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Soil Carbon Sequestration and Organic Farming:

An overview of current evidence

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EXECUTIVE SUMMARY

With the recent interest in the potential for agriculture to capture atmospheric CO_2, through the accumulation of soil carbon, measurements in this area have been viewed as increasingly important. Promoting soil health and encouraging the development of soil organic matter have always been central tenets of the organic approach, and the contribution of organic systems to this area has therefore been of considerable interest. This paper attempts to review the current evidence in this area, presenting the following main points:

1. Organic cropping systems have considerable potential for increasing soil carbon, through the incorporation of fertility building grass-clover leys and use of livestock manures within diverse crop rotations, when compared with specialist (eg: monoculture) cropping systems;
2. The exact amount of carbon that can be sequestered through organic management of cropping systems is still uncertain, due to the disparity in assessment methods, and farming/land-use systems;
3. The difference between the wide range of organic and conventional farm types is not yet clear, partly because of the current difficulty in defining these systems and their individual characteristics;
4. Organic management of grassland is unlikely to increase soil carbon levels over those from conventional management, but the reliance on legumes and biological instead of industrial nitrogen fixation will still have a positive impact on climate change mitigation through reduced fossil energy use and related carbon dioxide and nitrous oxide emissions;
5. Future work is needed in this area to (a) determine the common characteristics of organic and conventional farming systems in terms of carbon stocks and flows (b) ascertain the contribution of grass/clover leys in terms of providing soil carbon and (c) take full account of external factors such as previous land use.

Current/ongoing work may help us to answer some of these questions, until this work is completed however the authors conclude that while organic farming can certainly contribute to soil carbon sequestration within cropping systems, the precise quantification of this area remains uncertain. This should not prevent the implementation of organic farming as one of the methods for atmospheric CO_2 reduction in the United Kingdom.

1. INTRODUCTION

The potential for agricultural systems to sequester atmospheric carbon dioxide (CO_2) through building levels of soil carbon, has been an area of considerable interest in recent years, in view of greenhouse gas reduction targets set through such policy measures as annex B of the Kyoto Protocol and the Climate Change Act (2008). This briefing paper will review the evidence for organic cropping systems' contribution to soil carbon levels, referring to previous work in this area. This paper has focussed on arable cropping systems; grassland systems have not been considered in detail, despite being the most common type of organically managed land in the UK. This is because the differences in soil carbon levels between organic and conventionally managed grassland have not been found to be significant in the few studies that have examined this area (eg: Armstrong Brown et al. 2000). Despite this, many other benefits of organic grassland management are well-accepted, for example with regard to biodiversity and soil-quality (eg: Shepherd et al. 2003) however, a detailed consideration of these additional benefits is beyond the scope of this study.

Organic farming practices have been developed with an emphasis on the soil as a living ecosystem, building on the principle that the health of soil, plant, animal and man is one and indivisible (Balfour, 1943). With this as a central concept for the development of the organic principles (IFOAM, 2009) and standards, the improvement in the soil's characteristics is a central tenet of the organic approach. Indeed it is well documented that improved soil quality can be observed on organically managed farms, compared to conventional (Lampkin, 1990, European Union, 2007a). Organic farming systems also encourage a healthier soil ecosystem through provision of nutrients and energy, which are derived from organic matter (Watson et al. 2002) instead of from mineral fertiliser. Maintaining levels of soil organic matter (SOM) is therefore of paramount importance for the long-term productivity and sustainability of an organic system.

The causes of the improved soil characteristics observed on organic farms are claimed to be to the suite of practices used by organic farmers, including the utilisation of a fertility building ley in the rotation and the use of organic manures and composts, as opposed to mineral fertilisers (Azeez, 2009). Both of these measures have been shown to have a positive effect on levels of SOM in a number of studies (Hepperly et al. 2006; Clement & Williams 1967; Grace et al. 1995, cited by Watson et al. 2002) and are important aspects of ensuring the overall health of an organic farming system (Watson et al. 2002). Moreover, organic farming is the only system that has a legal definition setting out the importance of these practices, and in some cases official requirements are set out for their inclusion (Soil Association, 2008, European Union, 2007b).

