was reduced, there were increases in soil phosphate and thus the risk of increased phosphate loss to waters with resultant eutrophication.

Goulding warned that too much emphasis can be placed on soil carbon sequestration, in the absence of and at the expense of more integrated thinking. The soil carbon sequestration issue needs to be seen in the context of a package of other measures to improve land stewardship.

2. Summary of group discussion

The participants discussed the soil carbon sequestration issue from a diversity of perspectives. Broadly speaking, the areas explored can be categorised into the following themes:

a. Data and baselines

We do not have a global baseline for measuring existing carbon levels at the moment although limited national measurements are taking place patchily across the world. In the UK we have two major soil monitoring programmes, the National Soil Inventory (NSI) and the Countryside Survey (CS) and a variety of habitat specific or country specific monitoring programmes (see Emmett et al. 2006 for a review of all soil monitoring programmes)⁸ but less information on changes in soil carbon in response to certain land use and management transitions, particularly on grazing land. There are major gaps in soil knowledge, particularly on the variation between organic (both in the Soil Association and in than edaphic senses)

⁸ Emmett, B. A., H.I.J. Black, R.I. Bradley, D. Elston, B. Reynolds, R. Creamer, Z.L. Frogbrook, G. Hudson, C. Jordan, A. Lilly, A. Moffat, J. Potts, and E. Vanguelova (2006). *National soil monitoring network: review and assessment study*. Final Report December 2006. Project LQ09 Contract No: C03179. 42pp.

and non-organic grasslands. There are also major difficulties in monitoring change in organo-mineral soils due to the inherent higher variability in organic horizon depth and the requirement in peats to include peat depth and erosion measurements.

Obtaining soil carbon measurements is not a straightforward process, and one of the problems with the UK data sets (of which there are a number, although not necessarily covering all land use types) is the inconsistency in methodologies adopted. Although soil samples are relatively cheap to analyse, it is extremely important that a representative sample is taken and this can mean the collection of numerous samples from the same field and that when comparing findings at larger scale, that the same methodologies are adopted. It is also important to note that soil C changes very slowly, and there is a huge pool of C within soils which can 'mask' the effect of any management changes. It can therefore be several years before any changes from the practices employed can be confirmed and then widely adopted. To this end, inclusion of a soil carbon measurement in any carbon accounting mechanism or carbon footprint calculation could potentially be very misleading, costly and difficult to verify.

Most data on soil carbon is for the top layer only, with very little knowledge of the soil carbon content at depth below 25cm – there is clearly a need for more research at deeper soil levels. In particular there is a need for regionally specific data on soil carbon, and this requires more investment in soil monitoring. A comparison was made between the large amounts currently spent on water and biodiversity monitoring, which is far greater than that spent on soil monitoring.

One view offered was that spotting the opportunities for measures to sequester carbon is more important than identifying the baseline values particularly given the time and expense of soil carbon measurement. We already have a qualitative understanding of which soils are gaining and which are losing carbon. Accurately measuring soil carbon is a detailed expensive approach. One lower cost and more practical approach suggested might be to remote-sense activities such as changes in tree cover – this would give an activity based assessment of changes even though it would not actually measure changes in stock.

However there was opposition to this view on the grounds that there is no consensus at the moment as to whether trees actually increase soil carbon (as to opposed to the sequestration in their above-ground biomass). It was suggested that until we have a good evidence base for how soil carbon changes on different soil types with different ways of using and managing land, then using trees as a proxy for measuring soil carbon is a risky approach, that should rather go hand in hand with improved monitoring of soils.

It was also pointed out that some types of activity level monitoring are already being undertaken through the IACS mechanism linked to the EU Single Farm Payment. Measuring soil carbon and gathering the data is an additional challenge rather than a new exercise and could be built into existing systems. One suggestion for incentivising farmers was to introduce measures that incorporate soil carbon into existing agro-environment schemes, and perhaps making some of these measures obligatory, rather than voluntary.

There was a discussion as to who should be gathering this data. Is it the role of the public or private sectors? Some food industry players are starting to undertake their own measurements but it was noted that they may not have the expertise to undertake analysis to the high standards really needed. Hence public research money is needed.

