WOODY BIOMASS ENERGY CROPS: POSSIBILITIES FOR PHYSICAL AND BIOLOGICAL CARBON SEQUESTRATION

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Summary: Bioenergy through short rotation forestry could hold potential for fossil fuel displacement mitigating enhanced climate change by using various combustion, carbon capture technologies, and sequestration technologies. Two routes, gasification and pyrolysis, show potential for enabling bioenergy to become carbon negative rather than carbon neutral. One further relatively unexplored route is biochar, a naturally occurring material that may offer a unique link between bioenergy and sequestration that is both simple and energy bearing.

INTRODUCTION

Human induced enhanced global warming is now accepted by the IPCC (2007) as unequivocal. Attributed to anthropogenic greenhouse gas (GHG's) emissions, the impending climatic changes associated with global warming are considered to be the greatest threat facing mankind today (IPCC, 2001). A primary GHG, carbon dioxide (CO_2) is an infrared absorbing gas that is known to be responsible for more than half of the total warming potential of all GHG's (IPCC, 2001) which places it firmly in focus within GHG reduction strategies (Jaber, 2002). Although the IPCC (2007) Fourth Assessment Working Group I Report on climate science identifies the primary source of the increased atmospheric concentration of CO_2 since the pre-industrial period to be fossil fuel use, land use change was also identified as providing another significant but smaller contribution (IPCC, 2007).

Bioenergy systems are seen as playing an important synergistic role in addressing the displacement of fossil fuels, a vital step in fighting climate change (Cook and Bayea, 2000). Generally assumed to be a CO_2-neutral energy carrier (not including processing and transport), bioenergy allows carbon (C) to be stored in plants, emitted through decomposition or combustion, and up-taken once again during new re-growth (Schlamadinger *et al.*, 1995; Schlamadinger and Marland, 1996). Grown in short rotation forestry (SRF) plantations, an intensive form of silviculture, crops of trees are grown and harvested on a rotational basis over short periods of time to provide a constant supply of bioenergy feedstock (Heller *et al.*, 2003).

Biomass can be co-fired in large and efficient coal-fired electrical power plants with minimal modifications and efficiency penalty (Cook and Beyea, 2000) although typically only 3-5% of the co-fired feedstock maybe biomass (Hallam *et al.*, 2001). Technically, the use of wood chips for co-fired electricity production in existing coal fired power plants is an option which could be realised relatively easily, requiring few engineering modifications (Hartmann and Kaltschmitt, 1999). However, the widespread incorporation of bioenergy into the energy matrix of a country will inevitably lead to land use change through crop establishment, leading to the changes in soil C associated afforestation and soil disturbance (Paul *et al.*, 2002).

Soil disturbance plays an important role in soil organic carbon (SOC) dynamics, often leading to SOC pool depletion and loss of organic matter (Lal, 2002). Representing the largest actively cycling carbon pool within the terrestrial system (Follett, 2001; Janzen, 2004) SOC is estimated to contain around 2000Gt C predominantly situated within the top metre of the soil profile (Janzen, 2004). With 75% of the total terrestrial C stored within soil, woody biomass production when applied globally could have a significant effect on the global C budget (Paul *et al.*, 2002). Although SRF bioenergy may provide a means of renewable and carbon neutral energy, the emissions caused by soil disturbance and crop establishment would need to be offset to retain neutrality. But can the bioenergy be used to mitigate the impact of afforestation and soil disturbance? Can woody biomass energy crops be used as a 'CO_2 pump' to link biological and physical sequestration technologies for enhanced climate change mitigation?

BIOENERGY AND 'TRADITIONAL' CARBON SEQUESTRATION

Gasification, the thermal decomposition of organic matter to gas, tar and char in a low oxygen environment (Sadaka *et al.*, 2002), is within medium to large-scale bioenergy or co-fired plants (Franco *et al.*, 2003). Biomass gasification generates CO_2 along with other waste gases, however if employed in conjunction with carbon dioxide recovery (CDR) and storage techniques (physical carbon sequestration), has the potential to substantially reduce CO_2 emissions (Möllersten *et al.*, 2003). CDR, a form of emissions scrubbing and end-of-pipe technology (Kraxner *et al.*, 2003) was originally developed by the fossil fuel industry, and can be readily applied to fossil fuel combustion, bioenergy or co-firing (IPCC, 2001).

Although CDR technology is commercially available, significant financial offsets such as enhanced oil recovery, hydrogen production, or C credits need to be employed to make the process commercially viable (IEA, 2002). Due to the economic implications, few commercial ventures specifically addressing large-scale physical carbon sequestration post CDR using fossil fuels or bioenergy exist (IEA, 2002). While C sequestration does not represent a 'permanent' solution to carbon emissions, it does provide an extended solution for an undisclosed period of time storage (Hutchinson *et al.*, 2007). Should CDR and physical C sequestration be commercially viable and applied to a bioenergy system, a traditionally C neutral fuel source would transcend into a carbon negative process (Kraxner *et al.*, 2003).