Based on the high levels of adoption of these principles and farm practices on organic farms, it is possible to state that organic farming has the potential for increasing the carbon content of soils (Azeez, 2009). However the exact quantification of benefits in terms of amount of soil organic carbon (SOC) accumulation, compared to conventional, is still an area of debate. Part of the issue is related to the methodological challenge of comparing the two farming systems, and defining the characteristics that underlie them, it is also claimed by some that increases in soil organic matter derived from organic management might be undercut by organic systems' reliance on tillage (Macilwain, 2004) whereas others state that the increased residual biomass from the ley component of the rotation offsets any losses that will occur (Marriot and Wander, 2006). What is clear from existing studies is that the diversity in the approaches used to carry out assessments within this area makes comparisons difficult. This briefing paper will review the current state-of-the-art and will attempt to identify the common messages coming out of this developing area of research.

2. RESULTS AND DISCUSSION

A number of attempts have been made to quantify this area in recent years, a total of six studies from Northern Europe and two from the USA have been summarised in Table 1 below. The studies focus on the relative performance of arable systems, only two studies also consider pasture dominated farms in addition to arable (ie: Pulleman et al. 2003 and Armstrong Brown et al. 2000).

Table 1: Comparative studies illustrating difference between organically and conventionally managed soils

Author and country of study	Type of trial and farming systems covered	Farming systems covered	length of trial (years)	Average Sample depth	Organic vs conv. % difference	Manure/organic fertiliser added*	significant **	Additional authors' notes included in the papers reviewed
Pulleman et al. 2003 Netherlands	Farm systems trial: conv.; org; perm pasture	Arable and perm. pasture	70	20cm	**+60%**	External inputs	Y at 5%	Both organic and conventional soils were severley compacted. As a result favourable effects asscociated with a higher SOM content in the organic system, in terms of soil macrostructure, were not observed
Armstrong Brown et al. 2000 England	Soil assessment of 30 org and conv. farm pairs	Horticulture	1	31cm	**+57%**	Unknown	trend	Increased FYM use on organic and slightly reduced tillage intensity
		Arable	1	31cm	**+34%**	Unknown	trend	
		Pasture	1	30cm	**-12%**	Unknown	n/s	
Kirchmann et al. 2007 Sweden	3 Field plots: conv.; org; control	Arable	19	30cm	**+31%**	External inputs	not given	Concentrations of SOC decreased in both systems, however rate of decrease was less for organic. No discernable difference when factoring in manure input to organic system
Friedel et al. 2000 Germany	Soil assessment: 2 plots: org. and conv.	Arable	21	25cm	**+11%**	Unknown	n/s	No significant differences between organic and conventional
Hepperly et al. 2006 USA	3 field plots: manure based org; legume based org; conv.	Arable - manure	26	15-30cm	**+25%**	Proportionate to yield	Y at 5%	Annual soil C increase of 981 and 574 kg/ha in organic manure and organic legume systems
		Arable - legume	26	15-30cm	**+20%**	Proportionate to yield	Y at 5%	
Raupp and Oltmanns, 2006 Germany	3 field plots: inorganic fertiliser; org manure; biodynamic manure	Arable	25	not given	**+19%**	Proportionate to yield	n/s	Soil organic C acccumulation did not occur under conv. or organic management. However higher rates of FYM on organic plots preserved higher SOC contents, whereas increasing amounts of inorganic fertiliser had no effect.
Marriot and Wander, 2006 USA	Farming systems trial: legume and manure; legume based; conv.	Arable	10 avg	0-25cm	**+14%**	External inputs	Y at 5%	Organic systems retain more SOC than conventional systems, despite intensive cultivations
Fließbach et al. 2007. DOK trial Switzerland	4 Field-plots: organic; biodynamic; conv. mineral fertiliser; unfertilised control	Arable - biodynamic	21	0-20cm	**+6%**	Proportionate to yield	not given	SOM decreased across all systems, however extent of loss was less in organic. Biological parameters of soil quality were also enhanced in organic farming systems
		Arable - organic	21	0-20cm	**+2%**	Proportionate to yield	not given	