One key point made was that there is a need for sharing of information on soil carbon at an international level. Developing adequate monitoring, reporting and verification processes is particularly more problematic in the developing world and as such makes it harder for small scale farmers to participate. A regional based system was suggested whereby changes in

soil carbon at a regional rather than a farm-specific scale are estimated, with the benefits accruing on an equitable basis to the farmers in that region. Since the benefits of soil carbon sequestration are likely to be greatest in the developing world (as are the challenges) there is a clear role for DFID and other international development organisations to build work programmes in this area.

As regards the UK, a new national soil monitoring scheme which fulfils all the requirements of the variety of stakeholders has been designed by a consortium of lead researchers in the field (Black et al. 2008)⁹ but currently with no uptake by funders and it was suggested that this should be reviewed as a priority.

The effects of future warming on soil carbon are uncertain, and will be affected by the two opposing processes of increased rate of net primary productivity and increased rate of decomposition.

b. Soil carbon: trade offs and co-benefits with other environmental concerns

Relationship with nitrogen: We need to know more about how nitrogen fluxes vary in time and space and in particular the relationship between the carbon and nitrogen cycles in grasslands. This is important in view of the very high global warming potential of nitrous oxide and the fact that some practices to increase carbon storage can also lead to higher nitrous oxide emissions. We need more precise understanding of optimum manure application levels such that the carbon benefits outweigh any nitrous oxide emissions.

Fertility and yields: In the developing world there are likely to be particularly strong synergies between improvements in soil carbon and in yields since soils are on the whole more degraded; in addition manure provides a key source of nutrients, can improve the water holding capacity of the soils and hence can raise productivity. We need however to gain a much better understanding of the potential social and economic co-benefits - in particular what the no-regret options are - in order to understand how policies can be developed to incentivise carbon sequestration practices at the farm level.

Biodiversity, landscape value and the relationship with carbon storage: There were a range of views as to the relationship between soil carbon sequestration and biodiversity – and it is important also to be clear whether by biodiversity we are referring to microbial activity in the soil or above-ground biodiversity and productivity. It was pointed out that some crops are rather effective at carbon fixation and storage (e.g. monoculture coniferous plantations) but these are not biologically diverse systems. One commentator argued that intensively farmed grassland is almost certainly short rooted while a permanent meadow can include a range of deep and short rooted species, while another warned that we must be cautious about making sweeping statements on biodiversity. For example in semi-natural grasslands, the more types of grasses there are the more carbon is stored but in a heath land, species invasion can occur and lead to lower carbon storage if the bog-forming plants are out-competed. There was also a discussion around the fact that there are different understandings of what we mean by biodiversity – is it about the presence of ‘appropriate’ species, is it species richness, or plant functional type? The general conclusion drawn was that no sweeping statements as to the relationship between state and / or change in soil carbon and biodiversity either above or below-ground are possible but that the issue is being

⁹ Black, H., Bellamy, P., Creamer, R., Elston, D., Emmett, B., Frogbrook, Z., Hudson, G., Jordan, C., Lark, M., Lilly, A., Marchant, B., Plum, S., Potts, J., Reynolds, B., Thompson, R., and Booth, P. 2008. Design and operation of a UK soil monitoring network. Contract Report. Environmental Agency. ISBN 978-1-84432-936-6.

investigated at present in a range of projects in the UK including the Countryside Survey (www.countryside-survey.org.uk) Integrated Assessment due to be published in May 2010 and the Defra National Ecosystem Assessment.

Regarding landscape value and aesthetics, a switch from animal farming to woodland could increase soil and plant based carbon storage, but would leave us with a different looking landscape. Views on what sort of landscape we want, together with knock on effects on rural communities and economies, will influence the decisions made.

