*Commentary*

# Global warming and terrestrial carbon sequestration

It is reported that the present terrestrial biosphere became a net carbon (C) sink in the 1990s due to recent changes in land use and management, and fertilizing effects of nitrogen (N) and increased levels of atmospheric carbon dioxide ($CO_2$) (Schimel *et al* 2001). Computer model simulations show that the present sink will last until about 2050, but will turn into a source thereafter (Cox *et al* 2000), possibly due to conversion of natural ecosystems into agroecosystems (Tilman *et al* 2001). Current rate of global warming will also contribute to the sink-source transformation due to increased soil organic matter (SOM) oxidation (Gregory *et al* 1999). Further, in Amazon forests, it has been shown that the biomass of woody climbing plants (lianas) increased over the last two decades (Phillips *et al* 2002). They enhance tree mortality and suppress tree growth, so their rapid increase implies that the tropical terrestrial C sink may shut down sooner than current models suggest. In this context, the biggest challenge that mankind will have to face in the future, is to find ways to sustain the C sink for a prolonged period. The UNEP has predicted that global warming would reduce cereal production, which would result in further expansion of agroecosystems. Recent studies showed that fast turnover rates of organic C in the forest floor litter layer result in quick return of the C to the atmosphere in little over 3 years (Schlesinger and Lichter 2001). Additional C taken up by some forests in response to atmospheric $CO_2$ enrichment is partitioned preferentially to fast turnover pools (Norby *et al* 2001) (i.e. leaves and fine roots). It is a fact that C inputs to the soil always go through the fast turnover pool before entering the slow turnover pool. However, natural transformation of C from the fast pool to the slow pool is a very slow process. It is evident from very low C transformation from the terrestrial net primary production to the slow turnover pools, which is only 0·7% (Schlesinger 1990). Hence, this transformation cannot be considered as an efficient means of long-term C storage, particularly when compared with the current rates of atmospheric $CO_2$ elevation. Thus, forests are not likely to serve a major role as a long term C sink in an elevated $CO_2$ atmosphere.

It has been shown that dark green forest canopies reflect much less solar radiation than most other land surfaces such as snowy tundra, which reflect large amounts of the radiation (Pearce 2001). This tends to heat the earth surface of forested areas. Calculations at northern latitudes reveal that the warming as a result of planting forests will overwhelm any cooling effect due to the trees soaking up $CO_2$. Reforestation in light green tropical grasslands (e.g. Patanas) could also have a similar phenomenon.

Conventional agricultural activities are also not apparent to contribute to a net C sequestration (Schlesinger 1999). Agroforestry systems that have been proposed to sustain SOM in tropics will not sufficiently contribute to a C sink, as their organic C is entered mainly to the fast turnover pools. With the agricultural expansion, C sink brought about by deliberate actions would also not contribute enough to the C sequestration. Those points justify that terrestrial C sinks would be short term, one-off benefits that should not be considered as long term alternatives to cutting emissions.

It is indicated here that in terrestrial ecosystems a problem exists in the lack of transformation of plant litter into slow turnover pools. The major challenge therefore is to find ways to produce the slow turnover pools like refractory humus substances in the soils, which have turnover times over 1000 years. One way to enhance the production of the slow turnover pools is to increase the litter incorporation and humus formation rates in the soil. This can easily be done by direct inoculation of different groups of soil fauna to the litter layer. Litter fragmentation is performed by collembola (e.g. springtails), centipedes, millipedes and arachnids (e.g. mites). Transfer of the fragmented litter into humus layer by forming humus is done by earthworms and termites. Prior to the earthworm and termite activities, microbial decomposition on the fragmented litter generally releases some $CO_2$ to the atmosphere. But once the litter C was encapsulated forming humus due to ingestion by the fauna, a major portion of the litter is transformed to the slow pool. This has been evident from a rapid depletion of the fast pool, which was followed by an increase of the slow pool due to earthworm activity in a mixed forest (Van Camp *et al* 2001). In a spruce forest in Germany, the inoculation of earthworms markedly incorporated organic matter to a depth of 20 cm (Judas *et al* 1997). In a woodland flood plain in US, earthworms consumed all the litter deposited on the soil surface within several weeks (Knollenberg *et al* 1985). Removal of soil surface litter may also discourage the establishment of lianas in the forests, thus favouring tree growth. Soil faunal activities increase N availability and hence C sequestration in plants (Setala and Huhta 1991). These activities can increase crop production in agroecosystems. However under certain circumstances, litter incorporation into soil may reduce the N availability and consequently plant C sequestration (Seneviratne 2002), depending on soil and litter C/N ratios. This can be overcome by foliar application of nutrients. In the forest ecosystems, the foliar application can be performed using airplanes. This has other advantages: (i) It is important for efficient application of nutrients to increase nutrient use efficiency by plants, avoiding soil fertility limitations on the C sequestration. (ii) It helps to conserve soil C stores under elevated $CO_2$, by slowing microbial decomposition (Hu *et al* 2001), over direct soil application of nutrients. Incorporation of large amounts of litter into soil creates anaerobic conditions due to high consumption of $O_2$ in litter decomposition (Waid 1997). This prevents the enzyme phenol oxidase from eliminating phenolic compounds that inhibit biodegradation, thus resulting a conservation of soil C (Freeman *et al* 2001).

In view of those facts, it is clear that present, natural C sequestration processes are not efficient enough to remove the increasing atmospheric $CO_2$. Increasing forested area to increase C sequestration will not address the problem of terrestrial atmospheric warming, because of its complications in the solar radiation effects, in particular. Hence, it is apparent that judicious management of the existing forests for increased C sequestration and long-term storage is more important than planting new forests. In addition, it is important to develop alternative, perhaps artificial C sinks to the forests. One such material is magnesium carbonate-based cement that soaks up $CO_2$ as effective as natural grass and woodlands (Pearce 2002). Its production process requires a lower temperature than the Portland cement production, and hence halves the $CO_2$ emission. By directly replacing traditional Portland cement with this eco-cement in the built environment, it is estimated that the atmosphere could eliminate over a billion tones of $CO_2$ each year.

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GAMINI SENEVIRATNE
*Institute of Fundamental Studies,*
*Hantana Road, Kandy, Sri Lanka*
*(E-mail, gaminis@ifs.ac.lk)*