*After Leifeld and Fuhrer (2010) ** n/s = not significant

It is clear from Table 1 that although in many cases organic farming results in higher levels or lower reductions of soil carbon, in only three of the studies is this difference stated to be statistically significant. Moreover, the range of effects on soil carbon resulting from organic management differs widely across the studies. The authors' comments also illustrate that the differences between the two farming systems are not always clear with regard to manure use. This disparity was highlighted by Leifeld and Fuhrer (2010) in their review of 32 peer-reviewed publications, looking at the issue of soil carbon and organic farming. Although their analysis revealed a 2.2% average annual increase in soil carbon content (SOC) within organic systems, in 74% of cases the amount of organic fertiliser (ie: manure and/or compost) in the organic systems exceeded that applied in the conventional. Leifeld and Fuhrer (2010) state that a truly unbiased comparison of management types should be based on similar organic fertiliser (eg: manure) rates, and crop rotations incorporating fertility building leys, as neither of these aspects are unique to organic farming. Whilst this is true, an experiment of this kind would lose the significance of the farming system. In reality organic farmers are more likely to be using a fertility building period in their crop rotation and manures than non-organic; European organic regulations dictate that the fertility of the soil should be maintained and increased through crop rotations including legumes, and through application of manures or other organic material (European Union, 2007b). Certification bodies, such as the Soil Association in the UK, also require certified producers to include a balance of cropping and grass/clover leys in their crop rotations (Soil Association, 2008). Moreover, Marriott and Wander (2006) found that legume based and manure and legume based organic management resulted in similar levels of soil organic matter increase in their study, suggesting that the ley period alone is more significant than additions of manure, in terms of building soil carbon.

It is also clear that in practice conventional farms are increasingly abandoning the use of manure in favour of mineral fertilisers (Niggli et al. 2009). It therefore seems unlikely that in reality conventional farms will be adding similar amounts of manure/compost as organic, and a useful comparison cannot ignore this. Azeez (2009) also highlights that the use of external organic matter sources is fairly limited in the organic sector in the UK, with most of the farms sourcing manure from livestock managed as part of an integrated mixed farming system. Azeez (2009) also highlights that organic farms appear to provide much better soil carbon stabilisation conditions than non-organic holdings, suggesting that even if organic farms are importing carbon from outside of the system, the favourable soil conditions will help to ensure that this carbon is retained in the soil.

The results from the DOK trial in Switzerland (Fließbach et al. 2007) also found that when similar levels of manure inputs (but in a variety of methods) are applied to conventional, organic and biodynamic plots, the biodynamic system showed the highest SOC levels, with 6-7% higher organic carbon levels than either organic and conventional, although total levels of organic carbon decreased in all systems. The reason given for this was that the biodynamic system makes use of composted manure, which has a higher level of stable organic matter than fresh farmyard manure. There was a small difference between the standard organic and conventional plots (12% and 13% higher than 'no fertiliser' plots respectively) however this is likely to be a result of the crop rotation used on the conventional farm – the DOK trial used a similar rotation, incorporating a 2-3 year ley, within both the organic and conventional systems. If this element were removed from the conventional system, a larger difference between organic and conventional soil organic matter levels would be expected.

The DOK trial also found that in terms of biological soil quality (eg: microbial biomass) the differences between the conventional and organic/biodynamic systems were much greater (over 40% higher on organic plots), the effect of pesticides and mineral fertiliser can therefore not be excluded from an assessment of this nature (Fließbach et al. 2007) or underestimated in terms of effect in terms of improving soil nutrient availability and crop quality (Mondini et al. 1999). On a similar note it has been suggested that an increased quality of residue in the organic system may stimulate a greater amount of humus formation (Friedel et al. 2000, Raupp and Oltmanns, 2006) and that this can help to create more resilient systems, in terms of adapting to the effects of climate change (Niggli et al. 2007) through encouraging better soil structure, water retention and nutrient supply to crops (Azeez, 2009).

Based on the results from some of the trials described above, Freibauer et al. (2004) illustrated the higher degree of soil carbon sequestration that could result from a greater uptake of organic farming in the EU. Smith et al. (2005) built on this work through an exploration of the potential for C enhancement through a range of farming practices within the then EU-15, suggesting that organic farming was the only carbon sequestrating practice that has increased over the 10 year period from 1990 to 2000. The estimate of sequestration potential within these studies ranged from 0 to 0.5 tonnes of C per ha, however both studies highlighted the considerable uncertainty in this area; particularly as a result of the effects on N_2O emissions from manure management and leaching. This is an important consideration in terms of the greenhouse gas balance of the farming system, as N_2O is 298 times worse than CO_2 in terms of its Global Warming Potential (GWP).

