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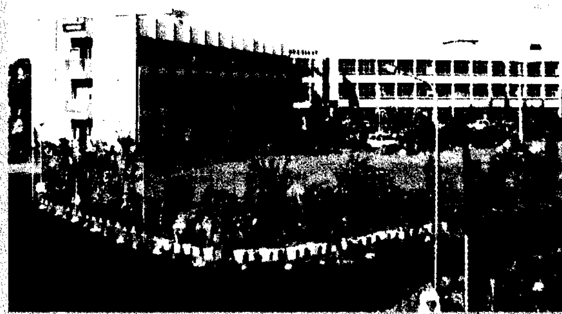

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Soil Carbon Budgeting and Trading to Benefit Rural Poor

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Climate change due to global warming as a result of increased concentration of green house gases (GHGs) in the atmosphere is a well established fact (IPCC 2007). Impacts of climate change are experienced through out the world. Climate change is a global problem with unique characteristics and involves complex interactions between climatic, environmental, economic, political, institutional, social and technological processes, which affect locally. The GHGs concentration and particularly of CO_2 in the atmosphere has increased dramatically from 280 to 378 ppm due to anthropogenic activity much correlated with the industrial development. The phenomenon of reducing the emissions and or fixing CO_2 is referred as mitigation strategy for climate change. This global phenomenon called for action by one and all wherever the opportunities existed to reduce the atmospheric concentration of carbon dioxide emissions. Reduction in the atmospheric concentration of CO_2 can be achieved through reducing the emissions and also through removal of carbon dioxide from the atmosphere and storage in fixed form. The Kyoto Protocol brought the mechanism of trading carbon units as a global mechanism to address the issue of reducing the emissions by the polluting industries and countries to meet the mandatory requirements.

For trading C units one needs to establish the fact through carbon budgeting that the emissions are reduced or more C is fixed. Carbon budgeting is the sum of all exchanges (inflows and outflows) of carbon compounds between the earth's carbon reservoirs (such as land mass, water bodies, and atmosphere) in the carbon cycle. Carbon trading, or more generically emissions trading, is the term applied to the trading of certificates representing various ways in which carbon-related emissions reduction targets might be met. Participants in carbon trading buy and sell contractual commitments or certificates that represent specified amounts of carbon-related emissions that either:

- are allowed to be emitted;
- comprise reductions in emissions (new technology, energy efficiency, renewable energy); or
- comprise offsets against emissions, such as terrestrial or oceanic carbon sequestration (capture of carbon).

Carbon dioxide being one of the important GHGs and it's role in climate change CO_2 is of strategic importance to the nations developed as well as developing and has acquired a "market value" globally for trading. For decades, there has been debate over what happens to the carbon dioxide released from the burning of fossil fuels and clearing of tropical rainforests (Christine *et al.* 2002). The CO_2 emissions trading systems place a monetary "value" on carbon that reflects the anticipated financial liabilities from emissions related to climate change impacts. Balancing the global carbon budget just got more difficult. The regulatory approach has gained significant political momentum, leading to the emergence of a new commodity market: the carbon market. In 2007, the C market was worth US$ 60 billion, and it is expected to grow exponentially over the coming decade.

The quick rise to popularity of emissions trading comes as a surprise for a number of reasons. Prior to the agreement of the Kyoto Protocol, emissions trading was a US regulatory approach that was only reluctantly accepted by the international community as part of the Kyoto deal (Grubb, Vrolijk *et al.*, 1999). This success story of the globalization of environmental policy against considerable obstacles raises the question about the driving forces behind the global spread of greenhouse gas emissions trading.

The prospect of a multi-billion financial market has mobilized a number of actors including potential industrial sellers, market intermediaries (banks, funds, etc.) and governments that want to position their countries in an emerging global carbon market (Matthews and Paterson, 2005). The very characteristics of emissions trading of being market-based and market-creating together with the broad-based effects of climate policy on the economy have led to a strong presence of economic interests in the diffusion of the instrument (Yandle and Buck, 2002).