The role of woodlands and tree planting: There were conflicting views as to whether on-farm woodland planting had much of an impact on overall farm GHG emissions. In general there is a need for better understanding on how trees can contribute to carbon sequestration – which trees, in which systems? A linked issue is that of biomass production for energy. Changes in soil carbon would be expected to increase under short-rotation bioenergy (such as willow or miscanthus), but it is difficult at this stage to confirm, since few measurements have been undertaken. If woodland were replaced with biofuels there is likely to be a slight loss in soil carbon. And if biofuel production in the UK leads to a reduction in, for example, UK beef production and an increase in beef imports from Brazil (in the absence of concomitant behaviour change) then the effects in terms of CO₂ emissions will be negative.

c. Soil carbon within the broader land use context

Relationship between soil carbon measures and land use change. There is, as one participant noted, potentially an inverse relationship between how much food we can grow and how much soil carbon we can sequester. Moreover, measures to increase carbon sequestration will be counterproductive if they led to land use change elsewhere – this said, it was also noted that many uplands are relatively unproductive from a food production viewpoint, and displacement by trees could arguably be more beneficial.

If peatlands currently put to arable production are reflooded, then there will be a need to produce an equivalent amount of food elsewhere. One participant pointed out that if there was a concomitant increase in productivity on land elsewhere then there need be no net reduction in food, although there may be increases in fertiliser related emissions. It was also noted that highly intensive production does not necessarily lead to greater soil carbon releases, provided that composts and manures and so forth are applied.

In short there are complex trade offs to consider and an integrated approach to addressing the need both for food and for the maintenance and fostering of sustainable ecosystems is needed. It was noted that two Foresight projects (on Land Use Futures and Global Food and Farming Futures) (are currently working on these issues from the UK and global perspectives.¹⁰

Understanding the agricultural sector as an evolving entity: It was pointed out that when we consider the agricultural sector as a whole, we must recognise that it is constantly evolving. There are ongoing changes that could be perceived as both positive and negative – for instance specialisation, more powerful machinery that disturb soils, environmental stewardship and strips. Other actions occurring include liming and the increase in bracken cover in Scotland.

¹⁰ <http://www.foresight.gov.uk/OurWork/ActiveProjects/LandUse/LandUse.asp>

Protecting what we have: One point was very clearly emphasised: we need to focus on protecting the carbon stocks we already have against carbon losses, as much as increasing the carbon we sequester. For example more carbon cannot be sequestered in existing grassland (if they are kept as grasslands) – but it can be lost. In particular the priority is the protection of peatland carbon stores.

d. Soil carbon and livestock systems

Livestock and grazing: We know very little about the impacts of grazing, and of different grazing practices on soil carbon sequestration. This is an absolute priority for further research given the prevalence of grasslands in the UK (and indeed globally).

Livestock and food security: There was a discussion around livestock production; various people pointed out that tackling the demand for meat and dairy products could lead to less pressure on land and fewer GHG emissions, while achieving global food security.¹¹ However, the positive function of livestock in making use of land unsuited to arable production and of using byproducts from other agricultural sectors – and hence contributing to food security - was also noted. There was also a discussion around the appropriate functional unit to use when measuring livestock emissions – should it be (as is standard) kg CO₂ eq / kg of product or might protein or calories (or ability to use otherwise unproductive land) be more appropriate? Some metrics show emissions arising from red meat to be less intensive than standard LCA might indicate. It was also noted that the UK agricultural sector is too compartmentalised, making resource flows that occur between sectors, which could improve efficiency, more difficult to account for.

The point was also made that the ‘need’ to double food production is open to challenge. The scale of production required depends both on our ability to reduce waste within the global supply chain and on consumption trajectories – that is, on the extent to which demand for meat and dairy products is either fostered or constrained. There was also some discussion about consumer behaviour and the drivers behind behaviour change, but on the whole it was felt that this very important subject falls outside the scope of this particular workshop.

