International Journal of Environmental Studies,
Vol. 64, No. 6, December 2007, 719–727

Carbon sequestration in the semi-arid tropics for improving livelihoods

S.P. WANI*†, K.L. SAHRAWAT†, T.K. SREEDEVI†, T. BHATTACHARYYA‡ AND CH. SREENIVASA RAO†

†International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India, ‡National Bureau of Soil Survey and Land Use Planning, Nagpur 440 010, Maharashtra, India

(Received 31 October 2007)

This paper reviews the research conducted by ICRISAT and its partners on the role of management systems on carbon sequestration and crop productivity in the semi-arid regions of India. It is now established that apart from water shortages, the dryland productivity is also constrained by low fertility mainly caused by the low organic matter status of most soils. Sequestration of atmospheric carbon dioxide in the soil has the potential to achieve the multiple objectives of improving the soil quality and fertility of the semi-arid tropical soils, increasing crop productivity, improving livelihoods and maintaining environmental quality.

Keywords: Soil quality; Low fertility; Carbon sequestration and soil fertility; Environmental quality; Semi-arid tropical soils; Dryland farming

Introduction

In the semi-arid tropical (SAT) regions, farmers suffer from water shortages. In addition, they face low rainwater use efficiency in terms of crop production. This is largely caused by inappropriate soil and water management and soil infertility. These are the major constraints to agricultural productivity and the reason for the low incomes of farmers. Indeed, maintenance of soil fertility in the SAT, a prerequisite for sustainable increase in productivity, is a major challenge to researchers and farmers alike. Soils in the SAT regions are low in organic matter and nutrient reserves. Prevailing production systems do not support sufficient inputs of organic matter for the maintenance of soil organic matter levels and hence soil quality.

In addition, under rainfed agriculture, the application of nutrients and organic matter through external sources is generally low, largely because of water scarcity, socioeconomic conditions of the farmers and the competing use of the crop residues; and the use of mineral fertilizers is confined to irrigated crops. Moreover, due to prevailing high temperature, drying and wetting cycles and low inputs of organic matter, the organic matter levels in the SAT soils are very low and usually present a declining trend.

*Corresponding author. Email: S.WANI@cgiar.org

International Journal of Environmental Studies
ISSN 0020-7233 print: ISSN 1029-0400 online
http://www.tandf.co.uk/journals
DOI: 10.1080/00207230701778262

Policy-makers, development agencies and researchers face a need for sustainable development and an obligation to improve the livelihoods of millions of poor in the SAT to meet the Millennium Development Goal (MDG) by 2015. The decline in agricultural productivity of the SAT soils can at least be partly attributed to human activity which has reduced soil quality. There is a direct link between soil quality and agricultural productivity on the one hand, and soil organic carbon (C) and soil quality on the other [1–3].

In the SAT, rainwater management is used in a holistic, watershed management approach to increase agricultural productivity and incomes by enhancing rainwater use efficiency through improved soil quality, efficient water and nutrient management options along with improved crops, cultivars and pest management practices [4]. The main objective of this paper is to offer a synthesis of research which demonstrates how C sequestration in the SAT soils could be enhanced. This would reduce poverty through sustainable development, using rainwater management as an entry point.

Results and discussion

Agricultural management practices influence the soil quality. This in turn impacts the productivity of soils. An increase in the soil's organic carbon pool favourably influences crop productivity by increasing the water holding capacity of the soil; improving the soil's physical properties, especially soil–water–air relations and improved supply of nutrients [3,5–7]. Moreover, the soil's organic carbon pool drives soil biological activity, which controls nutrient availability and overall nutrient cycling [8].

Rainfed agriculture is predominant (80%) globally. In developing Asia, it constitutes 60–65% and in Africa almost 90–95% [9]. Unlike the holistic approach taken for irrigated agriculture in green revolution areas in Asia, rainfed subsistence agriculture has been dealt with in compartments, such as soil conservation, water management, improved cultivars, fertilizer application, etc. The full potential of the technologies has not been realized nor have these been adapted on a sufficiently large scale to have substantial impact.

In Asia, a number of countries adopted a watershed management approach to develop rainfed agriculture to increase agricultural productivity. In India, until 2006, the Government of India invested about US$ 6 billions treating 38.5 M ha through a watershed development program. However, average crop yields under rainfed agriculture hover around 1–1.5 t ha^{-1} and are much lower than the achievable potential yields [9]. Meta-analysis of 311 case studies of watershed projects in India revealed that although watershed programs silently revolutionized rainfed agriculture, their vast potential could not be harnessed because of the compartmental approach, lack of community participation, inappropriate institutions, the lack of technical support, etc. [10].