Uncertainty in this area is also partly a result of the wide variability in assessment methods, as may be seen from Table 1 where the soil sample depth varies greatly across the studies. The heterogeneous nature of soils, land uses and management practices also leads to assumptions being made when making comparisons between systems (Dawson and Smith, 2007) and inconsistency in results can easily be due to effects other than those of current management. The short time-scale of many of the measurements carried out means that in many cases only a ‘snapshot view’ is presented and the previous land-use may still be having an effect at the time of the trial (Leifeld and Fuhrer, 2010). For example Sanderman and Baldock (2010) found that fewer than 50% of the studies in major reviews of SOC stocks have followed a change in management through time, focussing instead on the implementation effects from an established farming system.

The focus of existing studies on the effects from arable farming, also limits the applicability of the debate to pasture dominated or mixed farms, although Armstrong Brown et al. (2000) found that differences between conventional and organic management were limited to arable cropping areas - there was no significant difference in the topsoil characteristics of organic and conventional permanent pasture within their trial. Another issue with the comparison of data between studies is that many tend to focus on a wider range of issues other than only soil carbon sequestration, eg: crop yields and quality (Raupp and Oltmanns, 2006). Moreover, most have been completed outside of the UK and in somewhat specific locations, for example, the Pulleman et al. (2003) study was completed on a single biodynamic farm in Polder region of the Netherlands. The wider application of results which lack specificity to UK climate, soil types and land-use is therefore called into question.

Defining the characteristics of organic and conventional farming systems when making comparisons is also currently difficult, for instance there may be significant variation in the definition of organic farming standards between countries and certification bodies, and variation in the length of time since conversion to organic management (Hole et al. 2005). There are also issues with defining factors that are determined by the organic and conventional management of the system (eg: manure application rates) and these distinctions are not always clear cut when making comparisons (Lampkin and Padel, 1994). There are also considerable uncertainties concerning the scale of observation in studies. Many of the studies in Table 1 are carried out at the field scale, but these may be inappropriate if there are emergent properties at the whole-farm level. Some of the benefits of an organic approach, which focuses on holistic management and the positive interaction between a range of factors, may also be missed in a study that looks at only one element such as soil carbon. There are currently few studies which take account of these interactions; however work on this area is currently ongoing through the development of sustainability assessment methods and benchmarking tools (Lampkin et al. 2006).

Ongoing work by the Research Institute of Organic Agriculture, Switzerland (FiBL) is also seeking to address some of the above issues through the completion of a meta analysis which is collating over 45 studies which have looked at the issue of soil carbon in organic farming. Initial results are encouraging for organic producers in that recorded levels of SOC in topsoil are at a level of 1.47%, compared to 1.16% on conventional farms/plots. Preliminary results have also illustrated higher C stocks on organic farms (37.4 t C/ha on compared to 26.7 t C/ha on conventional) (Gattinger, 2010 – in preparation). This work has focussed on studies that have not been using imported organic matter (ie: for 70% of studies any organic fertilisers are sourced from livestock within the farm) and these first results would therefore suggest that a 'self-contained' organic farm can sequester more carbon than a conventional system. The final outcome of this work is expected in the spring of 2011.

3. CONCLUSION

Reviewing the above papers it is clear that the level of soil carbon sequestration resulting from organic cropping systems is still an area of great uncertainty. A better understanding of how legumes, in particular clover grass leys, and manures differ in terms of their contribution to soil carbon would help increase our understanding of this area (Marriott and Wander, 2006). Until this level of understanding is reached it would appear that while organic cropping systems can increase soil carbon levels, due to the common characteristics inherent to these systems (such as higher likelihood of rotations containing clover grass leys, integration of crops and livestock and less reliance on external inputs) it is not yet clear by how much individual farm types differ (eg: arable, horticulture, dairy). It is also clear that although plot based trials reviewed in this paper may be unbiased in terms of the variables applied, they potentially ignore the integration of livestock or the fundamental differences between organic and conventional farming practice in reality (eg: the lack of a fertility building phase on most conventional farms).

It should also be remembered that in terms of climate change mitigation, although agriculture in temperate zones can make a contribution in terms of C sequestration, this is likely to be a small percentage of global anthropogenic CO_2 carbon (less than 1%) and more significant reductions can be achieved by addressing the issue of fossil fuel burning and deforestation in the tropics (Smith et al. 1997). Moreover, recent work has highlighted that initial estimates of the potential CO_2 reductions that can be achieved through management of croplands has been overestimated, and that limited uptake of measures such as organic farming and zero-tillage limits their potential for climate change mitigation (Smith et al. 2005). Despite this, there is a small role for carbon sequestration in agricultural systems, and organic farming methods can clearly contribute to this (Freibaeur et al. 2004) however it is likely that within this context both specific farming systems (such as organic) and farm practices (such as the use of manure) have a role to play.

