

# FCRN Soil Carbon Workshop

## The potential for soil carbon sequestration, including the role of nitrogen

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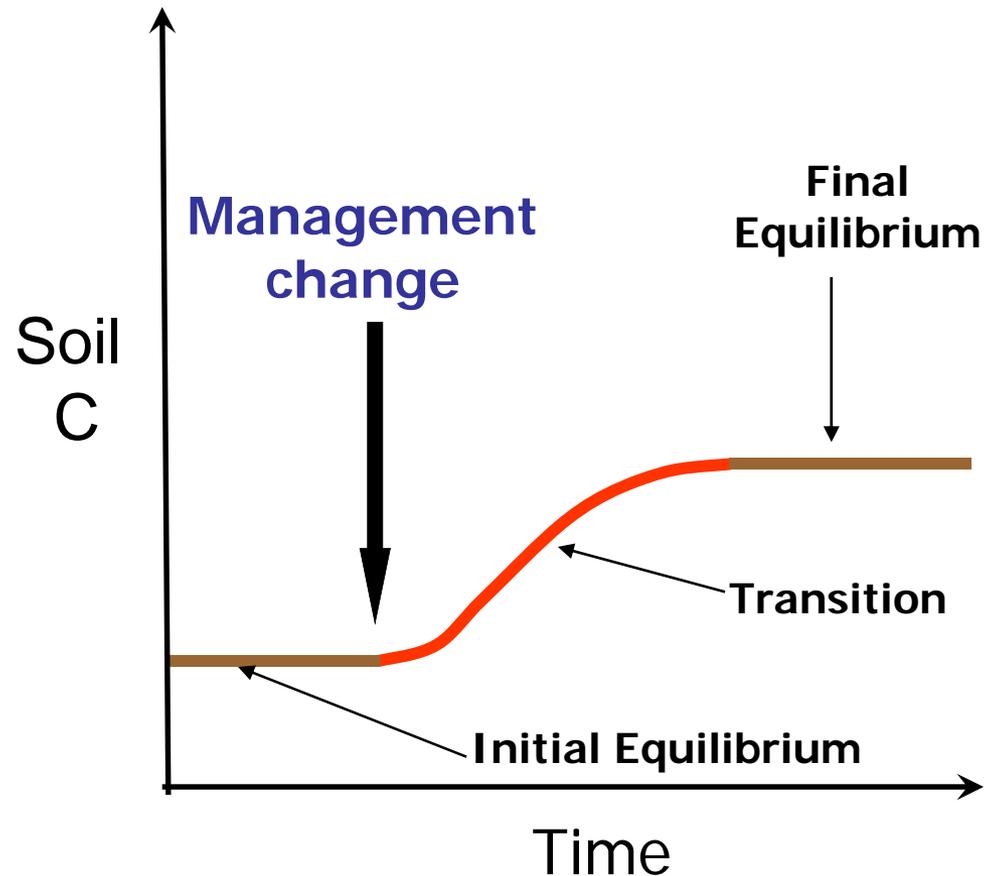


# Carbon sequestration

- Dictionary definition of sequestration: ‘to hold on to’.
- Using this definition, **any** increase in Soil Organic Carbon (SOC) could be called ‘sequestration’.
- But in the context of Climate Change (CC), ‘sequestration’ usually implies some **CC mitigation**.
- Must be a net transfer of C from atmosphere to land ..... **not just a movement between land C compartments**.

# Limitations to C sequestration in soil

- **Finite** – SOC moves towards new equilibrium value.
- **Reversible** – depends on continuing the new land management practice
- Potential **effects on  $N_2O$  and  $CH_4$**  – need full GHG budget



**But extra C good for soil quality**

# Does nitrogen impact on C sequestration?

(Scientific American, 8 January 2009)

Discussion began after the controversial findings of Magnani (University of Bologna) and his team:

for every 1 kilogram of nitrogen (N) deposited from the atmosphere, 400 kg of carbon would be absorbed by forests.

If this were true, it would imply a global CO<sub>2</sub> sequestration in forest ecosystems due to N deposition near 2.0 Pg yr<sup>-1</sup>, being 30 % of the estimated 7.1 Pg C yr<sup>-1</sup> release by human activities.