Wani *et al.* [3] reported the results of a long-term heritage watershed experiment initiated in 1976 at the ICRISAT Centre, Patancheru, Andhra Pradesh, under rainfed conditions to test the hypothesis that an improved system of catchment management in combination with an appropriate cropping system can sustain increased productivity and improve the soil quality of Vertisols, compared with the existing traditional farming practices. The improved system consisted of implementing soil and water conservation practices, with excess rainwater being removed in a controlled manner. The soil and water conservation practices were combined with improved, legume-based crop rotation and improved nutrient management. In the traditional system, sorghum or chickpea was grown in the post-rainy season with organic fertilizers, and in the rainy season, the field was maintained as a cultivated fallow.

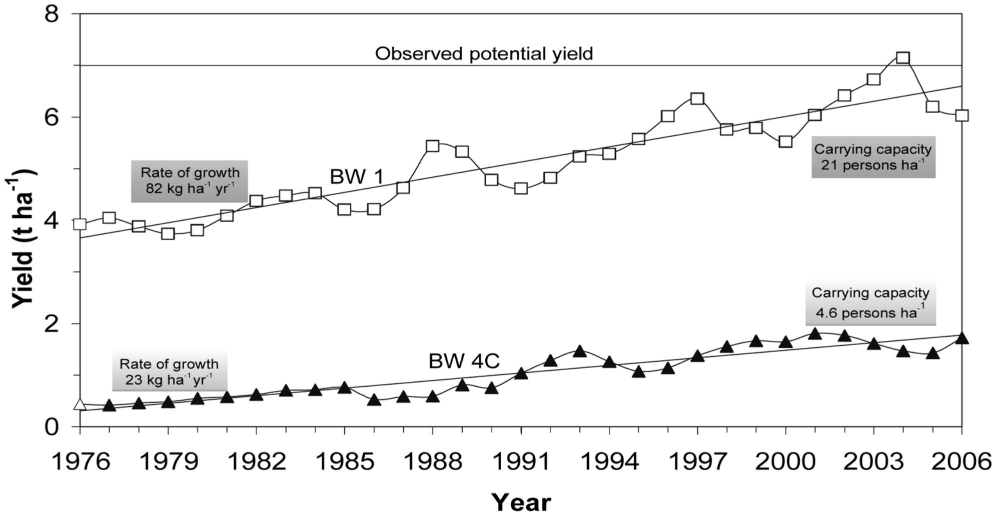

Figure 1. Three-year moving average of sorghum and pigeon pea grain yield under improved and traditional management in a deep Vertisol catchment at Patancheru, India.

The updated results from this study (figure 1) show 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 (figure 1). The improved system has 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 contains 46.8 t C ha^{-1} in the 0-120 cm soil profile as compared to the traditional management practices that contained 39.5 t C ha^{-1} (table 1). This amounts to a gain of about 7.3 t C ha^{-1} over the 24-year period ending in 2000. Overall, the improved system shows increased rainwater use efficiency (65% versus 40%), reduced runoff from 220 mm 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) [3].

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 [11].

The results of another long-term experiment with various cropping systems on Vertisols showed that the legume-based systems were more sustainable than the systems which were cereals only [2,12]. 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 of increased crop productivity as compared to the fallow-sorghum system [2]. 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, the Vertisols had higher soil organic C (SOC) and inorganic (carbonates) C

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 0–60	60–120	SE±
Soil respiration	Improved	723	342	7.8
(kg C ha^{-1})	Conventional	260	98	
Microbial biomass	Improved	2676	2137	48.0
(kg C ha^{-1})	Conventional	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	2684	1928	156.6
(kg N ha^{-1})	Conventional	2276	1884	
Olsen P	Improved	6.1	1.6	0.36
(kg P ha^{-1})	Traditional	1.5	1.0	

stocks in Vertisols than the Alfisols. Among the cropping systems, soybean-based systems had the highest SOC stock, whereas the sorghum-based system showed the highest soil inorganic C (SIC) in the 1.05 m soil depth (Ch. Srinivasa Rao, 2007, personal communication).

A study was conducted by ICRISAT and its partners 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 [13]. 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 [14–17]. Further, the study showed that soil under irrigated rice double cropping systems had higher concentrations of SOC and N than sites under a rice-upland crop sequence or other cropping systems with or without legumes [16]. Among the upland systems, the inclusion of legumes in rotation or as an intercrop, for example, cotton plus sorghum and pigeonpea intercropping system, positively influenced the concentration of SOC [17].

