Importance of inorganic carbon in sequestering carbon in soils of the dry regions

The world's most populated ecoregions in the tropics are also the regions where there is a high risk of natural resources and environmental degradation. The consequences of this degradation are severe soil degradation, contamination of surface and ground waters and emission of greenhouse gases from the soil into the atmosphere. Human activities, driven by socio-economic, political and cultural factors that exacerbate gaseous emissions, include conversion of lands under forest and natural vegetation to agriculture and other uses, biomass burning, lack of nutrient inputs under subsistence agriculture and draining of wetlands[1].

Soils in the tropics, especially those in the drier regions have low reserves of organic matter and plant nutrients. The soil carbon (C) pool composed of soil organic C and soil inorganic C is not only critical for the soil to perform its productivity and environmental functions, but also plays an important role in the global C cycle. The sequestration of atmospheric C in the soil and biomass not only reduces greenhouse effect but also helps maintain or restore the capacity of the soil to perform its production and environmental functions on a sustainable basis. Thus, there is a great interest in research on sequestration of atmospheric C into the soils for maintaining or restoring soil fertility and mitigating carbon dioxide emissions to the atmosphere[1].

Calcium carbonate is a common mineral in soils of the dry regions of the world, stretching from sub-humid to arid zones. It is estimated that arid and semi-arid regions cover over 50% of the total geographical area of India. The soils of these regions are calcareous in nature. According to an estimate by the National Bureau of Soil Survey and Land Use Planning, calcareous soils occupy about 230×10^6 ha and constitute 69% of the total geographical area of the country[2]. Some calcareous soils also occur in the humid and per-humid zones of the country, but the occurrence of calcareous soils in the per-humid zones is as a result of strongly calcareous parent material or in young geomorphic surfaces[3]. The arid and semi-arid regions of India are dominated by calcareous Vertisols and Vertic intergrades.

Despite the dominant role that calcium carbonate plays in modifying the physical, chemical and biological properties and behaviour of plant nutrients in the soil, its role in C sequestration in calcareous soils is not well researched. The role of soil inorganic carbon (SIC) is important for sequestering C, but the mechanisms involved are not well understood[1]. The soils of the arid and semi-arid regions may contain two to five times more SIC than soil organic C (SOC) in the top 1 m soil layer. For example, Bhattacharya *et al.*[4] estimated that the SOC stock in the top 150 cm depth of the black cotton soils (Vertisols and associated soils) of Maharashtra is 171 Gg (Gg = 10^9 g) and the stock of SIC is 3051 Gg. These estimates clearly demonstrate the predominance of SIC over SOC.

The SIC pool consists of primary inorganic carbonates or lithogenic inorganic carbonates, and secondary inorganic carbonates or pedogenic inorganic carbonates. Secondary carbonates are formed through dissolution of primary carbonates and re-precipitation of weathering products. The reaction of atmospheric carbon dioxide (CO_2) with water (H_2O) and calcium (Ca^{2+}) and magnesium (Mg^{2+}) in the upper horizons of the soil, leaching into the subsoil and subsequent re-precipitation results in formation of secondary carbonates and in the sequestration of atmospheric CO_2. The reactions can be represented as follows:

$$CO_2\,(g) + H_2O = H_2\,CO_3, \quad (1)$$

$$H_2CO_3 = H^+ + HCO_3^-, \quad (2)$$

$$CaCO_3 + H^+ = Ca^{2+} + HCO_3^-. \quad (3)$$

The overall reaction that leads to the dissolution of calcium carbonate at the soil surface, followed by its leaching in the soil profile, is as follows:

$$CO_2 + H_2O + CaCO_3 = Ca^{2+} + 2HCO_3^-. \quad (4)$$

The pedogenic inorganic C (PIC) formed from non-carbonate material is a sink for C and leads to C sequestration. On the other hand, pedogenic inorganic C formed from calcareous material may not be involved in C sequestration in the soil. Thus dissolution of carbonates and leaching in the soil profile may lead to C sequestration. Leaching of bicarbonates into the groundwater is a major mechanism of SIC sequestration. The rate of C sequestration by this mechanism may be 0.25–1.0 Mg C/ha/yr[5]. For SIC sequestration to take place, the groundwater is to be unsaturated with calcium bicarbonate[6]. The contribution of PIC from non-carbonate material may be 50–100 kg/ha/year[6].

Enhanced primary productivity of the vegetation and adoption of salinity control measures involving the use of gypsum and organic amendments can lead to leaching of calcium bicarbonate in the profile under irrigation. This would result in sequestering carbon and amelioration of salt-affected soils[7]. Unlike SOC, the role of SIC in C sequestration is not only less researched, but also less well understood. Sequestration of SIC certainly has implications when groundwaters unsaturated with calcium bicarbonate are used for irrigation. Reconstruction of carbonate fluxes in soil formed in strongly calcareous parent material over geological time periods suggests that this mechanism could account for upward of 1 Mg $ha^{-1}\,yr^{-1}$ of SIC[8]. These results provide definitive estimates of contribution that SIC can make to C sequestration in calcareous soils.

It has been postulated that aridity in the climate is responsible for the formation of pedogenic calcium bicarbonate and this is a reverse process to the enhancement in SOC. Thus increase in C sequestration via SOC enhancement in the soil would induce dissolution of native calcium carbonate and its leaching[4], resulting in SIC sequestration. Thus there may be a synergy in SOC and SIC sequestration. Initial estimates on SIC sequestration in soils should stimulate future research on its role in C sequestration for enhancing C stock in impoverished and degraded calcareous soils in the arid and semi-arid regions and mitigating the greenhouse effect.

