The effects of reduced tillage practices and organic material additions on the carbon content of arable soils

Summary Report for Defra Project SP0561

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1. Introduction

Both reduced tillage and the recycling of organic materials to land have been promoted as a means of increasing the storage of carbon in agricultural soils. For example, the recently published Stern report on the economics of climate change promoted reduced tillage as a means of enhancing the storage of carbon in agricultural soils. Stern (2006) cited the example of the Chicago Climate Exchange, where a minimum four-year commitment to continuous zero-tillage on enrolled areas was valued at $1-2 per acre per year (equivalent to approximately £1.25-£2.50/ha). Also, the 2006 UK Climate Change Programme included a policy commitment to "examine the scope and feasibility of a market based mechanism to facilitate trading of greenhouse gas reductions from agriculture, forestry and other land management sectors", which included looking at carbon storage in soils and forests as a potential abatement option. There are approximately 4.5 million ha of tillage land in England and Wales, so even small increases in soil organic carbon (SOC) storage per hectare of agricultural land could overall lead to important increases in carbon storage at a national level.

Changes in SOC are generally slow to occur and difficult to measure against the large background carbon content in arable soils in England and Wales (*c*.91 t/ha, assuming 28 g/kg SOC in the topsoil). After a change in management practice (e.g. the introduction of zero tillage or regular organic material additions) SOC will increase (or decrease) towards an equilibrium (after 100 years or more) that is characteristic of the soil type, land use and climate. Annual rates of SOC accumulation (or depletion) therefore change over time and gradually decline as the new equilibrium is approached, when they become zero. Typically, *c.*50% of the SOC accumulation achieved after 100 years of introducing a management change, occurs within the first 20 years. Maintaining SOC at the new equilibrium level is then dependent on continuing the new management practice indefinitely.

This report summarises results from a review (SP0561- main report) which aimed to determine the extent to which reduced tillage practices and organic material returns could increase the organic carbon content of arable soils under English and Welsh conditions[1].

2. Effect of reduced tillage practices on soil organic carbon

'Reduced tillage' is a term that is used to describe all non-plough based cultivation practices and has been suggested to increase SOC due to a reduction in soil disturbance and consequently the decomposition of organic matter (carbon). For the purposes of this report, the terms **'conventional tillage'** (i.e. ploughing to at least 20 cm), **'zero tillage'** (i.e. no cultivation) and **'reduced tillage'** (i.e. cultivation of the surface soil to a depth of no more than 15 cm) have been used. Approximately 50% of primary tillage practices in England and Wales in 2005 used mouldboard ploughing ('conventional tillage'), *c.*43% used reduced tillage (heavy discs, tines or powered cultivators) and *c.*7% used direct drilling/broadcasting ('zero tillage').

There have only been a limited number (six) of contrasting tillage studies in the UK. Taking an average of the SOC changes measured in these studies, our best estimate of the C storage potential of zero tillage under UK conditions is <u>310</u> kgC/ha/yr. This equates to *c.*0.34% of the typical carbon content of an arable soil in England and Wales (@ 91 t/ha). Reduced tillage was estimated to have half the C storage potential of zero tillage at <u>160</u> kgC/ha/yr. As outlined above, these estimated C storage potentials can only be regarded as

[1] Go to http://randd.defra.gov.uk/Document.aspx?Document=SP0561_6892_FRP.doc for SP0561-main report.

the *initial rate* of increase (up to *c*.20 years). Annual rates of SOC accumulation will decline (eventually to zero) as a new equilibrium is reached (after *c*.100 years). These estimates of potential C storage from zero and reduced tillage should also NOT be considered to be annually cumulative, as arable land in England and Wales is typically ploughed every 3 to 4 years to reduce the build-up in weeds, disease and soil compaction levels. It is arguable that much (if not most) of the stored C from reduced/zero tillage practices will subsequently be released as a result of the increased soil disturbance caused by periodic ploughing.

Reduced tillage has many benefits, besides protecting existing SOC levels and potentially increasing SOC; it can increase soil water infiltration rates and reduce water erosion, enhance soil water retention, and decrease production costs and fossil fuel (energy) consumption. For example, CO_2-C savings associated with reduced energy consumption have been estimated at 22 and 16 kg/ha/yr CO_2-C for zero and reduced tillage systems, respectively, compared with conventional tillage. However, zero tillage has also been shown to increase direct emissions of nitrous oxide (N_2O) by up to an equivalent of *c.*190 kg/ha/yr CO_2-C (compared with conventional tillage), due to an increase in topsoil wetness and/or reduced aeration as a result of less soil disturbance. Nitrous oxide is a powerful greenhouse gas with 310 times the global warming potential of CO_2, such that overall, increased N_2O emissions may completely offset the balance of greenhouse gas emissions compared with the amount of C potentially stored through changing from conventional to reduced/zero tillage practices. However, the evidence is not clear and further work is required to determine the effect of contrasting tillage systems on N_2O emissions, SOC storage and the overall balance of greenhouse gas emissions.