We also need to know more too about the effects of taking animals off grasslands – if grazing land reverts to woodlands, where will the food that livestock farming yields be produced and what might be the land use change implications? Growing a perennial energy crop such as willow or miscanthus instead of using land for grazing or feed production may be good for soil carbon and displace fossil fuels, but if it leads to the import of beef produced elsewhere the consequences may be negative. Indoor-reared livestock production systems are commonplace in many parts of the world and may ensure higher levels of production from the least necessary land as well as reduced net GHG emissions; however this is likely to have consequences for animal welfare.

e. Soil carbon measurements and its relationship with overall food chain emissions

A brief overview of the PAS 2050 was given:¹² in essence this represents an initial attempt to standardise how the GHG element of life cycle analysis is undertaken. In other words it

¹¹ Stehfest, E., · Bouwman, L., van Vuuren, D., ·den Elzen, M.,· Eickhout, B. and Kabat, P., 2009. Climate benefits of changing diet, *Climatic Change* DOI 10.1007/s10584-008-9534-6

¹² Publicly Available Specification for assessing product lifecycle GHG emissions
<http://www.bsigroup.com/Standards-and-Publications/How-we-can-help-you/Professional-Standards-Service/PAS-2050>

seeks to set out a standardised method of carbon footprinting. The data gained as a result of this process can be used for the industry in question to improve its processes and practices and can additionally lead towards the development of an external and independently verified carbon label. The relevance of the PAS 2050 to the carbon sequestration issue is that at present soil carbon gains are not included in the methodology. However the PAS 2050 does require companies to include in their accounting the emissions arising from agriculturally induced land use change, dating from January 1990. One-twentieth (5%) of the total emissions arising from the land use change must be included in the GHG emissions of these products in each year over the 20 years following the change in land use.

There was a general discussion about the difficulties of calculating accurate carbon footprints. A key problem is the lack of locally specific data; given the huge variability in emissions (particularly of nitrous oxide) national, regional and even local scale this can make the accuracy of any conclusions drawn and in particular any carbon label that results from the footprinting. Even where default figures are used, different researchers draw upon different sources for the defaults. There was a general view that LCA can give us a 'good enough' idea of the impacts of a product but not necessarily help us distinguish between different brands of the same product, owing to the difficulties and variabilities of data collection. It was suggested, however, that consistent use of the same default emission factors (eg. IPCC) might also provide a basis for rewarding farmers for undertaking various specified mitigation measures.

Other on-farm measurement tools that were mentioned were the Country Land and Business Association's CALM¹³ tool and the Cool Farm tool currently being developed by the University of Aberdeen. Neither of these, however, takes into account land use change emissions attributable to imported feeds, such as soy. Carbon calculators at the farm level can be useful in focusing farmers' attention on priority areas of concern but may not give results that are accurate enough to be applied at a commercial level.

There may be scope for developing a tier 2 methodology within existing models for calculating soil carbon sequestration. Soil carbon measurements could be undertaken while soil N is being assessed.

e. Carbon sequestration and the agricultural system:

A point was made that generalising about agricultural systems (intensive versus extensive; organic versus conventional) can be misleading as it can lead to sweeping conclusions. There is often as much difference within farm practices in the same system (conventional, for instance) as there is between systems. It may be more useful to consider specific agricultural practices or bundles of practices than general systems.

There was a discussion about what we want to get out of an agricultural system and what metrics we use to measure its sustainability. One suggestion was, in view of the fact that fossil fuel inputs will become scarcer and more expensive, that we need to consider the relationship between energy *in* (fossil fuel and other inputs) and energy *out* (food or biofuels value).

One participant noted that the prevailing goal of maximising output at minimum GHG expense was a very narrow approach since it does not consider the differences in suitability of different land types, and takes for granted the inevitability of the 'need' to double food

¹³ <http://www.calm.cla.org.uk/>

production. Other issues such as animal welfare may also be overlooked. Reference was made to the Royal Society's report on global crop production¹⁴ where it highlighted the need for "sustainable intensification" - wherein which yields are increased without adverse environmental impact and without the cultivation of more land. Of course this begs the question of how this might be achieved and how the inevitable trade offs will be managed.

As regards the UK, different possible land use models were touched upon. One approach might be to focus agricultural production in highly productive areas and use less productive areas for tree or perennial biomass planting to offset inevitable GHG emissions and give biodiversity diversity assets. Under this scenario, the landscape – and particularly the uplands – will experience a change in appearance and character and in its make up of flora and fauna.