In the last three decades, the political strategy of business in global environmental politics has shifted: while in the 70s and 80s business was often opposing environmental regulations, it has since moved on to engage with the process of global environmental politics (Falkner, 2008). No policy issue has brought as many business actors to the table as the case of climate change politics. Climate policy affects a very broad range of industries because it is essentially about energy supply and demand, the backbone of all industrial economies. With CO_2 being the main greenhouse gas, the fossil-fuel based energy system is at stake in climate politics. The technology providers can benefit from climate regulation by an uptake in demand for low-carbon energy technologies; for the renewable energy sector climate policy is driving demand for its products; the financial intermediaries are increasingly assuming a critical role in carbon trading; and the insurers have an interest in reducing the physical risks of climate change (Paterson, 2001).

The Global Environmental facility (GEF) is one of the global partnership mechanism among 178 countries, international institutions, NGOs and private sector put in place internationally to minimize the GHGs, minimize land degradation to address global environmental issues while supporting national sustainable development initiatives. Another mechanism put in place for trading of carbon units is the Clean Development Mechanism (CDM) where C sequestering or CO_2 emission reducing technologies are promoted and financially supported irrespective of the country or the region where they are implemented. The companies or countries that support the CDM projects get the credit for the amount of C emissions reduced due to efficient technologies or due to increased C sequestration. The tropical developing countries' potential to harness CDM projects is vast and remains to be tapped. At present Brazil, China, and India are leading the pack for the CDM projects approved. There are two types of C units traded globally viz; certified emission reductions (CERs) and verified emission reductions (VERs). The CERs units as in its' name need certification by recognized auditors who ascertain the mechanisms, processes, and actual quantification of the C units. It involves time, cost and has to be done at a scale of economy meaning big size projects could afford to take this route. However, many industries as well as responsible global citizens are taking the responsibility to manage the C emissions for their actions without mandatory sanctions or regulations. Such corporate bodies and individuals are trading the VERs C units and are off-setting the C emissions due to their regular activities such as traveling to office, official and personal travel, use of personal vehicles or other activities that emit CO_2 in the atmosphere. Reputed organizations and individuals verify the activities of communities that undertake C sequestering or reducing C emissions and are awarded the VERs and the costs are paid to the communities. Through this mechanism the poor communities are able to harness the benefits of global C trading and the communities are able to improve their incomes as well as undertake the environment stewardships. International Crops Research Institute for the Semi Arid Tropics, (ICRISAT) has facilitated the sale of VERs from the rural community based organizations (CBOs) to the World Bank, private companies and individuals benefiting the rural community.

The main objectives of carbon trading and budgeting is to :

- quantify the dependence on climate of the carbon stock in soil and the decomposition of this stock,
- develop various methodologies to monitor the changes in the carbon stock of soil,
- develop model cycling of carbon in soil, methodologies for estimating the carbon budget of forests based on forest inventory data,
- study impacts of land use and climate on organic matter transport, retention and fluxes to the coast,

- to investigate the impacts of land use and topography on the spatial distribution of catchments carbon pools,
- to study impacts of water quality and land use on greenhouse gas emission from lakes,
- to study impacts of temperature and vegetation on methane emission from lake littorals,
- make an overall assessment of the contribution of fresh water ecosystems to carbon

The benefits to the general community of trading emission reduction/offset certificates in a market include:

- the reduction in overall cost of meeting emission reduction targets.
- the progressively improved definition of a "price" for carbon, particularly as the market becomes more liquid and active, and assuming that all carbon certificate products are feasible, meaning that they are equivalent ways of addressing emission reduction;
- the opportunity to generate income from activities that previously attracted no additional revenue, such as investment in emission reduction, renewable energy generation, greenhouse-friendly fuels and carbon sequestration;
- the ability to use revenue from carbon sequestration to help fund additional planting of trees and other vegetation, for benefits such as salinity amelioration, biodiversity enhancement, conversion to greenhouse gas friendly fuels and energy, and employment and wealth creation in rural areas.

As we deal with soils and agriculture, let us closely follow the ways and challenges to harness the C trading market to benefit the poor communities engaged in agriculture. Soils and trees are major sinks for carbon and this potential remains untapped. Globally carbon stock of trees increased between the 1920s and the 2000s from 500 to 740 Tg, on an average, 3 Tg per year. The actual carbon balance of the trees was highly variable between the years as a result of variation in growth and harvests. In the 1920s, 30s, 50s and 60s, the trees were a source of carbon, as the harvests exceeded the growth. For the rest of the period, the trees were a sink of carbon. The highest annual sink values varied between 5 and 14 Tg. In the 1940s, the high values were caused by decreased harvests during the 2nd world war. Since the 1970s, the sink values have remained high despite increased harvests, as the growth rates of trees have increased even more than the harvests.