The disagreement among the scientists is about how large is this contribution of N with respect to C sequestration.

Research at forest monitoring plots found that, for 1 kilogram of N deposited from the atmosphere, approximately 30-70 kg of C was sequestered in both forests and forest soils. Multiplying this range by an estimated global N deposition, this corresponds to an annual global C sink of 0.15 - 0.35 Pg, being 2-4 % of the estimated release by human activities and c 10% Magnani's estimate.

(De Vries *et al.*, 2008. *Forest Ecology and Management* **258**, 1814-1823.)

Quinn *et al.*, 2010, *Nature Geoscience* (last Thursday): 0.31 Pg C yr<sup>-1</sup>.

1 Pg = 10<sup>15</sup> g = 1,000,000,000 tonnes

N fertiliser increases SOC in temperate regions, but only when crop residues were returned, and not in tropical regions.

(Alvarez, 2005, *Soil Use & Management* **21**, 38-52.)

A decrease in N in air pollution over the next 25 years will result in a 27% decrease in C sequestered by forests in The Netherlands but an increase in some biodiversity.

(Wamelink et al., 2009. *Forest Ecology and Management*, **258**, 1774-1779.)

So there is an important synergy between C and N, but the impact on C sequestration is not large.

# Land management changes that could sequester C

- Crop residues
- Manures and Biosolids
- N fertilizers
- Plough to Min-Till (reduced tillage)
- Arable to forest
- Biochar
- Subsoil C?

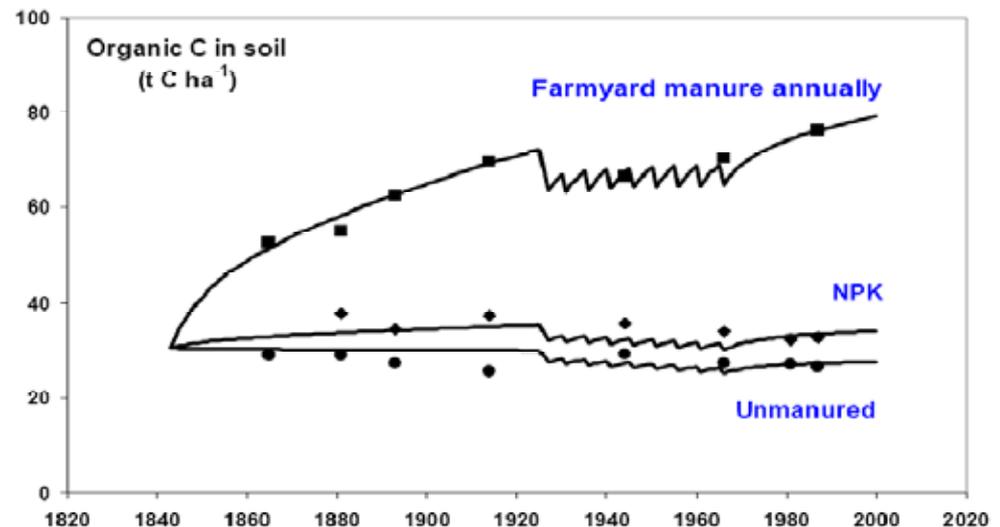
# Crop residues

- 22% crop residue C is retained by soil
- But, if the residue would have been applied to land anyway and not burned, even on another farm, there is no C sequestration



# Manures and Biosolids

- Manure increases SOC: c 23% of the FYM C and 56% digested sludge C is retained in the topsoil
- But most manure applied to land anyway
- So probably no C sequestration, merely a movement of C from one field to another



# Manures and Biosolids

Risk of increased direct and indirect (from emitted and re-deposited  $\text{NH}_3$  and leached  $\text{NO}_3^-$ )  $\text{N}_2\text{O}$  emissions if applied N is not effectively utilised.



