Sequestration of atmospheric carbon into subsoil horizons through deep-rooted grasses – vetiver grass model

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Choosing the strategies to mitigate global warming should envisage sustenance of soil carbon sink, and also long-term locking of excess carbon deep into the soil horizon. Fast growing grasses with penetrating deep root system would facilitate long-term locking of atmospheric carbon below plough layer with reduced chances of being recycled to atmosphere and recuperate soil carbon sink. Vetiver, a non-invasive C_4 grass with fast-growing tufted root system, reaching 3 m just in one year could be an ideal global candidate with a holding potential of 1 kg atmospheric carbon, sequestered annually deep into the soil pool from one sq. metre surface area.

The rising level of atmospheric CO_2 is believed to cause global warming at an alarming rate of 0.2°C per decade with an estimated average rise in global temperature of 3°C by 2100 (ref. 1). On an average, 3.2 Gt of carbon accumulate annually in the atmosphere on account of anthropogenic activities[2]. Oceanic uptake of anthropogenic CO_2 leads to decrease in sea water pH that lowers the saturation state for carbonate minerals, causing ocean acidification having detrimental consequences to marine organisms[3]. Therefore, sequestration of the excess carbon from the atmosphere necessitates a sustainable approach to capture excess CO_2 in an integrated manner that satisfies biogeochemical and ecosystem norms. A host of strategies are suggested for long-term sequestration of anthropogenic carbon emissions, including trapping of CO_2 as stable carbonate mineral in basalt rocks[4], pyrolytic conversion of plant biomass into biochar (black carbon) for locking up carbon[5], and saving and restoration of forests for reducing net carbon dioxide flux to the atmosphere[6,7], but carbon mitigation by photosynthetic capture by far remains a natural and sustainable proposition that complements environmental priorities and socio-economic interests. Photosynthetic increase of C stocks as soil organic carbon into the deeper soil horizons that have slower decomposition rate, would provide enhanced opportunities for stable organic matter as recalcitrant C, to realize long-term subsoil carbon sequestration[8]. Fisher *et al.*[9] discuss the potential of carbon storage in the terrestrial biosphere through sequestration of CO_2 by deep-rooted grasses. We underpin that vetiver grass that has far deeper root system growing up to 3 m in just one year (Figure 1) could be an ideal global candidate to potentially contribute to balancing the global carbon cycle by offsetting the effect of anthropogenic CO_2 emissions, and also recuperate soil carbon sink – providing a green path.

Enriching soil carbon sink

The conversion of soils from natural to agricultural use has led to substantial losses in terrestrial carbon. Soils are thought to have lost between 40 and 90 billion tonnes of carbon globally through cultivation and disturbance[10]. Even cultivation of biofuel crops considered for offsetting fossil fuel emissions would be at the expense of existing vegetation, croplands and soil carbon sinks. As such, the carbon sinks are at greater immediate risk from land-use changes. Therefore, sensitive land-use practices such as no-till agriculture that minimize soil carbon loss and results in higher carbon returns to the soil[11], and saving and restoration of forests that help sequester greater amounts of carbon than the emissions avoided by the use of liquid biofuels[6], would significantly enhance terrestrial carbon sink and also reduce atmospheric carbon. Therefore, in choosing the strategies to meet the challenges of global climate change, there is a need to uphold soil carbon sink, and also long-term locking of excess carbon deep into the soil horizon.

Photosynthetic assimilation of atmospheric carbon and the translocation of photo-assimilates to roots not only helps trap the excess CO_2 in deeper soil layers, but could partly replenish the soil organic carbon in the long run. Furthermore, microbial action in the root-zone accounts for sequestration of atmospheric carbon in the soil in mineralized form. Although organic carbon from decaying roots in the upper plough layer could be oxidized and recycled to the atmosphere, the penetrating roots would help facilitate long-term carbon storage of the major fraction deep into the soil horizon. It has been shown that grasses with 1 m deep roots, e.g. *Andropogon gayanus* sequester significant amounts of organic carbon deep into the soil with an estimated sequestration of 100–500 Mt carbon per year for an estimated area of 35 Mha – a substantial part of missing sink from the south American savannas[9]. The efficiency of photosynthetic carbon trap could be greater where roots grow faster and deeper, and root-architecture is fibrous penetrating a larger soil volume. This provides a natural system of sequestering carbon deep into soil layers with reduced chances of being recycled to atmosphere compared to biochar system that requires pyrolysis of biomass for carbon locking.

Vetiver grass as a natural candidate

Vetiver, *Vetiveria zizanioides* (L.) Nash, syn *Chrysopogon zizanioides* (L.) Roberty – a C_4 perennial grass is one such species that could be grown all across the globe from tropical to Mediterranean climate. The grass fits well in ecosystem service model contributing to regional and global economies for its multifarious environmental applications (www.vetiver.org), and offers sustainable opportunities for carbon sequestration. A native grass of India, initially valued for its aromatic oil, vetiver is now extensively used in soil conservation, land rehabilitation and pollution mitigation[12]. Its fast growing tufted roots that penetrate vertically deep into the soil promise an initial growth rate of 3 cm per day reaching over 2 m in just six months to 6 m in three years. This species holds annual biomass production potential of 100–120 tonnes per ha[13,14] – which is distinctly higher compared to 30–40 tonnes achievable for other biomass efficient plants e.g. *Miscanthus* grass[15], *Populus* spp., *Eucalyptus* spp. and *Salix* spp.[16]. Whereas the above-ground green part could be suitably utilized for handicrafts, fodder, organic mulch and liquid fuel with technological advancements such as lignocellulose to ethanol conversion[17] or more potent second generation biofuels like dimethylfuran[18], the fast growing roots that trap significant amount of atmospheric CO_2, facilitate uniform dispersal of stored carbon into the soil on account of their fibrous nature and provide enhanced opportunities for soil microbial action. Other than vetiver, there is no other grass species that has such a fast-growing tufted root system, amply suitable for translocating atmospheric carbon for sequestering underground deep into the soil. On the basis of cues from shoot-to-root biomass ratio[13,14,19], it is estimated that vetiver could potentially produce 20–30 tonnes of root dry matter per ha annually. Accordingly, considering half of the root dry matter as carbon component, this grass holds the potential of 1 kg atmospheric carbon added annually to the soil carbon pool from 1 sq. metre surface area.

Figure 1. One-year-old roots of vetiver from a natural growing site in Lucknow. The roots could penetrate though the hard pan soil.

Conclusion

Vetiver is now grown in over 100 countries. It could be established in all varied environments from wet to dry conditions and could thrive in a wide rage of soils from sandy to rocky, saline or alkaline[20]. Vetiver is non-competitive with adjacent crops. Instead, it enhances crop yields by moisture retention when planted as hedgerows along the contours. The plant is non-invasive, but in certain areas, e.g. north Indian plains where seed forming vetiver is prevalent, it can, to some extent, spread under swamp conditions. However, the plant types found in south India and elsewhere in the world are, by and large, non-seed forming and can be conveniently propagated vegetatively posing no threat of becoming weedy[21]. Strategic plantation of vetiver in crop fields, tree lines, river, road and rail-line embankments as hedgerows could potentially contribute to carbon sequestration vis-à-vis eco-technological management of soil, crops, agroforestry, and as a source of biomass and bioenergy.

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