Similarly, the carbon stock of soil increased between the 1920s and the 2000s from 910 to 990 Tg, on an average, 1 Tg per year. This is a third of the average annual carbon sink of trees in all forests (3 Tg) and a half of the carbon sink of trees in forests on mineral soil (2 Tg) (Aleksi *et al.*, 2004). Detailed studies of total carbon emission and the heterotrophic carbon emission were estimated to be 1065g-Cm^{-2} y^{-1} and 565g-$Cm^{-2}$$y^{-1}$, respectively. The total carbon supply was 1136g-Cm^{-2} y^{-1}, among which litter from floor vegetation accounted for 56%, fertilizer and paper bags 23%, and litter from peach trees 21%. Carbon from floor vegetation was the largest input to the soil and the soil carbon budget was positive (571g-cm^{-2} y^{-1}); hence the soil was acting as a carbon sink (Sekikawa *et al.*, 2003). Scientists estimate that, since the mechanization of agriculture began a few hundred years ago, some 78 billion metric tons more than 171 trillion pounds of carbon once trapped in the soil have been lost to the atmosphere in the form of carbon dioxide (CO_2).

With too little carbon in the soil, crop production is inefficient. Right now, the world's agricultural soils are alarmingly depleted of carbon, particularly in sub-Saharan Africa, south and central Asia and the Caribbean and Andean regions. These depleted soils provide an opportunity to convert them in to C sinks with suitable management practices and cropping systems. It is known that agricultural management practices influence the soil quality, which in turn impacts the productivity of soils (Wani *et al.*, 2003, 2007; Bhattacharya *et al.*, 2007). It is argued that increase in soil organic carbon pool favorably influences crop productivity by increasing water holding capacity of the soil, improving soil physical properties, especially soil-water-air relations and improved supply of nutrients (Wani *et al.*, 2003; Hudson, 1994; Emerson, 1994 and Pathak *et al.*, 2005). Moreover, the soil organic carbon pool drives soil bio-

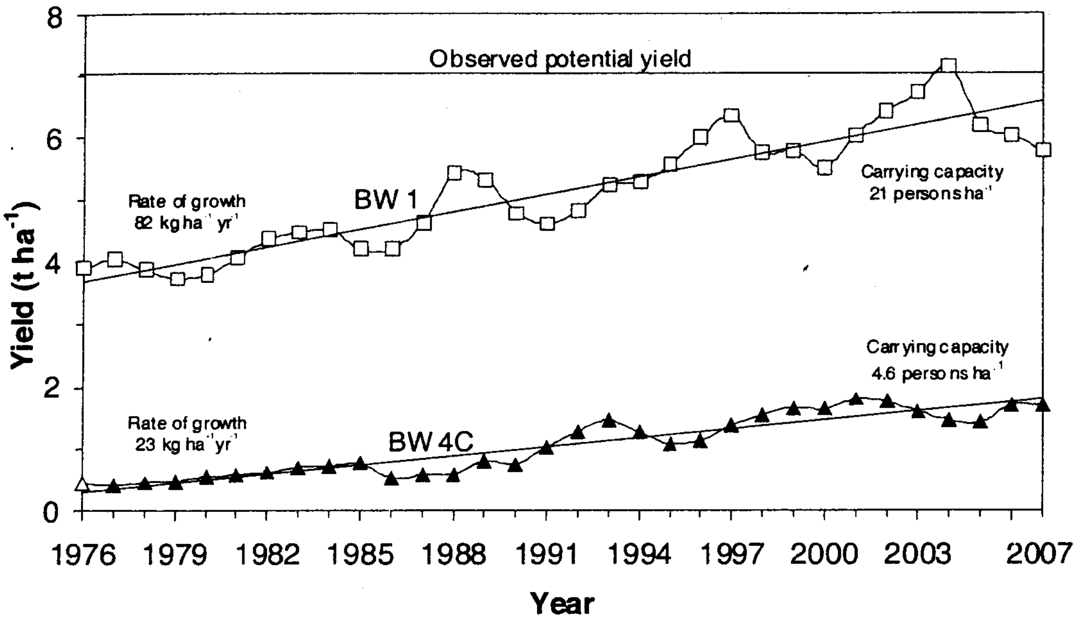

Fig. 1. Three-year moving average of sorghum and pigeon pea grain yield under improved and traditional management in a deep Vertisol catchment at Patancheru, India