But evidence suggests direct losses small:

Average loss, as  $\text{N}_2\text{O}$ , of N applied in slurry to:

- Arable land 0.8%
- Grassland 0.3%

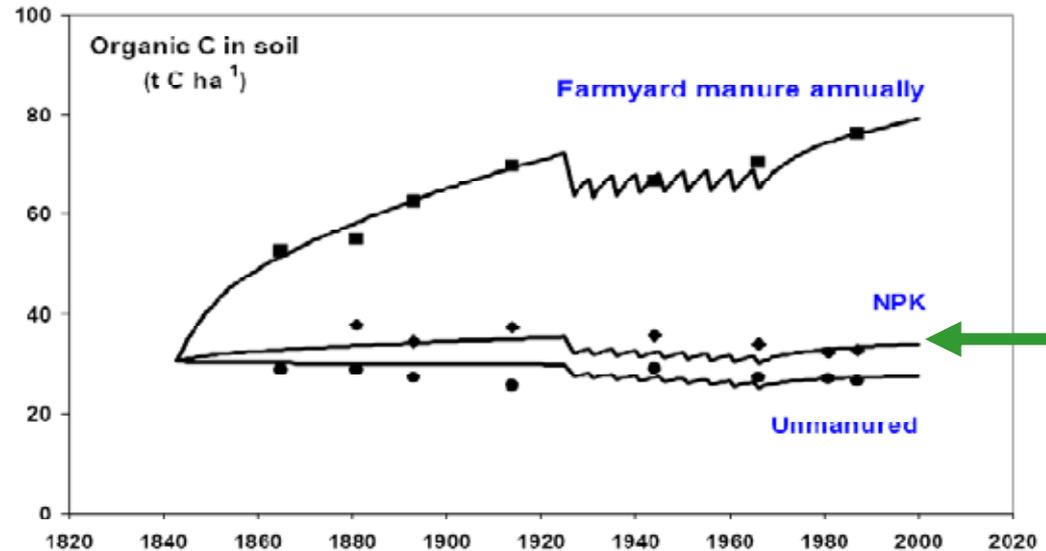
Smaller loss from grassland thought to be because of larger uptake of N over a longer period by grass.

# Alternative uses of crop residues, manures or biosolids

- Incinerate straw for generation of electricity and heat.
- Anaerobic digestion of biosolids to produce biogas (methane); residue can add some nutrients to soil.

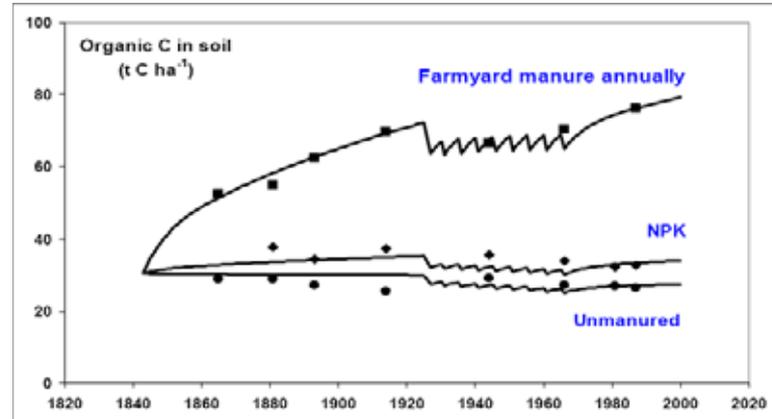
**Both deliver greater CC mitigation than adding the materials to soil, through displacement of fossil fuel, but few benefits for soil quality.**

# Fertilizers



- Fertilizers (especially N) increase crop yields and returns of organic C in roots and residues to soil.
- A genuine transfer of C from atmosphere to land and an increase in food production.

# Fertilizers



- SOC on Broadbalk increased by on average **0.2 t CO<sub>2</sub> ha<sup>-1</sup> yr<sup>-1</sup>** for only 50 years, then at equilibrium.
- But there are large GHG emissions (CO<sub>2</sub> + N<sub>2</sub>O) from manufacturing N fertilizer, **at least 0.7 t CO<sub>2</sub> equiv. ha<sup>-1</sup> yr<sup>-1</sup>**, as well as the losses of N<sub>2</sub>O ( and nitrate and ammonia) after application.

# Plough



# Min till



- Many claims of C sequestration after a change to min till from ploughing.
- Some evidence of overall SOC (surface) accumulation, but not large.
- Most experiments show increase in N<sub>2</sub>O emissions.