3. Effect of organic material additions on soil organic carbon

The recycling of organic materials to land provides a valuable source of nutrients and organic matter, and could potentially increase SOC levels. Currently, around 90 million tonnes of farm manures, 3-4 million tonnes of biosolids (treated sewage sludge) and 4 million tonnes of industrial 'wastes' are applied (on a fresh weight basis) annually to agricultural land in the UK.

There have been a number of long-term experiments (> 4 years) investigating the effect of various organic material additions on SOC, many of which have been summarised within the Global Change and Terrestrial Ecosystems Soil Organic Matter Network database (GCTE SOMNET). These, together with results from more recent experimental studies in the UK, were used to estimate potential increases in SOC following the addition of a range of organic materials (Table 1). The results are based on average changes in SOC measured at 8 farm manure study sites, 10 biosolids study sites, 4 green compost study sites and 8 straw incorporation study sites. There have been no UK studies measuring SOC changes following the application of paper crumble. Measurements of the proportion of recalcitrant[2] (lignin) and readily decomposable carbon within paper crumble suggest it would behave similarly to farm manures, so an identical C accumulation rate was assumed. As with reduced tillage, the estimates of potential SOC increases given in Table 1, should be regarded as the *initial* (*c*.20 years) rate of SOC increase.

It is debatable whether increases in SOC following the application of farm manures and soil incorporation of cereal straw can be considered genuine additional carbon storage (against a present day baseline), as nearly all of these materials are already applied to land. The exception being *c*.580,000 tonnes of poultry litter that are used for electricity generation.

[2] Recalcitrant organic carbon is characterised by a slow turnover rate (>100 years).

Similarly, only 1% of biosolids are presently landfilled (although historically greater amounts were landfilled). Only if the organic materials are diverted away from landfill, can the increased SOC be regarded as genuine additional carbon storage (against a recent/present day baseline). This is probably the case for compost and paper crumble applications, with *c*.480,000 tonnes of green compost and *c*.700,000 tonnes of paper crumble currently recycled to agricultural land. However, at current production and application rates they are only applied to relatively small areas of land (<50,000ha), although compost use on agricultural land is expected to increase at least 3 to 5-fold over the next decade.

Table 1. Potential increases in SOC following the application of a range of organic materials at 250 kg/ha total N

Organic material	Application rate (t/ha dry solids-ds)	Potential increase in SOC (kg/ha/yr/t ds)	Potential increase in SOC (kg/ha/yr)	% of SOC stocks in England & Wales[c]
Farm manures	10.5	60	630	0.69
Digested biosolids	8.3	180	1500	1.64
Green compost	23	60	1400	1.54
Paper crumble	30[a]	60[d]	1800[d]	1.98
Cereal straw	7.5[b]	50[b]	370	0.41

[a] Typical application rate of primary or secondary chemical/physically treated paper crumble = 75 t/ha fresh weight, supplying 150 kg/ha total N. [b]fresh weight of straw. [c]Assuming 28 g/kg SOC in the top 25 cm & a bulk density of 1.3 g/cm^3 (91tC/ha). [d]Average SOC increase per tonne dry solids applied assumed to be the same as for farm manures (which have a similar composition of carbon compounds).