BIOENERGY AND BIOCHAR SEQUESTRATION

Pyrolysis, a thermochemical conversion process similar to gasification, can be optimised to produce high energy density pyrolytic oils, gas and biochar through the conversion of biomass into liquid (bio-oil or bio-crude), biochar and non-condensable gases such as acetic acid, acetone, and methanol (Dembiraş, 2000). Pyrolysis heats the feedstock in the absence of air to produce high-energy fuels with high fuel-to-feed ratios at lower temperature than gasification. The most efficient process for biomass conversion, pyrolysis is capable of a 95.5% fuel-to-feed efficiency, allowing competition with non-renewable fossil fuels (Dembiraş, 2000). The yield of biochar being dependent on carbonisation temperature, can increase from 25.6% at 800°C to 66.5% at 300°C, increasing the fixed carbon from 55.79% to 93.15% (Ogawa *et al.*, 2006).

Formed as a result of incomplete combustion, charred materials such as biochar are ubiquitous in many terrestrial environments and illustrate unique physical and chemical properties (Forbes *et al.*, 2006). A generally porous material, biochar retains water, breathes well, and has a great potential for improving the permeability of soil (Kadota and Niimi, 2004). Having adhesion properties, biochar also prevents the leaching of fertiliser ingredients, and can significantly increase plant growth and crop yields (Kadota and Niimi, 2004). As naturally occurring derivative of forest fires, biochar (also known as black carbon, charcoal, biochar, and char) is expected to be relatively inert for extended periods due to its aromatic structure (Forbes *et al.*, 2006; Ogawa *et al*. 2006). Already recognised as a soil improving material in Japan by the Ministry of Agriculture, Forestry and Fisheries (Ogawa, 1998), biochar plays a significant role in the soil C pool and is becoming of increasing interest as a potential C sequestration tool (Hamer *et al.*, 2004; Forbes *et al.*, 2006). However, currently biochar has yet to be proved for its stability in soil, and as such cannot as yet be regarded as a carbon sink (Ogawa *et al.*, 2006).

INVESTIGATING BIOCHAR STABILITY IN SOIL

To investigate the stability of biochar in soil, three contrasting soil types were chosen for use within the study: Manawatu fine sandy loam (harvested from 40° 23′ 30″ S 175° 37′ 54″ E); Tokomaru silt loam (harvested from 40° 23′ 54 S 175° 36′ 49 E) and, Egmont black silt loam (harvested from 39° 49′ 01″ S 174° 56′ 35″ E). Harvested from the top 20cm of the soil profile, the field capacity, field moisture, and the C and Nitrogen (N) percentage content of each soil types was determined.

A sieved homogenised sample of each soil type, with all organic debris, stones and pebbles removed was divided into four sub-samples of 135g equivalent oven dry weight. Each sub-sample was then placed into a beaker in an air-tight, septum fitted, preserving jar of a known headspace with a test tube holding 10ml of distilled water for atmospheric moisture level maintenance. The sealed jars, or incubation chambers, were then placed on a tray and covered with thick polythene to create a darkened microcosm system and maintained within a 20°C ± 1°C temperature-controlled laboratory for the entire duration of the experiment. Respiration levels were monitored for elevation, instigated through soil disturbance during sample preparation. Once a plateau had been reached, biochar was added to each sub-sample to increase the C equivalent of the soil dry mass by 4.8% for each soil type. The soil incubations were then adjusted to -10 kPa using distilled water (monitored and maintained throughout the study). Four replicate controls were monitored for each soil type.

The atmospheric CO_2 was measured periodically by extracting 1ml atmospheric samples using a calibrated glass-syringe with gas-tight valve. By injecting the sample into the gas calibrated CO_2 Analyser the atmospheric C percentage was determined. Post analysis, the atmosphere of each incubation chamber was then flushed with ambient air and re-sealed.

Post biochar treatment analyses showed lower accumulated mean C flux (mg) (Figure 1) in the Manawatu soil ($B = 0.202$, $p = 0.046$) but significantly lower levels in the Egmont soil ($B = -0.552$, $p < 0.001$). No statistically significant difference was found between the Tokomaru control and the amended Tokomaru soil incubations. However, all soil types showed a sequestering trend to varying degrees (Figure 2).