logical activity, which controls nutrient availability and overall nutrient cycling (Johnston, 1986). The updated results from long-term study at ICRISAT (Fig. 1) showed that the average grain yield of the improved cropping system over 30 years was 5.1 t ha^{-1} y^{-1}, nearly a five-fold increase in the yield over the traditional cropping system (average yield about 1 t ha^{-1} y^{-1}). The annual gain in yield in the improved system was 82 kg ha^{-1} yr^{-1} compared with 23 kg ha^{-1} yr^{-1} in the traditional system (Fig. 1). The improved system had a higher carrying capacity (21 persons ha^{-1}) than the traditional system (4.6 persons ha^{-1}).

The fertility status of the soil as measured by organic carbon, total nitrogen and phosphorus, and available nitrogen and phosphorus has increased under the improved system compared to the traditional system. More importantly, under the improved catchment management system, the soil contained 46.8 t OC ha^{-1} in the 0-120 cm soil profile as compared to the traditional management practices that contained 39.5 t OC ha^{-1} (Table 1). This amounted to a gain of about 7.3 t OC ha^{-1} over the 24-year period ending in 2000. Overall, the improved system showed increased rainwater use efficiency (65% vs 40%), reduced runoff from 220 m to 91 mm and soil loss from 6.64 t ha^{-1} to 1.5 t ha^{-1} along with increased crop productivity, carrying capacity of land (both of men and animals, C sequestration and soil quality (Wani *et al.*, 2003).

Several soil and crop management practices affect C sequestration in the soil. Among them, conservation tillage, regular application of organic matter at high rates, integrated nutrient management, restoration of eroded soils, and soil and water conservation practices have a relatively high potential for sequestering C and enhancing and restoring soil fertility in the longer-term (Lal, 1999).

The results of another long-term experiment with various cropping systems on Vertisols showed that the legume-based systems were more sustainable than the only cereal systems (Wani *et al.*, 1995; Rego *et al.*, 2003). Vertisols planted to legume-based systems, using the broad-bed and furrows (BBF) landform had up to two folds higher N mineralization potential and organic C content, thus providing evidence to the increased crop productivity as compared to fallow-sorghum system (Wani

Table 1. Biological and chemical properties of semi arid tropical Vertisols in 1998 after 24 years of cropping under improved and traditional systems in catchments at ICRISAT Center, Patancheru, India

Properties	System	Soil depth		SE±
		0-60	60-120	
Soil respiration	Improved			
(kg C ha^{-1})	Conventional	723	342	7.8
		260	98	
Microbial biomass	Improved			
(kg C ha^{-1})	Conventional	2676	2137	48.0
		1462	1088	
Organic carbon	Improved	27.4	19.4	0.89
(t C ha^{-1})	Conventional	21.4	18.1	
Mineral N	Improved	28.2	10.3	2.88
(kg N ha^{-1})	Conventional	15.4	26.0	
Net N mineralization	Improved	- 3.3	- 6.3	4.22
(kg N ha^{-1})	Conventional	32.6	15.4	
Microbial biomass N	Improved	86.4	39.2	2.3
(kg N ha^{-1})	Conventional	42.1	25.8	
Non-microbial organic N	Improved	2569	1879	156.9
(kg N ha^{-1})	Conventional	2218	1832	
Total N	Improved			
(kg N ha^{-1})	Conventional	2684	1928	156.6
		2276	1884	
Olsen P	Improved	6.1	1.6	0.36
(kg P ha^{-1})	Traditional	1.5	1.0	

et al., 1995). Similarly, the results from a long-term experiment conducted at several sites across India, covering different agro-ecoregions and cropping systems, showed that after 25 years of experimentation, the Vertisols had higher soil organic C (SOC) and inorganic (carbonates) C stocks in Vertisols than the Alfisols. Among the cropping systems, soybean-based systems had highest SOC stock, whereas sorghum-based system showed highest soil inorganic C (SIC) in the 1.05 m soil depth.