# Overall benefits of No- / Min-till

- Possibly small SOC accumulation:
  - Stern Report estimates  $0.14 \text{ t C ha}^{-1} \text{ yr}^{-1}$  sequestered under No-till.
  - Recent estimate from UK experiments 0.31 (+/- 0.18)  $\text{t C ha}^{-1} \text{ yr}^{-1}$  sequestered under No-till; perhaps half this for Min-till.
  - But in UK Min-tilled land often ploughed every few years.
- Other benefits of No- / Min-till:
  - Concentration of organic matter near surface: good for soil structure, seedling emergence water infiltration and retention.

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Powlson & Jenkinson (1981). *J. Agric. Sci.* **97**: 713-721.

Baker *et al* (2007). *Agric. Ecosys. Env.* **118**: 1-5.

# Net GWP effects of change to Min-Till

- Extra 3 kg N<sub>2</sub>O ha<sup>-1</sup> yr<sup>-1</sup> could offset sequestration of 0.3 t C ha<sup>-1</sup> yr<sup>-1</sup> \* .  
(Rothamsted experiments found an extra net emission of 4 kg N<sub>2</sub>O ha<sup>-1</sup> yr<sup>-1</sup> from min-tilled land compared to ploughed land)
- No consistent pattern but reviews suggest N<sub>2</sub>O emissions usually increase under Min-Till
- NB. Most agricultural systems produce a net increase in GWP

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\* Johnson *et al.* (2007) *Env. Poll.* **150**: 107-124.