Another approach might be to maximise livestock's capacity to make use of land unsuited to arable production, to make the most of agricultural byproducts, and to avoid the use of grains grown on prime arable land to feed livestock. This approach could preserve the existing visual character of the uplands and its existing make up of species. It would however necessitate a reduction in meat consumption - otherwise the shortfall in production would be compensated for with an increase in imports.

Both scenarios are at this stage speculative and detailed systems-based modelling is needed in order to understand their implications and potential for implementation.

A comment was also made that since some UK agriculture is likely to benefit, at least initially, from temperature increases, then its role, from a global food security perspective, might be to maximise production so that the surpluses can be consumed in other parts of the world. This of course risks a repeat of the damaging impacts that export dumping have had on agricultural production in the developing world. It also runs counter to very strong (albeit contested) arguments that agricultural development in poor countries is key to economic development and the raising of standards of living in general.

There was a discussion of the potential for moving agriculture towards more perennial systems, which help store more carbon and are less energy intensive (because of the reduced need for ploughing), an example being perennial wheat. This is an under-researched area.

f. Research into policy

The broader socio-economic context: it was emphasised that measures to increase soil carbon will also be affected by other drivers, including the scarcity of phosphate fertiliser, oil prices and so forth. Farmers will make decisions about land use in response to a very wide range of these drivers. As a democracy we cannot autocratically dictate land use: we need consultation and public buy-in on any regulatory changes that are required. It was also noted that the short term actions we need to take to reduce emissions by 34% or 42% by 2020 may be very different from the measures we will need to adopt in order to reach the 80% target by 2050. It is important not to implement short term measures that make it harder to attain the more drastic long term cuts needed.

Communicating carbon sequestering practices to farmers and incentivising their uptake: This was an area identified as of critical importance. We need to work out what

¹⁴ Reaping the benefits: Science and the sustainable intensification of global agriculture, Royal Society, London, October 2009

measures farmers can adopt that will be unambiguously beneficial and what we can do to reward their uptake. It was also noted that when measuring and rewarding measures to sequester soil carbon we need to be sure that these measures are additional – that they would not have been done anyway. It was noted that lessons can be drawn from other farmer-oriented projects and applied in the carbon sequestration context. In other words there may be existing models that can be rolled out. This applies both in the developed and developing world contexts.

Action in Wales: A brief overview was given of the Welsh Assembly's programme of work to examine the climate change issue as part of a wider analysis of the agricultural and land use sectors. Work is being done on livestock systems, particularly into the dairy sector; as well as on biomass and sinks; and on renewables. A technical report has recently been published¹⁵ which seeks to establish what the optimum balance for Wales might be between intensive and extensive systems, on approaches to fostering uptake of mitigation measures and on behavioural issues. Among other things, the report identifies a range of research gaps on soil carbon, including issues in measuring emissions related to soil carbon and land use, and land management. With respect to soil carbon and plant biomass, literature values were collated for all intervention measures and the midpoint of the range reported was applied to the landcover / soil type combinations present in Wales - except where Welsh studies indicated that different values should be used. The potential for different land use change strategies to reduce GHG emissions over a 50 year timescale (2010-2060), together with the effects of different levels of farmer uptake were assessed. The report highlights the need to take undertake these types of local assessments to ensure compatibility with local conditions, including the potential trade-offs and co-benefits for other ecosystem services.

3. The research gaps and priorities

A number of knowledge gaps were identified. This section draws out some of the research priorities that emerged during the course of the discussion.

a. Synthesis and first steps

First of all we need to pull together what we already know so that we can act quickly. We already know quite a lot and there is also considerable agreement on key points.