This review has focussed on the issue of soil carbon, and the potential for organic farming systems to contribute to sequestration of atmospheric CO_2. However, it should be remembered that in terms of climate change mitigation, there are many other ways in which organic farming can contribute. For instance, lower rates of fossil energy use have been identified on organic farms, compared to conventional (Cormack and Metcalfe, 2000; Lampkin, 2007). Organic systems can also reduce N_2O emissions, through avoidance of mineral fertiliser manufacture (Niggli et al. 2009). There is also great potential for organic farming to contribute to coping with climate change effects in the near future, through higher diversity, robust varieties and better soil quality (Niggli, 2010). Quantification of such benefits will take time and considerable investment in research; however it is already clear that organic farming will have a significant role to play in creating a lower greenhouse gas agriculture in the UK.

4. REFERENCES

Armstrong Brown, S.M., Cook, H.F. and Lee, H.C. 2000. Topsoil characteristics from a paired farm survey of organic versus conventional farming in southern England. *Biological Agriculture & Horticulture*. 18:37-54.

Azeez, G. 2009. Soil Carbon and Organic Farming. [online]. www.soilassociation.org. Accessed 12/12/10.

Balfour, E.B. 1943. *The Living Soil*. New York: Universe books.

Clement, C.R. and Williams, T.E. 1967. Leys and soil organic matter II. The accumulation of nitrogen in soils under different leys. *Journal of Agricultural Science*. 59: 133-138.

Cormack, W., Metcalfe., P. 2000. Energy Use in Organic Farming Systems. Defra Final Project Report. [online]. www.orgprints.org/8169. Accessed 01/03/09.

Dawson, J.J.C. & Smith, P. 2007. Carbon losses from soil and its consequences for land management. *Science of the Total Environment*. 382: 165-190.

European Union. 2007a. Organic Farming: Good Practice for Soil Quality Preservation. [online]. http://ec.europa.eu. Accessed 12/12/10.

European Union. 2007b. Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91. [online]. http://eur-lex.europa.eu. Accessed 12/10/09.

Fließbach, A., Oberholzer, H.R., Gunst, L., Mäder, P. 2007. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. *Agriculture, Ecosystems & Environment*. 118: 273-284.

Freibauer, A., Rounsevell, M.D.A., Smith, P., Verhagen, J. 2004. Carbon sequestration in the agricultural soils of Europe. *Geoderma*. 122: 1-23.

Friedel, J.K., 2000. The effect of farming system on labile fractions of organic matter in calcari-epileptic regosols. *Journal of Plant Nutrition and Soil Science*. 163: 41–45.

Gattinger, A. 2010 in preparation. Carbon levels in agricultural soils under organic and non-organic management – a meta analysis. [online]. www.icrofs.org/pdf/2010_lca_workshop/andreas_gattinger.pdf. Accessed 9/12/10.

Grace, P., Oades, J.M., Keith, H., and Hancock, T.W. 1995. Trends in wheat yields and soil organic carbon in the Permanent Rotation Trial at the Waite Agricultural Institute, South Australia. *Australian Journal of Experimental Agriculture*. 35: 857-864.

Hepperly, P.R., Douds, D., and Seidel, R. 2006. The Rodale Institute Farming Systems Trial 1981 to 2005: long-term analysis of organic and conventional maize and soybean cropping systems. In: Raupp, J., Pekrun, C., Oltmanns, M. and Köpke, U. (Eds), Long-term Field Experiments in Organic Farming. International Society of Organic Agriculture Research (ISOFAR): Bonn, pp. 15-31.

Hole, D.G, Perkins, A.J, Wilson, J.D, Alexander I.H, Grice, P.V, Evans, A.D. 2005. Does organic farming benefit biodiversity? *Biological Conservation*. 122: 113-120

International Federation of Organic Agriculture Movements – IFOAM. 2010. The Principles of Organic Agriculture. [online]. www.ifoam.org. Accessed 16/12/10.

Kirchmann, H., Bergström, L., Kätterer, T., Mattsson, L., and Gesslein, S. 2007. Comparison of Long-Term Organic and Conventional Crop–Livestock Systems on a Previously Nutrient-Depleted Soil in Sweden. *Agronomy Journal*. 99:960-972.

Lampkin, N. 1990. *Organic Farming*. Ipswich: Farming Press.