# Arable



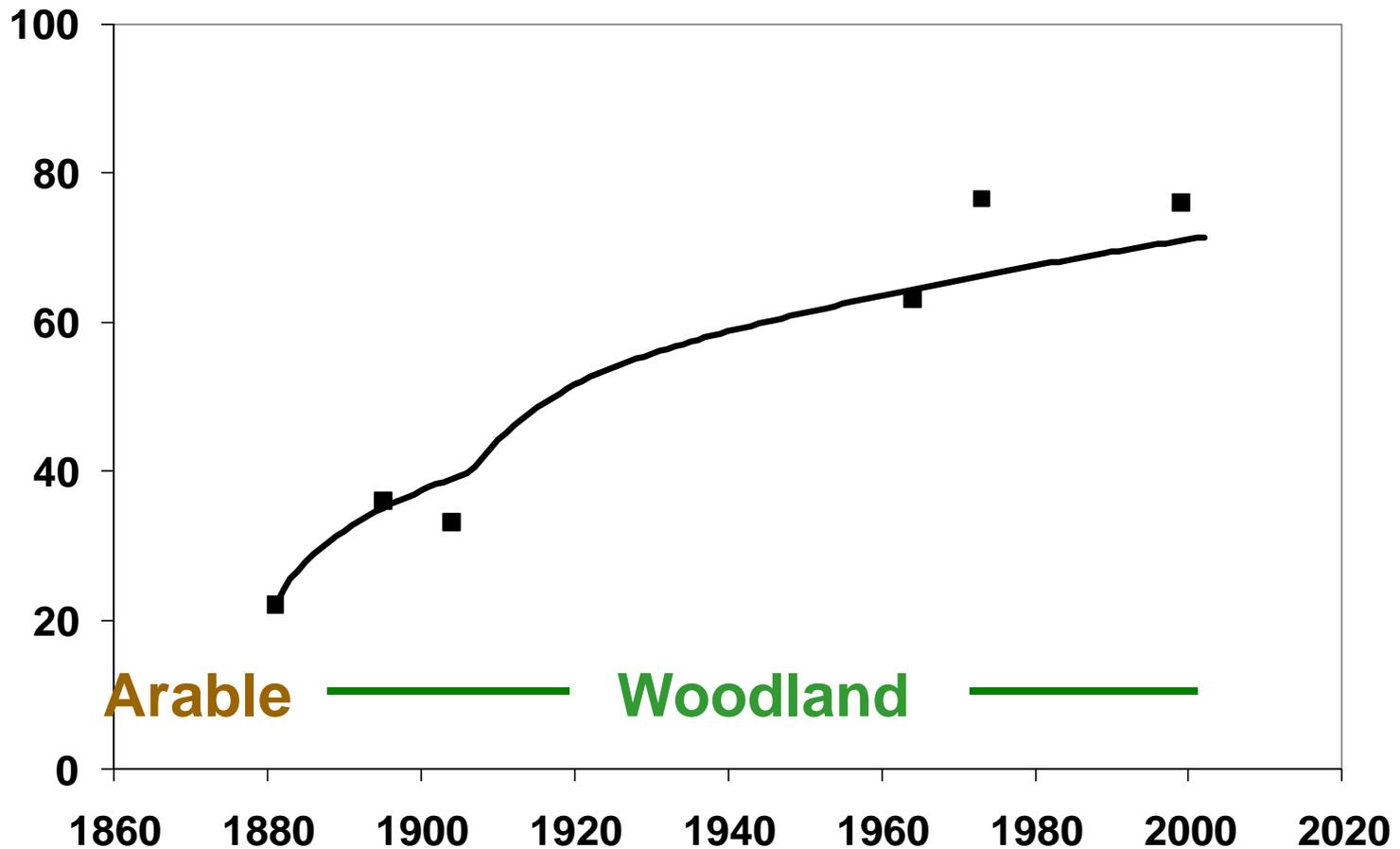
# Forest



- Genuine C sequestration.
- But must be certain that removal of land from crop production *at one location on the planet* does not cause land clearance (deforestation, ploughing grassland, wetland drainage) elsewhere.
- Other GHGs: expect increase in CH<sub>4</sub> oxidation and reduction in N<sub>2</sub>O emission provided N deposition low.

# Change in soil carbon after the conversion of arable land to woodland by natural regeneration on the Broadbalk Experiment

Data points and model (Roth-C 26.3; solid line) prediction



# Biochar

## A handful of carbon

Locking carbon up in soil makes more sense than storing it in plants and trees that eventually decompose, argues Johannes Lehmann. Can this idea work on a large scale?



To meet the challenges of global climate change, greenhouse-gas emissions must be reduced. Emissions from fossil fuels are the largest contributor to the anthropogenic greenhouse effect, so a reduction in fossil-energy use is a clear priority. Yet, because some emissions will be unavoidable, a responsible strategy also means actively withdrawing carbon dioxide from the atmosphere: carbon sequestration faces multi-factor challenges: the net withdrawal of carbon must be long term and substantial, it must be accountable and must have a rapid or large-scale leakage. One technology that can meet these needs is biochar sequestration. When with biomass production, it is a technology that reduces emissions sequesters carbon. In my view, an attractive target for energy inclusion in the global carbon

An existing approach to sequester carbon dioxide in soil organic matter (see indeed, methods for sequestration through afforestation accepted as inadvisable in the Kyoto Protocol. But taken a step further biomass without any low-temperature pyrolysis, grasses or crop twofold higher carbon



### Black is the new green

In 1879, the explorer Herbert Smith engaged the wisdom of farmers in Montana with later of the Amazon, convincing everything from the millions of tons of biochar. The biochar is a product of a process that has been used for many years, and is a by-product of a process that has been used for many years. The biochar is a product of a process that has been used for many years, and is a by-product of a process that has been used for many years.

Let's start with the idea of stable carbon sequestration. The idea of stable carbon sequestration is to store carbon in a form that is stable for a long time. This is done by using a process that has been used for many years, and is a by-product of a process that has been used for many years.

of the Amazon into the twenty-first century world of carbon sequestration and biochar. They want to follow what the green revolution did for the developing world: plants with a black revolution on the world's soils. They are looking for a way to store carbon in a form that is stable for a long time. This is done by using a process that has been used for many years, and is a by-product of a process that has been used for many years.

The soil scientists, ecologists, geographers, agronomists, and soil biologists who study soil are now agreeing that the Amazonian dark soils, terra preta do Indio, were made by the first human agricultural societies, who were much more numerous than currently supposed. The dark patches correspond to the

biochar or 'black soil' was produced from energy with normal (or in America) and production from biomass or crop residue. Thousands of millions of acres are covered with more than 100 years old biochar. The largest patches are found in the Amazon basin, the largest patches are found in the Amazon basin, the largest patches are found in the Amazon basin. The largest patches are found in the Amazon basin, the largest patches are found in the Amazon basin.