In particular it might be useful to review the existing models that deal with soil carbon and assess their strengths and weaknesses. The new national monitoring scheme developed by Black et al should be revisited and reviewed.¹⁶

b. Primary research

There is a need for funding for more soil carbon measurements on a regional-specific basis, to include the subsoil as well as the surface, together with a refinement of the methodology. We do not know what the saturation point for carbon sequestration is under different types of vegetation. We need to model this. Then we can have an idea of the different possible

¹⁵ *Land Use and Climate Change group report to Welsh Assembly Government*, March 2010

¹⁶ Black, H., Bellamy, P., Creamer, R., Elston, D., Emmett, B., Frogbrook, Z., Hudson, G., Jordan, C., Lark, M., Lilly, A., Marchant, B., Plum, S., Potts, J., Reynolds, B., Thompson, R., and Booth, P. 2008. *Design and operation of a UK soil monitoring network*. Contract Report. Environmental Agency. ISBN 978-1-84432-936-6
<http://wales.gov.uk/topics/environmentcountryside/farmingandcountryside/farming/landuseclimatechange/group/?lang=en>

sequestration trajectories to 2020 and beyond. We need also to know more about the relationship between sequestration and soil water content.

We need to know more about the potential for sequestering carbon in the subsoil – that is, below cultivation depth.

We need more research on carbon-nitrogen interactions – on the relationship between soil carbon sequestration and nitrogen emissions both from organic and inorganic fertilisers.

We need to explore key questions regarding the relationship with woodlands, as highlighted above. Some of these questions include: does more reactive nitrogen in the ecosystem result in more carbon fixation and if so under what conditions does this occur? What other limiting factors are in play when it doesn't occur? Also under what conditions does woodland result in greater emissions of nitrous oxide?

We need to consider the scope for applying soil carbon measurements into life cycle analysis, taking into account issues of leakage and permanence.

We know very little about the impacts of grazing, and of different grazing practices on soil carbon sequestration. This is a priority for further research. We also need to know more about the knock-on effects of taking animals off grasslands and putting grasslands either to biomass production or allowing them to regenerate naturally.

We need to know more about the relationship between soil carbon management practices and different aspects biodiversity, including microbial, plant-related and so forth.

We need to know more about trees and how they can contribute to carbon sequestration – which trees, in what circumstances, taking into account the overall goal of food security.

We need to make sure that we understand better the relationship between carbon storage and land use change (for example, that measures to increase soil carbon do not have perverse land use impacts elsewhere) particularly in relation to the issues of permanence and leakage.

Knowing more about carbon especially in upland grazing systems is very important since we have so much of that type of land. We need to know more about the carbon implications of converting: arable to grassland; grassland to trees and vice versa, within a food security context.

We need to undertake more research into the potential afforded by perennial crops.

We do not properly understand trophic interactions (the interactions between grazing animals, above-ground insects and animals, plants and soil organisms, from worms and beetles to bacteria and fungi) and their relationship with carbon storage. There are likely to be important links in this system that change with the type of farming practice adopted, but these are not well researched and understood. More research is needed in order to manage farming systems better.

We need more primary research on biochar – this is in fact taking place, through the work programme of the UK Biochar Research Centre.¹⁷

We need more research into the impacts of rotational systems and mixed farming systems on soil carbon (and sustainability in general).

¹⁷ <http://www.geos.ed.ac.uk/sccs/biochar>

We need to know more about the potential of coastal regions in acting as soil carbon sinks and about the scope for restoring carbon rich habitats. Flood management strategies could include consideration of carbon retention and sequestration.

c. Policy research

We need to develop simple ways of communicating effective approaches to farmers, as well as to develop systems of incentivising action. Farmers are asking what they can do – we need to be able to answer them.

We need to explore ways of incorporating soil carbon sequestration activities into existing environmental stewardship schemes, taking into account issues of permanence and leakage.

We need to think about what we want in the next round of CAP reform. There is scope for incorporating soil carbon measures both in Pillar 2 and possibly in Pillar 1. We also need to learn from other European countries who may be ahead of us.

We need to undertake more work into approaches for building soil carbon sequestration in developing world countries, and to engage the international development community in these activities.

4. Possible role of the FCRN

The role of the FCRN is to broker discussion between policy makers and the research community to ensure that the necessary research is funded and undertaken. The FCRN will use the findings from the discussion that have arisen from this workshop to take this forward.

5. Participants

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