A study was conducted by ICRISAT and its partners (NBSS&LUP, CRIDA, and IISS) to determine the C status of soils at 28 benchmark sites, covering arid, semi-arid and moist humid tropical locations in India to identify C sequestering systems (ICRISAT, 2004). The study revealed that after 20 years, the Vertisols had higher C sequestering potential than the Alfisols, the legume-based systems with high management sequestered more C than the cereals, the horticultural (fruit) systems and grass lands sequestered more C than the annual crop systems (Bhattacharyya *et al.*, 2007, 2007a; Sahrawat *et al.*, 2005; Ramesh *et al.*, 2007). Further, the study showed that soil under irrigated rice double cropping systems had the higher concentrations of SOC and N compared to sites under rice-upland crop sequence or other cropping systems with or without legumes (Sahrawat *et al*., 2005). Among the upland systems, the inclusion of legumes in rotation or as an intercrop, e.g., cotton plus sorghum and pigeonpea intercropping system, positively influenced the concentration of SOC (ICRISAT, 2004; Bhattacharya *et al*., 2007b; Ramesh *et al*., 2007).

All these findings on increasing C sequestration in the SAT were evaluated in the community watersheds using rainwater management as an entry point to increase and sustain the crop productivity and increase farmers' incomes. In Adarsha Watershed, Kothapally, Ranga Reddy district in Andrha Pradesh, India, crop productivity was increased by two to four folds and farmers' incomes were more than doubled in five years. By managing community watersheds holistically not only the resilience of the natural resources was built but also of the community to cope with the future challenges including due to climate change. The impact of holistic management of the natural resources in the watershed was evident during the 2002 drought year, when in Kothapally although total income was reduced (US$945 vs US$613) during drought year, the share of agriculture income in the total family income was not affected. This was not the case in untreated nearby village, where in along with reduced total income, the share of agricultural income was reduced to 12% only and farmers migrated in search of livelihoods.

In the watershed due to increased productivity and incomes from the maize/pigeonpea system enabled the farmers to move away from cotton-based system with reduction in cotton area to half and increased pigeonpea area by three folds. The results using simulation modeling showed that with farmers' conventional management practices, soil organic C in Adarsha watershed will be depleted as is observed in most farmers' situations. However, with improved management options such as planting *Glyricidia* on bunds to generate N-rich organic matter for applying in the fields, use of balanced fertilization and improved cultivars along with organic manure application would increase C stocks in soils in 30 years.

The unproductive degraded common property lands in the watersheds were rehabilitated through soil and water conservation measures and biodiesel plantation with *Jatropha* and *Pongamia* (Wani and Sreedevi, 2007). Biofuels are often seen as a major constituent part of a sustainable global energy economy, especially for the rapidly growing transport sector. One of the main concerns about rapid increase in biofuel production and consumption is that it will require large amounts of valuable agricultural land and scarce water. Combined with growing concern that climate change will reduce availability of cultivatable land in vulnerable regions (Lester, 2006) increased demand for biofuels could increase pressure on scarce water supplies in some regions and on vulnerable tropical habitats. New techniques, such as cellulosic biomass by microbial 'metabolic engineering', may produce biofuels fuels from undifferentiated biomass, requiring much less land and far lower energy inputs. This vegetable oil as energy source opportunity is harnessed by the Powerguda watershed villagers who have identified oil processing as a key growth area for the future. The village has an oil mill to process the *Pongamia* oilseeds. The women SHGs have undertaken plantation of 4500 *Pongmia Pinnata* nitrogen-fixingtrees in the degraded forests. The Powerguda village became an environmental pioneer when villagers sold the equivalent of 147 t of carbon dioxide in verified emission reduction to the World Bank. The Velchal community in Ranga Reddy district of Andhra Pradesh has established three year old plantation of Jatropha and Pongamia mix on 300 ha common property lands under fully rainfed situation. The ICRISAT-GTZ- Kirloskar Oil Limited and Government of A.P. is establishing decentralized straight vegetable oil (SVO) and energy system in the village. The oilseed cake a byproduct after extracting oil is used as a environment-friendly organic source of plant nutrients minimizing the dependence on fossil fuel-based chemical fertilizers (Wani *et al*., 2006; Wani and Sreedevi, 2007). This is an innovation system to translate the strategic research findings from invaluable long-term experiments to develop a sustainable pro-poor mechanism through harnessing the power of collective action through participatory research and development strategy in the fragile SAT ecosystem.