## ENHANCING SOIL PRODUCTIVITY WITH CHAR

By Gillian Triggs, managing editor

A new research on a sustainable method that could enhance food production is known as char, a product of biomass. The technology has been identified by scientists from South America as a sustainable agricultural technology. The byproduct of a new biomass...

SA, Inc., a wholly owned subsidiary of Energy Systems Corporation, a Canadian company known in the industry as Pymatech. This technology has been identified by scientists from South America as a sustainable agricultural technology. The byproduct of a new biomass...

applied, but the third had 2.5 times of char applied per acre and the third had 5 tons. Pymatech also has shown about seven additional tons of biochar to research outside the U.S. Results of the trials are expected later in the year.

"Not only does Pymatech's biochar have the potential to raise high-yield crops of corn studies 20 percent, but also to reduce the need for fertilizers and pesticides, which would have far-reaching benefits," says Crimley. Researchers have demonstrated some of the char does in the soil. "First, char reduces the nutrient retention in the soil. Secondly, it increases the balance of beneficial microorganisms in the soil, and it has good retention of nutrients and nitrogen compounds. This

biochar also means that biochar is a more environmentally friendly way to store carbon dioxide in the soil. The char allows for a lot more carbon to be sequestered than the soil alone. It will provide benefits to the agricultural world and yield benefits to the world. The char allows for a lot more carbon to be sequestered than the soil alone. It will provide benefits to the agricultural world and yield benefits to the world.

biochar is a by-product of the fast pyrolysis process. Pymatech and other companies around the world are researching its properties to determine its benefits for agriculture. Biochar and other biomass products are being used to improve their production capacity, improve carbon and improve yield.

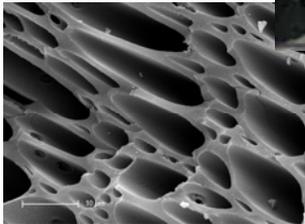
To determine how much char could and should be applied to soil and how much of a difference it can make in yield, Pymatech has partnered with Harsco BioEnergy LLC in Waterloo, Iowa, to conduct field trials. Dr. Jim Crimley at Harsco BioEnergy is conducting the trials. Crimley's field trials involve three crops of corn to be planted 800 feet long and 30 feet wide. The top had no char



© Pymatech Inc.

# Biochar: sources and attributes

- Organic material burned/pyrolysed slowly under limited oxygen
  - Bi-product of bioenergy (pyrolysis of biofuel crops, straw, or wastes)
  - In natural ecosystems from fire
- Highly stable, porous, active surfaces





