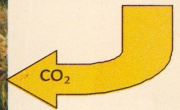
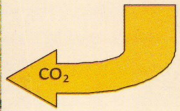
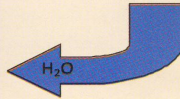


CARBON SEQUESTRATION DURING REHABILITATION OF DEGRADED HILLS



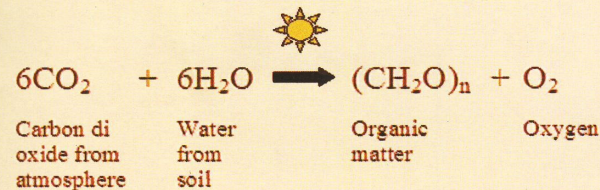
ARID FOREST RESEARCH INSTITUTE

(Indian Council of Forestry Research & Education)

New Pali Road, Jodhpur-342005

Human activities including land use changes have increased, and will continue to increase, the concentration of the atmosphere carbon-di-oxide (CO_2). From values of about $280 \mu\text{mol mol}^{-1}$ (part per million, ppm) between the end of the last glaciation and about 1750 AD, atmospheric CO_2 has increased to about $393.8 \mu\text{mol mol}^{-1}$ in 2012. This value may increase to about $550 \mu\text{mol mol}^{-1}$ by 2050. Small scale experiments indicate that the higher CO_2 levels increase the rate of photosynthesis and plant productivity. However, limitation by water supply in semi-arid and arid areas, and by the supply of photosynthetically active radiation in the humid tropics may affect land productivity and carbon sequestration in vegetation as well as in soils.

Afforestation and forests development may play a critical role in regulating the climate through the carbon cycle; removing carbon from the atmosphere through the photosynthesis as they grow, and storing carbon in leaves, woody tissue, roots and organic matter in soil. Photosynthesis is a process by which plants synthesize organic matter (glucose) and release oxygen after taking carbon dioxide from atmosphere, light from sun and water from the soil as indicated by equation provided below:



Strategies for mitigating global warming aim both at reducing the emission of green house gases (GHGs) from the various source as well as developing sinks that can absorb GHGs (CO_2 in particular). Possible ways of CO_2 sequestration are geological, ocean, mineral and biological, and terrestrial. Forests alone contain 234 billion tonnes carbon in vegetation, 62 billion tonnes in roots, 41 billion tonnes in dead wood, 23 billion tonnes in litters and 398 billion tonnes in soils throughout the world. Soils are the third largest storage of carbon globally, that store about 2.5 times the amount of carbon

in the atmosphere and almost 3 times the amount of carbon in the vegetation. In soil, carbon sequestration CO_2 is removed from the atmosphere and stored in the soil in the form of soil organic carbon (SOC) - primarily mediated by plants through photosynthesis. However, in arid and semi-arid climates, soil carbon sequestration also occurs from the conversion of CO_2 from air (available in the soil) into inorganic forms such as secondary carbonates, though the rate of inorganic carbon formation is comparatively low.

Measures to enhance the growth in primary forests, to facilitate secondary growth, and increasing plantation areas would increase the carbon sink. While forest mitigation activities and policies aimed at reducing forest degradation and deforestation increase the sink size, rehabilitation of degraded areas including the Aravalli hills is expected to become increasingly important in such endeavor. In a process of developing regional strategies for rehabilitation of degraded lands and mitigation of climate change involving forests will require complex analyses of the trade-offs between different land-uses like forestry and other land uses, forest conservation for carbon storage and other environmental services, i.e. biodiversity and watershed conservation, and sustainable forest harvesting to provide society fodder, timber and bio-energy resources.

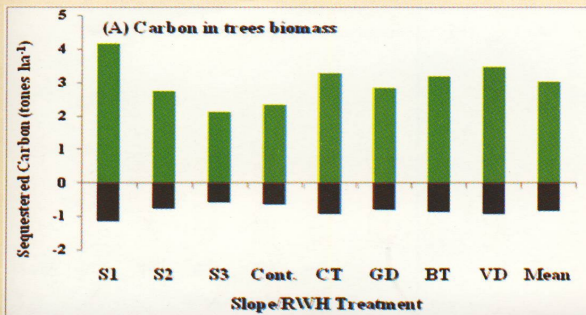
For such regional strategies and to have a knowledge on the role of rainwater harvesting on rehabilitation work (carried out in Baranandra Kho forest block area of Chhataripada/Gauapada village in Banswara district of Rajasthan and covers an area of about 17 ha) and corresponding carbon sequestration an assessment of carbon stock has been done in vegetation (belowground and aboveground biomasses of trees, shrubs, bamboo and herbaceous layer) as well as in the soils. In the experiment, rehabilitation of hills was done in varying slope categories viz. <10%, 10-20% and >20% slopes though afforestation under mixed plantation and adopting (excluding a control) four different RWH devices viz. contour trench (CT), gradonie trench (GD), box trench (BT) and V-ditch (VD). This work has been conducted under the project '**Efficacy and economics of water harvesting devices in controlling run-off losses and enhancing biomass**

productivity in Aravalli Ranges'.