As agriculture systems are not yet accepted for C trading under the Kyoto Protocol we need to build good data sets and establish that agricultural systems and particularly so in the tropics are potential C sequestering systems. The tropical soils can also be very potential sinks for the carbon like the tropical forests and efforts are needed to establish these facts. The leading role soil surveyors have to play in this regard. The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) has undertaken the path breaking research in the area of C sequestration (Velayutham *et al.*, 2000; Bhattacharya *et al.*, 2007b). We need to overcome the lethargy and the feeling that the land use survey and planning is a routine activity and embrace that this area of expertise has to play very critical role in the emerging trends to cope with the challenges of climate change and food security. The role of soil survey in obtaining a global carbon budget is (1) to help people make use of stratifications unique to pedology (2) to provide data that is relevant to decisions of interest, especially the stock of carbon, (3) to help interpret the available information that itself differs in time, space and concept (4) to reduce the amount of point sampling while maintaining reliability of information. The basic survival of human beings depends on the soil productivity and we have a major responsibility on us to ensure the sustainable development and meet the millennium development goals.

References

Aleksi Lehtonen, Jari Liski, Raisa Mäkipää, Thies Eggers, Petteri Muukkonen, Taru Palosuo and Mikko Peltoniemi. (2004). Carbon budget of finish forest from 1920 to 2000. Vienna.

Bhattacharyya, T., Chandran, P., Ray, S.K., Pal, D.K., Venugopalan, M.V., Mandal, C. and Wani, S.P. (2007). Changes in levels of carbon in soils over years of two important food production zones of India. *Current Science*,93: 1854-1863.

Bhattacharyya, T., Pal, D.K., Chandran, P., Ray, S.K., Durge, S.L. and Wani, S.P.. (2007a). Available K reserve of two major crop growing regions (alluvial and shrink-swell soils) in India. *Indian Journal of Fertilisers*, 3(4), 41-46, 49-52.

Bhattacharyya, T., Chandran, P., Ray, S.K., (Mrs) Mandal, C., Pal, D.K., Venugopalan, M.V., Durge, S.L., Srivastava, P., Dubey, P.N., Kamble, G.K., Sharma, R.P., Wani, S.P., Rego, T.J., Pathak, P., Ramesh, V., Manna, M.C. and Sahrawat, K.L. 2007b. Physical and chemical properties of selected benchmark spots for carbon sequestration studies in semi-arid tropics of India. Global Theme on Agroecosystems Report no. 35. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and New Delhi, India: Indian Council of Agricultural Research (ICAR). 236 pp.

Christine, L., Goodale and Eric A. Davidson (2002). Carbon cycle: Uncertain sinks in the shrubs. Nature 418, P:593-594.

Emerson, W.W., (1995). Water retention, organic carbon and soil texture. *Australian Journal of Soil Research*, 33, 241-251.

Falkner, R. (2008). Business Power and Conflict in International Environmental Politics. Basingstoke, Palgrave.

Grubb, (1999). The Kyoto Protocol. A Guide and Assessment. London, Earth scan.

Hudson, B.D. 1994. Soil organic matter and available water capacity. *Journal of Soil and Water Conservation*, 48, 188-193.

ICRISAT (2004). Identifying systems for carbon sequestration and increased productivity in semi-arid tropical environments (National Agricultural Technology Project (NATP) Project code: RNPS 25). 2004, Project completion report submitted to the NATP Directorate, Santhosh Nagar, Hyderabad. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 277 pp.

IPCC (2007). *Climate Change 2007. The Physical Science Basis.* Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (eds) Cambridge University Press, Cambridge, UK, 996 pp.

Johnston, A.E. (1986). Soil organic matter: effects on soils and crops. *Soil Use and Management*, 2, 97-105.