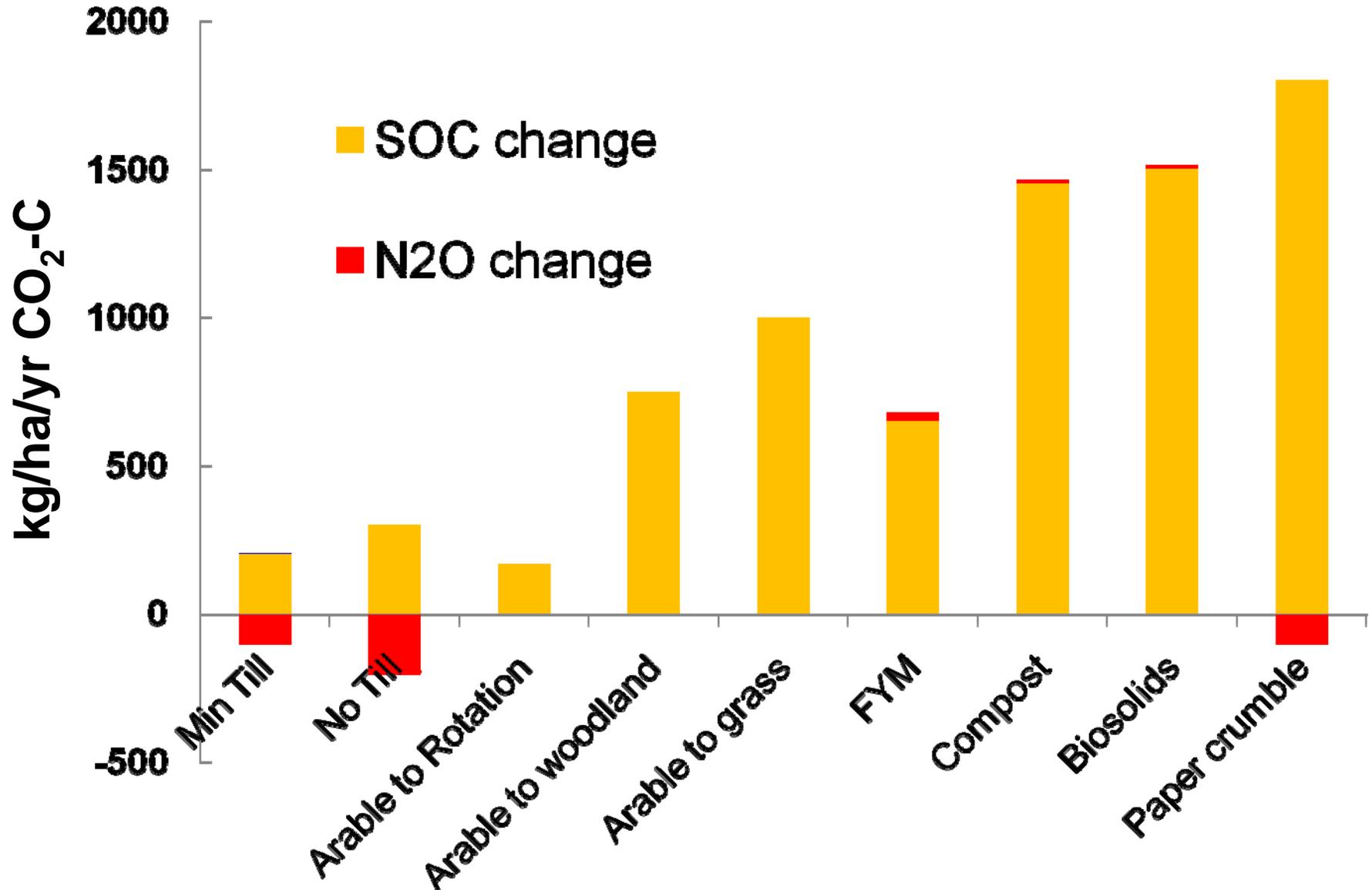
# Biochar: proposed effects on soil

- Near-permanent increase in soil C
- Greater stabilisation of other soil C
- Suppression of greenhouse gas emission
- Enhanced fertiliser-use efficiency
- Improvement in soil physical properties
- Enhanced crop performance
- Increased soil biodiversity