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 [4]. In Adarsha Watershed, Kothapally, Ranga Reddy district in Andrha Pradesh, India, crop productivity was increased two to four fold (table 2); and farmers' incomes were more than doubled in five years. 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 versus US$ 613) by drought, the share of agriculture income in the total family income was not affected (figure 2). This was not the case in an untreated village nearby, where along with reduced total income, the share of agricultural income was reduced to 12% only and farmers migrated in search of livelihoods.

Table 2. Crop yields in Adarsha watershed Kothapally, Andhra Pradesh, India during 1999–2006.

Crop	1998 base-line yield	Yield (Kg ha $^{-1}$)									
		1999–2000	2000–2001	2001–2002	2002–2003	2003–2004	2004–2005	2005–2006	2006–2007	Average yields	SE±
Sole maize	1500	3250	3750	3300	3480	3920	3420	3920	3630	3640	283.3
Intercrop maize Traditional	–	2700	2790	2800	3083	3130	2950	3360	3180	3030	263.0
	–	700	1600	1600	1800	1950	2020	2270	2150	1785	115.6
Intercrop pigeonpea Traditional	190	640	940	800	720	950	680	920	970	860	120.3
		200	180	–	–	–	–	–	–	190	–
Sole sorghum Traditional	–	3050	3170	2600	2425	2290	2320	2250	2080	2530	164.0
	1070	1070	1010	940	910	950	1025	1080	990	1000	120.7
Intercrop Sorghum	–	1770	1940	2200	–	2110	1980	1960	1850	1970	206.0

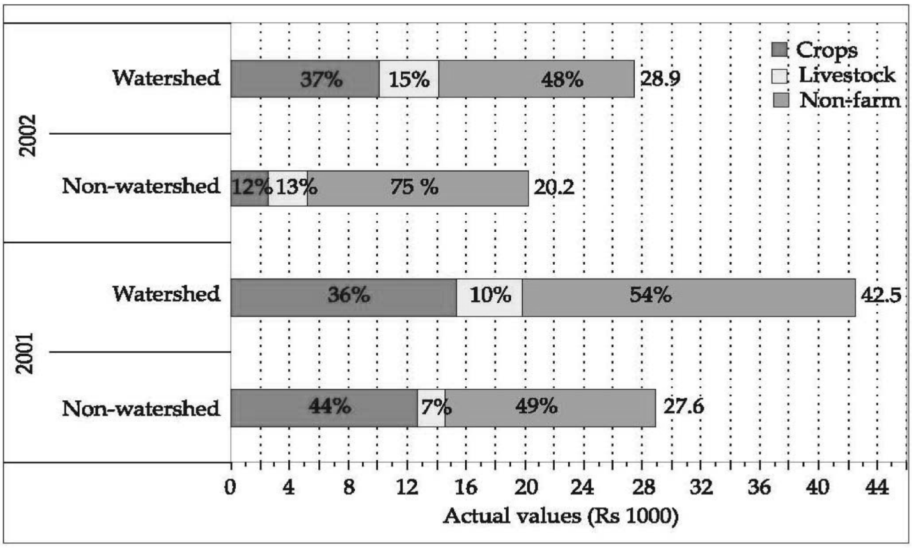

Figure 2. Income stability and resilience effects during drought year (2002) in Adarsha watershed, Kothapally, AP, India.

In the watershed with increased productivity of maize/pigeonpea and sorghum/pigeonpea intercropping systems, farmers shifted from cotton crop to maize/pigeonpea and sorghum/pigeonpea intercrops; and the area under pigeonpea increased from 60 ha in 1999 to 180 ha in 2006. The productivity (biomass and grain) of pigeonpea increased due to the planting of a wilt-tolerant improved cultivar along with improved management; and this increased the area under pigeonpea-based systems. We used simulation modelling to assess the role of the pigeonpea crop in the production systems at Kothapaplly watershed in Andhra Pradesh, using the CENTURY model version 5 [18]. The results showed that with farmers' conventional management practices, soil organic C will be depleted as is observed in most farmers' situations. However, with proved 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, there would be increased C stocks in soils in 30 years [19]. These results of the simulation study on the role of pigeonpea in the cropping systems are in accord with those observed in the long-term experiment conducted at the ICRISAT farm in Patancheru, India [3].