Lampkin, N. 2007. Organic farming's contribution to climate change and agricultural sustainability. Paper presented at Welsh Organic Farming Conference, Builth Wells, October 2007.

Lampkin, N., Fowler, S.M., Jackson, A., Jeffreys, I., Lobley, M., Measures, M., Padel, S., Reed, M., Roderick, S, Woodward, L. 2006. *Sustainability assessment for organic farming – integrating financial, environmental, social and animal welfare benchmarking.* Aspects of Applied Biology, What will organic farming deliver? 79: 9-13. Warwick: Association of Applied Biologists.

Lampkin, N. and Padel, S. 1994. *The Economics of Organic Farming: An International Perspective*. Oxon: CAB International.

Leifeld, J. and Fuhrer, J. 2010. Organic Farming and Soil Carbon Sequestration: What Do We Really Know About the Benefits? *AMBIO: A Journal of the Human Environment*. 39: 585-599.

Macilwain, C. 2004. Is organic farming better for the environment? *Nature*. 428: 797-798.

Marriott, E.E. and Wander, M.M. 2006. Total and Labile Soil Organic Matter in Organic and Conventional Farming Systems. *Soil Science Society of America Journal*. 70: 950-959.

Mondini, C., Cantone, P., Marchiol, L., Franco, I., Figliolia, A., Leita, L. 1999. Relationship of available nutrients with organic matter and microbial biomass in MSW compost amended soil. In: Anac, D., Martin-Prevel, P. (Eds.), Improved Crop Quality by Nutrient Management. Springer: Netherlands, pp. 305-308.

Niggli, U., A. Fließbach, H. Schmid, and A. Kasterine. 2007. Organic Farming and Climate Change. Geneva: International Trade Center UNCTAD/WTO. [online]. www.ifoam.org. Accessed 9/12/10.

Niggli, U., Fließbach, A., Hepperly, P. and Scialabba, N. 2009. Low Greenhouse Gas Agriculture: Mitigation and Adaptation Potential of Sustainable Farming Systems. Rev. 2. [online]. http://www.ifr.ac.uk/waste/Reports/LowGreenhouseGasAgriculture.pdf. Accessed 17/12/10.

Niggli, U. 2010. Climate Change and Organic Farming. Presentation Given at International Federation of Organic Agriculture Movements (IFOAM) Climate Camp, 2010. [online]. www.organicandclimate.org. Accessed 17/12/10.

Pulleman, M., Jongmans, A., Marinissen, J. and Bouma, J. 2003. Effects of organic versus conventional arable farming on soil structure and organic matter dynamics in a marine loam in the Netherlands. *Soil Use and Management*. 19: 157-165.

Raupp, J., Oltmanns, M. 2006. Soil properties, crop yield and quality with farmyard manure with and without biodynamic preparations and with inorganic fertilizers. In: Raupp, J., Pekrun, C., Oltmanns, M. and Köpke, U. (Eds), Long-term Field Experiments in Organic Farming. International Society of Organic Agriculture Research (ISOFAR): Bonn, pp. 135-155.

Sanderman, J., and Baldock, J. 2010. Accounting for soil carbon sequestration in national inventories: a soil scientist's perspective. Environmental Research Letters. [online]. http://iopscience.iop.org/1748-9326/5/3/034003. Accessed 08/12/10.

Shepherd, M., Pearce, B., Cormack, B., Phillips, L., Cuttle, S., Bhogal, A., Costigan, P. and Unwin, R. 2003. An Assessment of the Environmental Impacts of Organic Farming. A review for Defra-funded project OF0405. [online]. http://orgprints.org/6784/2/OF0405_909_TRP.pdf. Accessed 14/02/11.

Smith, P., Andrén, O., Karlsson, T., Perälä, P., Regina, K., Rounsevell, M. & van Wesemael, B. 2005. Carbon sequestration potential in European croplands has been overestimated. *Global Change Biology*. 11: 2153-2163.

Smith, P., Powlson, D.S., Glendining, M.J. & Smith, J.U. 1997. Potential for carbon sequestration in European soils: preliminary estimates for five scenarios using results from long-term experiments. *Global Change Biology*. 3: 67-79.

Soil Association. 2008. *Soil Association Organic Standards*. Bristol: Soil Association.

Watson, C.A., Atkinson, D., Gosling, P., Jackson, L.R., Rayns, F.W. 2002. Managing soil fertility in organic farming systems. *Soil Use and Management*. 18: 239-247.