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Biological carbon sequestration must and can be a win-win approach

An editorial comment

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What concentrations of atmospheric carbon dioxide should we not exceed, what is a safe level? The opinions necessarily diverge. But the stakes are high and probably we are well advised to shoot for a lower value (Schneider 2009) since dangerous climate change and irreversible consequences have graduated from a possibility to a near certainty (Solomon et al. 2009). If 350 ppm should be our target (Hansen et al. 2008), it is clear that we have to actively withdraw carbon dioxide from the atmosphere, not only reduce emissions from fossil fuels. The same is still true for less ambitious targets.

But we should not delude ourselves; the reverse argument is equally true. Even the most ambitious sequestration method or package of methods will not buy us out of the need for serious efforts to reduce greenhouse gas emissions from energy generation. We must use energy more efficiently, and we must substitute fossil energy with renewable energy at a much larger scale than is presently established. The work on sequestration options should not divert funds from these efforts.

Biocarbon approaches appear to deliver the most immediate options for carbon sequestration—options that can be implemented in the near future. Ornstein et al. (2009) propose a rather drastic but theoretically effective way of using photosynthesis to draw down atmosphere carbon dioxide: large-scale afforestation of the World's largest deserts through irrigation with desalinized sea water.

Afforestation of the Sahara desert and the Australian outback may be an extremely worrying proposition for most, and correctly so. There surely are many hurdles to success with such an approach that begin with implementation and end with permanence of the forests that may succumb to logging, forest fires or pest infestation. Fires may lead to massive and rapid evasion of carbon dioxide as seen for the 1997 fires of forests and especially peatland in Indonesia (Page et al. 2002). Bark beetle infestation is currently leading to wide-spread mortality in pine forests in some areas such as western North America (Negrón et al. 2008). However, some feel

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that risks from interventions of the type that Ornstein et al. are proposing, pale at the dawn of catastrophic climate change. These arguments have merit, too. Once polar ice disappears, likely associated with ice sheets slipping into the oceans, currently low-lying areas may become uninhabitable. Many of such areas are now home to hundreds of millions of people. What is worse?

It may be argued that an intervention such as the one proposed by Ornstein et al. need not be a one-shot deal. Rather, it may involve critical local evaluation of the sustainability of afforestation, and be linked to monitoring of its full environmental and social impacts without allowing loop holes. If the sustainability criteria are not met, then projects must be abandoned at any juncture of implementation. However, one might question whether weaving sustainability criteria into large-scale mitigation efforts can really reduce the risk of unintended consequences if linked to the construction of large and costly infrastructure (in this case desalinization plants).

Another concern for interventions such as the proposed afforestation is that one region would carry the responsibility to save the rest of the world from climate disaster. Is that fair? Not, if it is a burden. Ornstein et al. make the valid case that timber and potentially other products generate economic opportunities for local populations that could make it worth while and provide advantages when participating in climate mitigation. But this is a discussion that only the local population can lead. And there are the obvious and well-known challenges that revenues may actually not reach local populations, but be largely distributed among implementing agencies that provide no local return. Converting the Sahara desert into a forest surely comes with profound changes in life style, customs, biodiversity, or regional climate among probably many others.

But why should we employ carbon sequestration that creates liabilities at all? If we have to stash away large amounts of carbon to create temporary relief in our emission balance, then it must come at no extra burden to the environment and people. Or can we take it a step further and even create environmental and social value beyond climate change mitigation? That would be a strategic approach because the global impact of any sequestration technology relies on scaling to a level that delivers large storage. While the individual project may provide the desired carbon dioxide withdrawal, it is necessarily uncertain how many projects of any given sequestration approach can be realized on a global level. If, however, carbon sequestration comes with an environmental benefit—whether it delivers a large or only a small global carbon dioxide withdrawal from the atmosphere—societal investments will be rewarded under any outcome. A classic win–win situation.

Carbon sequestration in agriculture, for example, is typically linked to sustainability outcomes, no matter whether it scales to a significant or less significant tool in mitigating global warming. Increasing soil organic carbon is a good idea in any situation to generate or maintain healthy soils (Lal 2004). It will benefit the farm economy of those farmers who sequester the carbon, and anyone can participate without a regional bias. Conservation agriculture can be practiced anywhere in the world and tuned to local needs and abilities. Admittedly, drylands have lower net primary productivity, and therefore lower amounts per unit area to barter with. But all the more important is the judicious handling of biomass carbon to promote sustainability in such areas.

How feasible is carbon sequestration in agriculture? The jury on carbon sequestration through reduced or no-tillage is still out (Baker et al. 2007). Any carbon accrual through reduced tillage is certainly dependent on the soil type, crop and climate.