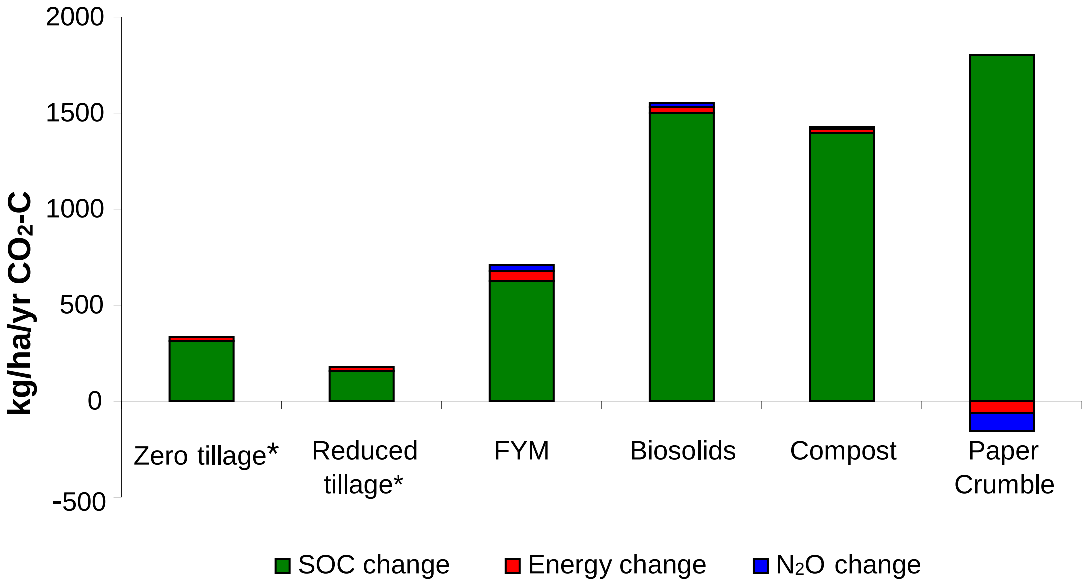
The application of organic materials to agricultural soils can, however, help to maintain (and enhance) *existing* SOC levels. Also, they help to improve soil structure and aggregate stability, which in turn can increase soil water retention and water infiltration rates (thereby reducing the risks of soil erosion) and improve plant nutrient uptake. Most organic materials that are applied to land also provide a valuable source of plant available nutrients, thereby reducing the need for inorganic fertilisers. This provides both cost and energy (fossil fuel) savings involved in manufacturing inorganic fertilisers (particularly N). Moreover, the application of organic materials can lead to environmental pollution due to N and P losses to water courses, as well as gaseous emissions of ammonia and N_2O to the atmosphere. The latter (N_2O emissions) are important as they have the potential to affect the overall balance of greenhouse gas emissions, from increased SOC storage, through applying organic materials to land. However, reductions in inorganic fertiliser N usage (and hence direct N_2O emissions from this source) offset most of these losses following organic material additions.

4. Net carbon storage potential of reduced tillage and organic material returns– relationship to other climate change mitigation options

The maximum CO_2-C ‘saving’ potential of zero/reduced tillage and organic material additions derived from this review are summarised in Figure 1. The application of biosolids, green compost and paper crumble offer the best opportunities for CO_2-C ‘savings’, with almost all of these due to increased SOC storage (rather than changes in energy use or N_2O emissions). However, as outlined above, only if the organic materials are diverted away from landfill, can the increased SOC be regarded as genuine additional carbon storage.

These management options are just some of those that have been proposed as potential measures for climate change mitigation within arable agriculture. It is probable that land-use change from for example, arable cropping to *permanent* willow/poplar biomass cropping, *permanent* grassland or woodland, offers the greatest potential for increased soil C storage and overall mitigation of greenhouse gas emissions from agricultural land, with estimated C storage/saving rates of over 1800 kg C/ha/yr. However, of equal importance is the preservation of existing SOC stocks, particularly by avoiding the ploughing out of existing permanent grasslands.

Figure 1. Maximum CO_2-C 'savings' from zero/reduced tillage and organic material additions to arable land.



*Tillage figures exclude any potential change in N_2O emissions

5. Conclusions

This review has shown that there is limited scope for additional soil carbon storage/ accumulation from zero/reduced tillage practices and organic material applications, over and above present day normal farm practice. Indeed, there are questions over the implications of such practices for nitrous oxide (N_2O) emissions and the overall balance of greenhouse gas emissions (expressed on a CO_2-C equivalent basis). SOC accumulation is finite and reversible, and SOC levels will only remain elevated if the practice is continued indefinitely. Only the application of biosolids (treated sewage sludge), compost and paper crumble appear to offer the same level of CO_2-C 'savings' that have been predicted for land-use change options (e.g. reversion of arable land to *permanent* grassland, woodland or willow/poplar biomass production). With the probable exceptions of compost and paper crumble applications (which are largely a result of recent diversions away from landfill), almost all of the other organic materials considered were already applied to land, so it is questionable whether this can be regarded as genuine additional carbon storage (against a recent/present day baseline). Probably of more importance, is the maintenance of existing SOC levels and the avoidance of ploughing out permanent grasslands.

The predominant justification for returning all organic materials to soil should therefore be for maintaining existing SOC levels, and completing natural nutrient and carbon cycles, not additional carbon storage for climate change mitigation *per se*. Similarly, should reduced tillage be encouraged, it should be for its protection of existing SOC levels and benefits to soil water retention and prevention of erosion, as well as reduced production costs and energy use, rather than for additional carbon storage *per se*.