As several factors influence the potential carbon content of the plants, for example: the density of plantation, survival and growth rate, change in stock through regeneration etc., the carbon sequestration calculations in vegetation has been done based on the actual measurement of trees, shrubs, bamboo (*Dendrocalamus strictus*) and herbaceous biomass. Above-ground and below ground biomasses were estimated using regression equations from the literature (based on collar diameters/basal area and above-ground biomass, respectively). For carbon content calculation, a factor of 0.48 was applied for tree, shrubs and bamboo oven dry biomasses and 0.43 for herbaceous dry biomass. Soil carbon stock was calculated based on an estimated organic carbon and bulk density of the soils.

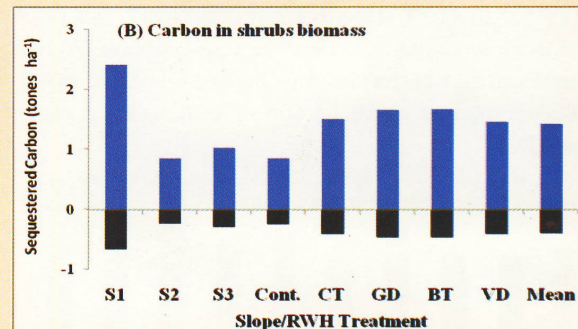
The rehabilitation work proved best in terms of increased carbon in terms of growth because of facilitative effects of RWH and afforestation promoting regeneration of herbaceous vegetation and development of soil and soil organic matter. Carbon sequestered in different plant habits (tree, shrubs, bamboo and herbaceous vegetation), different components like root (below ground biomass) and shoots (above-ground biomass) and soils are described here:

Carbon sequestration in trees: Net carbon sequestered in both above- and below-ground trees (*Acacia catechu*, *Acacia nilotica*, *A. leucophloea*, *A. senegal*, *Butea monosperma*, *Emblica officinalis*, *Holoptelea integrifolia*, *Tectona grandis*, *Prosopis juliflora* and *Zizyphus mauritiana* etc.)



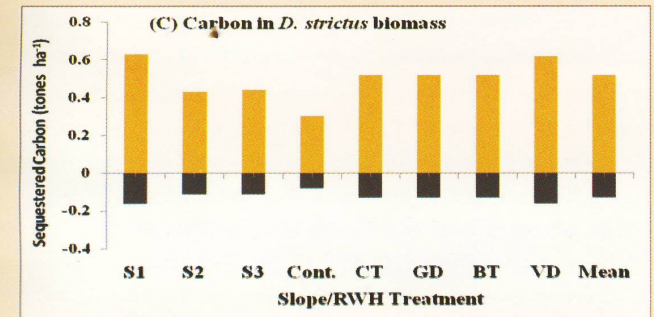
biomasses were highest in <10% slope (S₁) and decreased upslopes (S₂ and S₃). Among RWH treatments, sequestered carbon was lowest in the control plots and highest in VD plots, i.e. 0.93 tone (t) ha⁻¹ in roots (negative bars) and 3.45 t ha⁻¹ above-ground (positive bars). Effects of RWH was such that in increased carbon storage in tree biomasses by 20.8%, 33.7%, 39.9% and 46.0%, respectively in GD, BT, CT and VD plots (Figure A). Average C-sequestered in tree biomass was 3.01 t C ha⁻¹.

Carbon sequestration in Shrubs: Carbon sequestered in shrubs (*Calotropis procera*, *Capparis sepiaria*, *Helicteres isora*, *Indigofera argentea*, *Jatropha curcas*, *Lantana camara*, *Zizyphus nummularia* etc.) ranged from 1.08 t ha⁻¹ in 10-20% slope to 3.07 t ha⁻¹ in <10% slope area.