A full assessment of all greenhouse gas emissions during its life cycle may in some cases show an offset of the soil carbon accrual by emissions such as through N_2O emissions or increased nitrogen fertilizer needs (Li et al. 2005). This is precisely the argument flagged for carbon sequestration by way of manure additions to soils that may actually result in greater N_2O emissions from soils (Schlesinger 1999). Biochar production by pyrolysis and application to soil (Lehmann 2007) can deliver net life cycle emission reductions and carbon sequestration under a range of scenarios (Gaunt and Lehmann 2008). However, forest clearing for biochar production does not deliver net life cycle emission reductions with acceptable payback time, and dedicated biomass plantations are unlikely to be profitable. If crop land under any scheme is converted to land use that only delivers carbon sequestration, the delivered emission reductions may be cancelled by emissions generated through land-use conversion from natural vegetation into crop land at a different location (Searchinger et al. 2008). However, this does not have to always be the case and net sequestration can be achieved when options are evaluated carefully.

The challenge for most approaches to agricultural and specifically soil carbon sequestration clearly is the distributed nature of the sequestration and the fragmented and highly variable activities and ecosystem responses. This does not only make verification of net emission reductions laborious, but also poses significant hurdles to implementation in a carbon abatement scheme. For example, the precise amount of carbon accrual to be traded depends on many factors such as what soil management was present before the change in practice, what are the soil type and climate, what practice is implemented and so on. Also, biochar systems deliver vastly different sequestration and emission reductions depending on the baseline conditions, the pyrolysis unit, biomass types and cropping system. Avoided emissions from biochar conversion of green waste (using slow pyrolysis bioenergy production with the capacity of 2 t h^{-1}) may be as high as 3.8 t CO_2e t^{-1} dry feedstock, in comparison to wheat straw with only 1.1 t CO_2e t^{-1} (Gaunt and Cowie 2009). If biochar is integrated into a horticultural production system, emission reductions in the order of 0.7–2.6 t CO_2e ha^{-1} may be claimed, in comparison to only 0.1–0.5 t CO_2e ha^{-1} for wheat (Gaunt and Cowie 2009).

As variable as the magnitude of sequestration across different approaches are also their costs (Fig. 1). This is only in part a result of uncertainty but also of variability of the opportunities. Biological sequestration options certainly exist that come at an

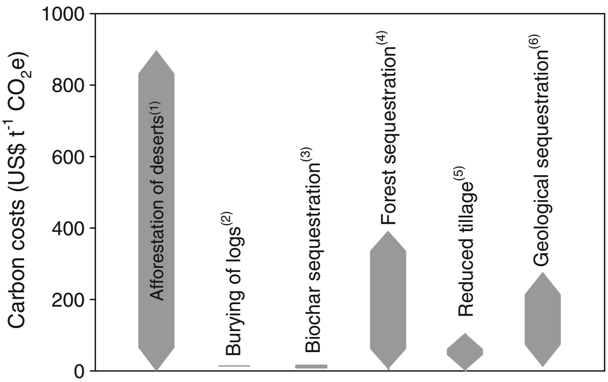

Fig. 1 Carbon costs of different biological sequestration approaches in comparison to geological sequestration, shown as a range (*upper and lower end of the bars*); *(1)* Ornstein et al. (2009), *(2)* Zeng (2008), *(3)* Gaunt and Lehmann (2008), *(4)* van Kooten et al. (2004), *(5)* Manley et al. (2004), *(6)* IPCC (2005)

affordable price. The question is how many of these opportunities can be tapped given the competition for carbon and its many uses beyond sequestration of carbon. Competing uses for biomass may also change over time. Today's biomass waste may be tomorrow's resource. A very important consideration is potential conflicts between food production versus other biomass uses, which deserves a separate discussion.

One potentially significant competitor for carbon sequestration in agricultural and forest soils is bioenergy. Whether we should use dead trees in old-growth forests as a substitute for coal as proposed by Ornstein (2009) or whether we should bury (Zeng 2008) or pyrolyse them (Lehmann 2007) for carbon sequestration, is an important strategic decision. Similar decisions have to be made between either maximizing crop residue return for soil carbon sequestration or withdrawing a safe amount for bioenergy generation. Offsetting fossil fuel emissions through bioenergy may sound attractive and would theoretically contribute to energy security with important ancillary geopolitical benefits. On the other hand, there are very few if any known alternatives to the withdrawal of atmospheric carbon dioxide through biological carbon sequestration that can be implemented in the near future. This begs the question whether we should use photosynthetically fixed organic carbon for sequestration and production of bioproducts rather than as a source of energy, and preferentially use renewable wind, water and solar energy to replace fossil fuels. Using biomass for energy generation, the photosynthetically fixed carbon rapidly returns to the atmosphere as carbon dioxide. Keeping as much of the organic carbon in bioproducts and soils would constitute a net withdrawal of carbon dioxide from the atmosphere that may be important for a comprehensive climate mitigation scheme. Pyrolysis with biochar sequestration is an option that delivers both withdrawal of atmospheric carbon dioxide and energy production (Lehmann 2007). Any bioenergy generation, however, adds complexity to the use of biomass, as the source of biomass is often distributed in agricultural and forest landscapes and the need for energy is not always co-located.