1. Lal, R., *Adv. Agron.*, 2002, **76**, 1–30.
2. Velayutham, M., Mandal, D. K., Mandal, C. and Sehgal, J. L., National Bureau of

Soil Survey and Land Use Planning Bulletin No. 35, NBSS and LUP, Nagpur, 1999.
3. Pal, D. K., Dasog, S., Vadivelu, S., Ahuja, R. L. and Bhattacharya, T., in *Global Climate Change and Pedogenic Carbontes* (eds Lal, R. *et al.*), CRC/Lewis Publishers, Boca Raton, Florida, 2000, pp. 149–185.
4. Bhattacharya, T., Pal, D. K., Velayutham, M., Chandran, P. and Mandal, C., *Clay Res.*, 2001, **20**, 11–20.
5. Wilding, L. P., in *Carbon Sequestration in Soils: Science, Monitoring and Beyond* (eds Rosenberg, N. J. *et al.*), Battelle Press, Columbus, 1999, pp. 146–149.
6. Nordt, L. C., Wilding, L. P. and Drees, L. R., in *Global Climate Change and Pedogenic Carbonates* (eds Lal, R. *et al.*), CRC/Lewis Publishers, Boca Raton, Florida, 2000, pp. 43–64.
7. Gupta, R. K. and Abrol, I. P., in *Advances in Soil Science*: *Soil Degradation* (eds Lal, R. and Stewart, B. A.), Springer-Verlag, Berlin, 1990, pp. 223–288.
8. Izaurralde, R. C., Rosenberg, N. J. and Lal, R., *Adv. Agron.*, 2001, **70**, 1–75.

K. L. SAHRAWAT

International Crops Research Institute for the Semi-Arid Tropics,
Patancheru 502 324, India
e-mail: klsahrawat@yahoo.com

INDEST Consortium

In a major initiative under the Department of Secondary and Higher Education, Ministry of Human Resource and Development (MHRD), an Indian National Digital Library in Science and Technology (INDEST) has been set up. With the launch of INDEST, in the initial phase, at least 38 major technological institutions in the country such as the IITs, IISc, NITs, RECs and IIITs are slated to benefit. The doors are now open for new consortia members, as the whole concept is open-ended. INDEST serves to benefit members by ‘shared subscription’ through a consortium of libraries. The sharing of resources at highly discounted rates of subscription hopes to increase access to e-journals, etc. for researchers across the country, while obtaining better terms of agreement with publishers. The consortium’s web address is http://www.library.iitb.ac.in/indest/. The aim, according to INDEST, is to improve ‘quality and quantity of research’.

Presently, science and technology institution libraries bear about Rs 4 crores as expenses for subscription towards journals etc. This costs the Government of India approximately Rs 150 crores annually, to support library acquisitions all over the country for centrally funded institutions. INDEST could provide comparable or even better facilities of information-sharing at Rs 18.6 crores, that is the funding invested by the Government of India per annum in the consortium. The quantum of government support is not likely to vary in future years, according to Pawan Agarwal, MHRD.

Based on the recommendations of the MHRD Task Force, institutions have been grouped into three categories. Category I comprises IISc, Bangalore and the seven IITs. Category II, all the RECs/NITs; Indian School of Mines, Dhanbad; North Eastern Regional Institute of Science and Technology, Itanagar, and the Sant Longowal Institute of Engineering and Technology, Chandigarh: Category III comprises six IIMs (Ahmedabad, Bangalore, Kolkata, Indore, Kozhikode, Lucknow); the National Institute of Training in Industrial Engineering, Mumbai, and the Indian Institute of Information Technology and Management, Gwalior. Few additional members have recently joined Category III, such as the Dhirubhai Ambani Institute of Information and Communication Technology, Gandhinagar; TIFR Laboratory of Computational Mathematics, Pune; Birla Institute of Technology, Ranchi; Nirma Institute of Technology, Ahmedabad, and SONET, Hyderabad. AICTE has set-up a committee to find out the possibility of AICTE-accredited institutions joining the consortium.

The electronic resources available through INDEST are the following:

Full-text electronic resources:

- IEEE/IEE Electronic Library (http://ieeexplore.ieee.org)
- Elsevier: Science Direct (http://www.sciencedirect.com)
- Springer Verlag’s link (http://link.springer.de/)
- ProQuest: Applied Science and Technology Plus (http://www.il.proquest.com/pqdauto/)
- ProQuest: ABI/Inform Complete (http://www.il.proquest.com/pqdauto/)
- ACM Digital Library (http://portal.acm.org/portal.cfm)

Online Databases:

- Ei Compendex Plus and INSPEC (http://www.engineeringvillage2.org/)
- SciFinder Scholar (Access through a Z39.50 Windows-based interface)
- MathSciNet (http://www.ams.org.mathscient)
- ISI Web of Science (http://isiknowledge.com/)
- J-Gate Custom Content for Consortia (http://www.informindia.co.in).

Belonging to a particular category determines type of access, as usability and suitability of various electronic resources have been the criteria for selection to a particular category.

On 4 March 2003, the first annual meeting of INDEST consortium was held at IIT Delhi. According to Pawan Agarwal, the resources of management, civil and mechanical engineering institutions were not adequately covered, although the Task Force had identified such resources. He spoke of the issues involved that confronted INDEST, such as funding, selection of resources, spreading the benefits to all institutions, collaborative working, shifting to an electronic work environment, training of users, copyright issues and lack of networking.

Further, mention must be made of efforts currently on by several agencies to form their own ‘Nets’, such as UGC, CSIR, ICAR, etc., outside of the INDEST consortium. The MHRD hoped that there would be no duplication of efforts and such dissenting voices would eventually