In the watersheds, along with the cultivated lands, unproductive wastelands also exist on a toposequence. Our continuing work showed that in such unproductive areas, with the implementation of soil and water conservation practices, non-edible oil legume trees such as *Pongamia* could be successfully grown. These plants, once established, can rehabilitate degraded lands and also provide stable source of income to the rural poor through the sale of oil seeds used for extracting oil for use as a source of renewable energy. In the Powerguda village in the Jainoor mandal of Adilabad district, about 30 km east of Utnoor town in Andhra Pradesh, India, the creation of hamlet-level self-help groups (SHGs), headed by women, empowered local communities and served as an important social instrument in the fight against poverty. Public investment in watershed management and implementation of improved agricultural practices helped to transform the livelihoods of indigenous poor farmers.

As a result of the watershed project and the implementation of improved agricultural management practices and community empowerment, average household incomes increased by 77% over three years [20]. More importantly, the Powerguda villagers 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-led SHGs have undertaken plantation of 4500 *Pongmia Pinnata* trees in the degraded forests. In October 2003, 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 emission reduction was calculated on the basis of 51 t of *Pongamia* seed oil substituting for petroleum diesel over 10 years (table 3). The World Bank paid US$ 645 to Powerguda to neutralize the emissions from air travel and local transport by international participants attending an international conference in Washington, DC, USA held on 19–21 October 2003. This was the first time that the multilateral agency made a direct payment to an Indian village for exporting environmental services. This should not be seen as a token but read as a signal for wider change.

Further, the oil seed cake, a by-product after the extraction of oil from the seeds, is an excellent source of plant nutrients and organic carbon for improving the soil quality and productivity [21]. The application of N to maize and cotton through *Pongamia* seed cake was found to be far superior for increasing maize and cotton yields as compared to the N supplied through fertilizer [21]. The *Pongamia* nursery with a capacity of 20,000 saplings should be able to meet oil need, and even produce a surplus, which can be sold to the forest department as an effort in community forest management. This is environmental change at the grassroots level. This is the sustainable development of village India.

Perspectives

The conversion of natural to agricultural ecosystems generally depletes the soil organic carbon pool in the dryland soils of the SAT regions; and Indian agricultural systems in the

Table 3. Carbon calculations for Powerguda village in Andhra Pradesh, India, 2003–2012.

Year	Oil yield (kg)	Trees	Total oil yield (kg)	C (t)	CO_2 eq (t)	Value (US$)	Discount value (at 3%)	NPV
2003		3600	410	0.3198	1.1737	6.7158	1	6.7158
2004			494	0.38532	1.41412	8.09172	0.97	7.84897
2005			590	0.4602	1.68893	9.6642	0.94	9.08435
2006	0.5		1125	0.8775	3.22043	18.4275	0.91	16.769
2007	1		3600	2.808	10.3054	58.968	0.88	50.7125
2008	1.5		5400	4.212	15.458	88.452	0.85	51.8918
2009	2		7200	5.616	20.6107	117.936	0.82	96.7075
2010	2.5		9000	7.202	26.4313	151.242	0.79	119.481
2011	3		10,800	8.424	30.9161	176.904	0.76	134.447
2012	3.5		12,600	9.828	36.0688	206.388	0.73	150.663
			51,219	40.1328	147.287	842.789		644.321

1. Carbon emission reduction from fuel switch (from petroleum diesel to *Pongamia* oil) is 78%.
2. Carbon value is calculated at US$ 21 t^{-1} of carbon, or US$ 5.722 t^{-1} of CO_2 equivalent.
3. Present values are discounted at 3%.
4. *Pongamia* trees planted in June 2003 will produce oil from 2006.
5. Survival rate for plants is assumed at 85% of 4500 trees 3600 trees.
6. Oil yields in 2003, 2004 and 2005 are extracted from *Pongamia* seeds collected in nearby forest.

drylands are no exception. However, adoption of restorative and conservation resource management practices have the potential to enhance soil organic carbon; and also the implementation of these practices leads to the formation of secondary carbonates (common in the SAT soils of India) in the soil profile, resulting in the sequestration of C through soil inorganic C [22].

In the SAT areas, the challenging task of maintaining soil organic matter, increasing agricultural productivity, reducing rural poverty and most importantly, reducing atmospheric concentration of $CO_{2,}$ can be confronted through increased C sequestration measures. Rainwater management, as an entry point to holistic community watershed management, provides the opportunity for the efficient management of natural resources to reduce poverty, leading to sustainable development. Diversification of rainfed systems with high-value legumes such as groundnut, soybean, pigeonpea, greengram, etc., not only improves systems' sustainability in the fragile rainfed ecosystems but also contributes significantly in protecting the environment. Rehabilitation of degraded lands with *Pongamia Pinnata* and income from the sale of carbon units and oil can benefit the poor. These good case studies in the SAT areas demonstrate – irrefutably – that developing C markets and biofuel initiatives can be harnessed to benefit the poor and reduce poverty, while maintaining environmental quality.