**Philosopher's Stone of Climate Change!**

# C sequestration summary:

## Maximum CO<sub>2</sub>-C 'savings' from land management options 'Year 1'



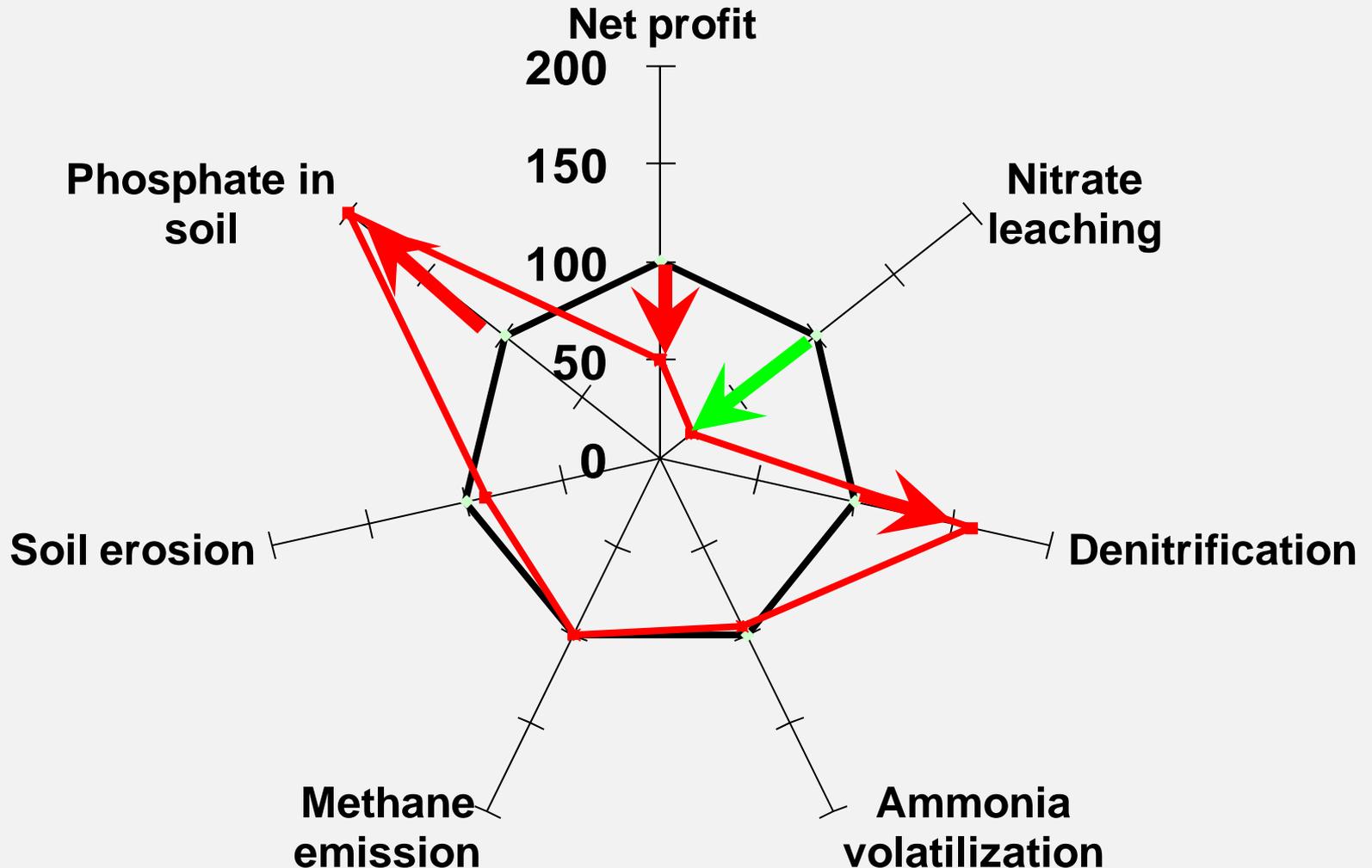
# Risks of increased C loss: land clearance for agriculture

- Immediate loss of C from vegetation and longer-term loss of SOC on 1 - 100 year timescale.
- BUT – some conversion is inevitable if we are to feed 6.5 billion people (9 billion soon).
- We currently depend for food supply on past clearances (e.g. Europe, Asia, N. America) – no global understanding then!
- A need for rational decision making on land use – not just short-term profit.
- Integrate global scale thinking (and national scale actions) on food security *and* climate change.

# **We need integrated solutions**

- Avoid impacts of 'single-issue' politics and policy
- LCA for integrated solutions

# Possible effect of changing farm practice to minimise nitrate leaching



# Conclusions

- Not all increases in SOC genuinely mitigate CC.
- Incorporation of organic ‘wastes’ or crop residues does not usually mitigate CC:
  - but benefits for soil quality and functioning;
  - greater CC mitigation from using biosolids and residues for bioenergy production.
- Large GHG emissions from N fertiliser manufacture outweigh any climate change benefit from increased SOC from increased crop residue returns.
- Min-till gives small increases in SOC and other benefits for soil.
- Conversion of arable land to forest or grass *is* genuine sequestration, but limited opportunities for this.

# Conclusions

- Too much emphasis on soil C sequestration risks less attention to major climate change threats:
  - Land clearance for agriculture (food or biofuels)
  - Other deforestation
  - Wetland drainage
- Priorities:
  - good land stewardship including increased efficiency of N use, reduced tillage, maintaining 'green' cover
  - **integrated solutions**

# Acknowledgements

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