Could the distributed nature and variation of biomass opportunities become an asset when moving towards more sustainable land-use systems? Distributed and small-scale sequestration activities may ensure sustainability because they derive many of their returns from sources other than carbon sequestration or from a combination of sources. These could include enhancement of crop yields in an agricultural system, reduced off-site pollution by agrochemicals in lawns or recreational value in parks. If a certain sequestration technology financially or socially relies on multiple value streams that include not only climate mitigation but also other environmental benefits, the approach may prove sustainable in a distributed system.

Distributed carbon sequestration systems may show adaptability to changing economic as well as climate conditions, since they are locally controlled. Sustainability would be served if both environmental costs and benefits are born locally, thereby providing an incentive to minimize any detrimental environmental consequences. Any failure to design a successful approach will be a small-scale failure that can be resurrected locally, rather than a catastrophic failure that leaves entire regions in ecological disaster or does not achieve any climate benefits. Large-scale projects may seem straightforward to implement, but may be more difficult to control.

A valid question is whether carbon credits may ever be effective with such distributed carbon sequestration activities. The revenues created for small-scale agricultural systems may never reach individual farmers because they may generate only low returns even under high carbon prices. But they may be efficient in driving adoption programs for carbon sequestration that have multiple sustainability and livelihood benefits including crop productivity and security to name only a few. On the other hand, could we also reward these other sustainability outcomes of carbon sequestration in soils? Could we see that this is a worthwhile investment in addition to climate change mitigation? If we do, we should pay a premium for projects that sequester a sensible amount of carbon in agricultural soil rather than discount it. Stacking benefits and rewarding sustainability outcomes is in our collective interest. And while climate change mitigation may be our immediate incentive, restoring environmental quality as a whole should be the long-term achievement.

References

Baker JM, Ochsner TE, Venterea RT, Griffis TJ (2007) Tillage and soil carbon sequestration—what do we really know? Agric Ecosyst Environ 118:1–5

Gaunt J, Cowie A (2009) Biochar, greenhouse gas accounting and emissions trading. In: Lehmann J, Joseph S (eds) Biochar for environmental management: science and technology. Earthscan, London

Gaunt J, Lehmann J (2008) Energy balance and emissions associated with biochar sequestration and pyrolysis bioenergy production. Environ Sci Technol 42:4152–4158

Hansen J, Sato M, Kharecha P, Beerling D, Berner R, Masson-Delmotte V, Pagani M, Raymo M, Royer DL, Zachos JC (2008) Target atmospheric CO_2: where should humanity aim? The Open Atmosph Sci J 2:217–231

IPCC (2005) IPCC: special report: carbon dioxide capture and storage. Prepared by working group III of the intergovernmental panel on climate change, Cambridge University Press, Cambridge, UK

Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. Science 304:1623–1627

Lehmann J (2007) A handful of carbon. Nature 447:143–144

Li C, Frolking S, Butterbach-Bahl K (2005) Carbon sequestration in arable soils is likely to increase nitrous oxide emissions, offsetting reductions in climate radiative forcing. Clim Change 72: 321–338

Manley J, van Kooten GC, Moeltner K, Johnson DW (2004) Creating carbon offsets in agriculture through no-till cultivation: a meta-analysis of costs and carbon benefits. Clim Change 68:41–65

Negrón JF, Bentz BJ, Fettig CJ, Gillette N, Hansen EM, Hayes JL, Kelsey RG, Lundquist JE, Lynch AM, Progar RA, Seybold SJ (2008) Research in the Western United States: looking toward the future. J For 106:325–331

Ornstein L (2009) Replacing coal with wood: sustainable, eco-neutral, conservation harvest of natural tree-fall in olrd-growth forests: an editorial essay. Clim Change. doi:10.1007/s10584-009-9625-z

Ornstein L, Aleinov I, Rind D (2009) Irrigated afforestation of the Sahara and Australian outback to end global warming. Clim Change. doi:10.1007/s10584-009-9626-y

Page SE, Siegert F, Rieley JO, Boehm HDV, Jaya A, Limin S (2002) The amount of carbon released from peat and forest fires in Indonesia during 1997. Nature 420:61–65

Schlesinger W (1999) Carbon sequestration in soils. Science 284:2095

Schneider S (2009) The worst-case scenario. Nature 458:1104–1105

Searchinger T, Heimlich R, Houghton RA, Dong F, Elobeid A, Fabiosa J, Tokgoz S, Hayes D, Yu T-H (2008) Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. Science 319:1238–1240

Solomon S, Plattner GK, Knutti R, Friedlingstein P (2009) Irreversible climate change due to carbon dioxide emissions. PNAS 106:1704–1709

Van Kooten GC, Eagle AJ, Manley J, Smolak T (2004) How costly are carbon offsets? A meta-analysis of carbon forest sinks. Environ Sci Policy 7:239–251

Zeng N (2008) Carbon sequestration via wood burial. Carbon Balance Manage 3:1