Nevertheless, there is an urgent need to develop pro-poor mechanisms for the sale of carbon units as an alternative to the certified emission mechanism under the Kyoto Protocol. The rainwater can be managed more efficiently by adopting a small catchment approach, which is distinctly different from water management at the river basin scale. The holistic use of rainfed agriculture is superior to the traditional compartmental approach. Through the convergence of related purposes, we can achieve multiple benefits from the investments made in the watershed development program. The sequestering of atmospheric carbon dioxide in the soil is a win-win strategy because the sequestration of C improves the soil quality and productivity on one hand and maintains environmental quality on the other. If Mahatma Gandhi were alive today, he would say that this is one way to serve the people and to keep alive village India.

References

[1] Lal, R., 2004, Soil carbon sequestration impacts on global climate change and food security. *Science,* **304,** 1623–1627.

[2] 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.

[3] 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.

[4] Wani, S.P., Singh, H.P., Sreedevi, T.K., Pathak, P., Rego, T.J., Shiferaw, B. and Iyer, S.R., 2003, Farmer-participatory integrated watershed management: Adarsha watershed, Kothapally, India, An innovative and upscalable approach. A case study, in: R.R. Harwood and A.H. Kassam (Eds) *Research towards integrated natural resources management: Examples of research problems, approaches and partnerships in action in the CGIAR* (Washington, DC: Interim Science Council, Consultative Group on International Agricultural Research), pp. 123–147.

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

[6] Emerson, W.W., 1995, Water retention, organic carbon and soil texture. *Australian Journal of Soil Research,* **33,** 241–251.

[7] 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 and S.M. Swinton (Eds) *Natural Resource Management in Agriculture: Methods for Assessing Economic and Environmental Impacts* (Wallingford: CAB International), pp. 75–96.

[8] Johnston, A.E., 1986, Soil organic matter: effects on soils and crops. *Soil Use and Management,* **2,** 97–105.

[9] Rockström, J., Hatibu, N., Theib, O. and Wani, S.P., 2007, Managing water in rainfed agriculture, in: D. Molden (Ed.) *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture* (London: Earthscan/Colombo, Sri Lanka: International Water Management Institute), pp. 315–348.

[10] Joshi, P.K., Jha, A.K., Wani, S.P., Tewari, L. and Shiyani, R.L., 2004, Meta-Analysis to Assess Impact of Watershed Program and People's Participation. Global Theme on Agroecosystems. Report No.12, Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics, 20 pp.

[11] Lal, R., 1999, Soil management and restoration for C sequestration to mitigate the greenhouse effect. *Progress in Environmental Science,* **1,** 307–326.

[12] 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.

[13] 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.

[14] Bhattacharyya, T., Chandran, P., Ray, S.K., Pal, D.K., Venugopalan, M.V., Mandal, C., and Wani, S.P., forthcoming, Changes in levels of carbon in soils over years of two important food production zones of India. *Current Science.*

[15] Bhattacharyya, T., Pal, D.K., Chandran, P., Ray, S.K., Durge, S.L. and Wani, S.P., 2007, 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.

[16] 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.

[17] 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.

[18] Parton, W.J., Schimel, D.S., Cole, C.V. and Ojima, D.S., 1987, Analysis of factors controlling soil organic matter levels in Great Plain grasslands. *Soil Science Society of America Journal,* **51,** 1173–1179.

[19] Shrivastava, M., 2006, Simulating Carbon Sequestration at Micro-Watershed Scale With Changes in Cropping Pattern and Management Systems. Major Project Report, in partial fulfillment of the requirements for the degree of mater of Master of Science in natural resources management, submitted in June 2006 to the Department of Natural Resources, TERI School of Advanced Studies, IHC, Lodhi Road, New Delhi, India.

[20] D'Silva, E., Wani, S.P. and Nagnath, B., 2004, The Making of New Powerguda: Community Empowerment and New Technologies Transform a Problem Village in Andhra Pradesh. Global Theme on Agroecosystems Reoprt no. 11. Patancheru 502 324, Andhra Pradesh, India:. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), 28 pp.

[21] Wani, S.P., Osman, M, D'Silva, E. and Sreedevi, T.K., 2006, Improved livelihoods and environmental protection through biodiesel plantations in Asia. *Asian Biotechnology and Development Review,* **8**(2), 11–29.

[22] Sahrawat, K.L., 2003, Importance of inorganic carbon in sequestering carbon in soils of the dry regions. *Current Science,* **84,** 864–865.