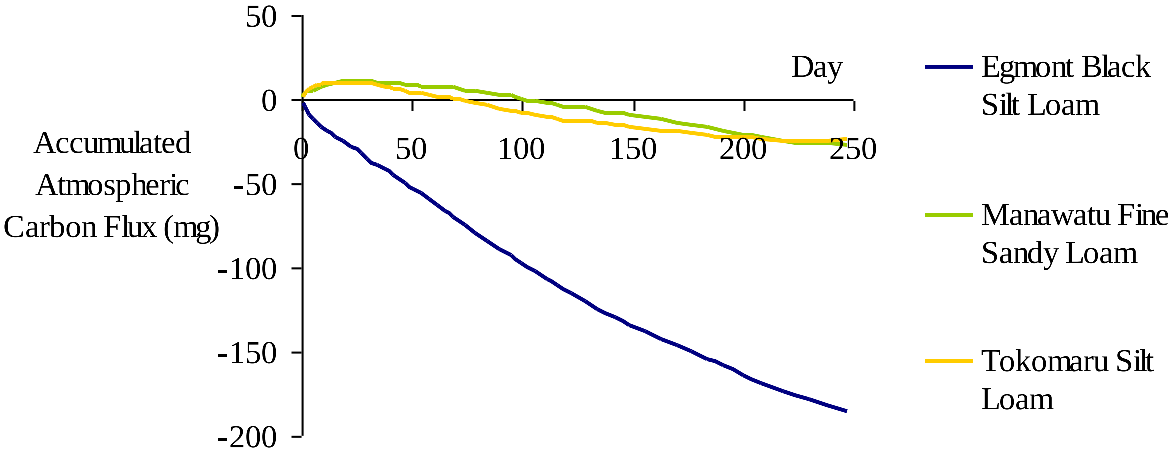

Figure 1. Accumulated (cumulative) mean carbon flux (mg) per soil type when amended with biochar.

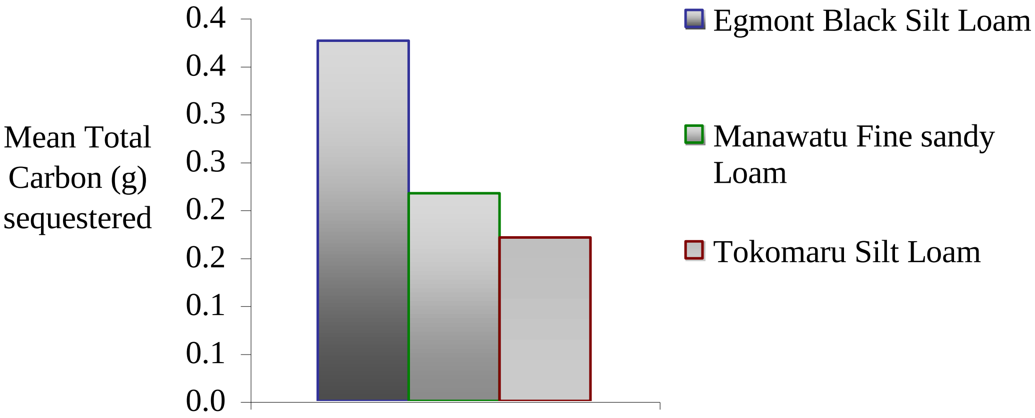

Figure 2. Mean net carbon sequestration (g) after basal soil respiration, background atmospheric carbon (CO_2) levels, and carbon additions through conditioner application have been accounted for per soil type.

DISCUSSION AND CONCLUDING REMARKS

Soil respiration is one of the primary fluxes between soils and the atmosphere (Bowden *et al.*, 2004). Relatively small changes in soil respiration may dramatically alter CO_2 flux, atmospheric concentrations and soil C sequestration rates (Bowden *et al.*, 2004). By monitoring soil respiration (CO_2) over time within incubation chambers and comparing the results of amended and unamended soils, the effects of biochar application may be isolated and determined.

It is interesting to note that although a proportional amount of carbon was added to each soil type via the addition of biochar, significantly different sequestration rates were observed. To increase the soils by 4.8% of the carbon equivalent of the soil dry mass, the Manawatu and Egmont soil both received 0.28g, while the Tokomaru soil received 0.21g. However, the Egmont soil sequestered 42% more C than the Manawatu soil. The Tokomaru soil sequestering 78% of the C held in the Manawatu soil. Hence, a clear conclusion can be drawn that the soil respiration response to biochar additions varies significantly between soil type, although the reason for this is as yet unknown.

Observing soil respiration in biochar amended soil suggests further trials should be conducted to estimate sequestration potential in reference to soil type. The study suggests that biochar does have potential for sequestration within soil. However, its potential under SRF, its ability to promote root growth and the effect on crop yield is yet to be determined. Hence, the question remains, can woody biomass energy crops be used as a ‘carbon dioxide pump’ to link biological and physical sequestration technologies for enhanced climate change mitigation? The answer… definitely maybe.

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