Lal, R. (1999). Soil management and restoration for C sequestration to mitigate the greenhouse effect. *Progress in Environmental Science* 1, 307-326.

Lester, R. Brown (2006). The Earth Is Shrinking: Advancing Deserts and Rising Seas Squeezing Civilization, Earth Policy Institute 15 November 2006, http://www.earth-policy.org/Updates/2006/Update61.htm

Matthews, K. and M. Paterson (2005). "Boom or Dust? The Economic Engine Being the Drive for Climate Change Policy?" Global Change, Peace and Security (17): 59-75.

Paterson, M. (2001). "Risky Business. Insurance Companies in Global Warming Politics." Global Environmental Politics 1(4): 18-42.

Pathak, P., Sahrawat, K.L., Rego, T.J. and Wani, S.P. 2005. Measurable Biophysical indicators for impact assessment: changes in soil quality. In: B. Shiferaw, H.A. Freeman, H.A. and S.M. Swinton (Eds.) *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts* (Wallingford, UK: CAB International), pp. 75-96.

Ramesh, V., Wani, S.P., Rego, T.J., Sharma, K.L., Bhattacharyya, T., Sahrawat, K.L,, Padmaja, K.V., Gangadhar Rao, D., Venkateswarlu, B., Vanaja, M., Manna, M.C., Srinivas, K. and Maruthi, V. (2007). *Chemical Characterization of Selected Benchmark Spots for C Sequestration in the Semi-Arid Tropics, India*. Global Theme on Agroecosystems Report no. 32. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT); and New Delhi, India: Indian Council of Agricultural Research (ICAR), 106 pp.

Rego, T.J., Nageswara Rao, V., Seeling, B., Pardhasaradhi, G. and Kumar Rao, J.V.D.K.. (2003). Nutrient balances – a guide to improving sorghum – and groundnut based dryland cropping systems in semi-arid tropical India. *Field Crops Research*, 81, 53-68.

Sahrawat, K.L., Bhattacharyya, T., Wani, S.P., Chandran, P., Ray, S.K., Pal, D.K. and Padmaja, K.V. (2005). Long-term lowland rice and arable cropping effects on carbon and nitrogen status of some semi-arid tropical soils. *Current Science*, 89, 2159-2163.

Sekikawa, S., Kibe, T., Koizumi, H. and Mariko, S. (2003). Soil Carbon Budget in Peach Orchard Ecosystem in Japan. Environmental Science. VOL.16, P:97-104.

Velayutham, M., Pal, D.K. and Bhattacharyya, T. (2000) Organic carbon stock in soils of India. In: Lal, R., Kible, J.M. and Stewart, B.A. (eds.) Advances in Soil Science. Global Climate Change and Tropical Ecosystems. CRC Press, Boca Raton, Florida, pp. 71–95.

Yandle, B. and Buck S. (2002). "Bootleggers, Baptists, and the Global Warming Battle." Harvard Environmental Law Review 26(1): 177-229.

Wani, S.P., Rego, T.J., Rajeswari, S. and Lee, K.K. (1995). Effect of legume-based cropping systems on nitrogen mineralisation potential of Vertisol. *Plant and Soil* 175, 265–274.

Wani, S.P., Pathak, P., Jangawad, L.S., Eswaran, H. and Singh, P. (2003). Improved management of Vertisols in the semiarid tropics for increased productivity and soil carbon sequestration. *Soil Use and Management*, 19, 217-222.

Wani, S.P., Osman, M., Emmanuel, D'Silva and Sreedevi, T.K. (2006). Improved Livelihoods and Environmental Protection through Biodiesel Plantations in Asia. Asian Biotechnology and Development Review. Vol. 8. No. 2, pp.11-29.

Wani, S.P., Sahrawat, K.L., Sreedevi, T.K., Bhattacharyya, T. and Sreenivasa Rao, Ch.. (2007). Carbon sequestration in the semiarid tropics for improving livelihoods. International Journal of Environmental Studies, Vol. 64, No. 6, December 2007. 719-727.

Wani, S.P. and Sreedevi, T.K. (2007). Strategy for Rehabilitation of Degraded Lands and Improved Livelihoods through Biodiesel Plantations. *In* proceedings of 4th International Biofuels Conference held during 1-2 February 2007 at New Delhi. pp. 50-64