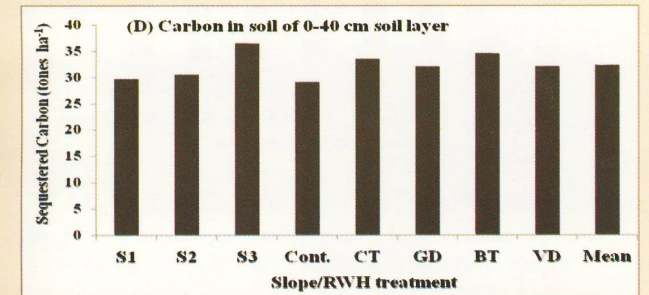
It ranged from 1.09 t ha⁻¹ in the control plot to 2.13 t ha⁻¹ in BT plots (Figure B). Average carbon sequestered in above-ground and below-ground biomasses of shrubs were 1.43 t ha⁻¹ and 0.39 t ha⁻¹, respectively. Shrubs in VD, CT, GD and BT plots sequestered 73.3%, 76.4%, 94.7% and 96.4% higher carbon as compared to the shrubs in the control plots.

Carbon sequestration in Bamboo : Carbon sequestered in bamboo (*Dendrocalamus strictus*) was to the level of 0.54 t ha⁻¹ in 10-20% slope to 0.80 t ha⁻¹ in <10% slope with mean value of 0.65 t C ha⁻¹.

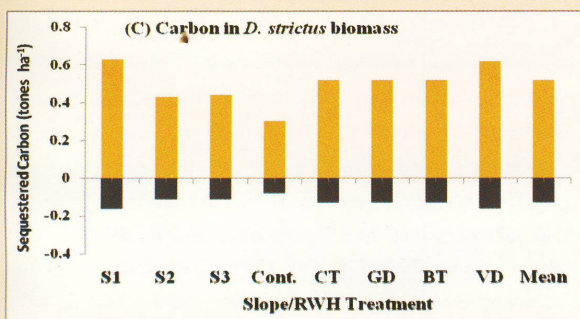


The variations in sequestered carbon were 0.38 t C ha⁻¹ in the control plots to 0.79 t C ha⁻¹ in the VD plots (Figure C). Average contribution of root and shoot (above-ground) to the total carbon sequestered were 0.13 t C ha⁻¹ and 0.51 t C ha⁻¹, respectively.

Carbon sequestration in soils: Carbon sequestration in soils is mediated through plants photosynthesis, root turn-over, root exudates and litter decompositions. These processes resulted in carbon accumulation up to 29.8 t C ha⁻¹ in <10% slope to 36.6 t C ha⁻¹ in >20% slope. RWH treatments enhanced carbon sequestration, which ranged from 32.1 t C ha⁻¹ in VD plots to 34.6 t C ha⁻¹ in BT plots as compared to 29.2 t C ha⁻¹ in the control plots (Figure D).

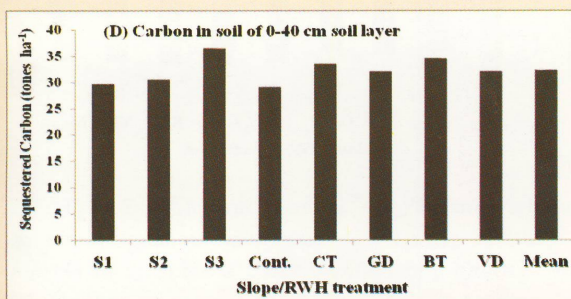


Total carbon sequestered in 65 months (value in 2010 – value in 2005) in both vegetation and soils ranged from 23.86 to 36.94 t C ha⁻¹. Among the slopes it varied from 29.92 t C ha⁻¹ in <10% slope to 34.08 t C ha⁻¹ in >20% slope (probably due to greater rate of soil formation). Sequestered carbon ranged from 30.29 t C ha⁻¹ in GD plots to 32.64 t C ha⁻¹ in BT plots as compared to 25.29 t C ha⁻¹ in the control plots (Table 1). This indicates the impact of these activities in restoration and



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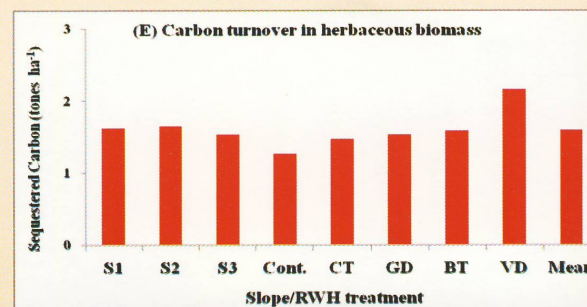
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consequent effects on carbon sequestration in vegetation and soils. Annual rate of carbon sequestration were 1.10 t C ha⁻¹ year⁻¹ in vegetation and 4.93 t C ha⁻¹ year⁻¹ in soils. **Interestingly, out of 6.13 t C ha⁻¹ sequestered in total biomass, the contribution through plantation was 1.45 t C ha⁻¹, whereas the rest, i.e., 4.68 t C ha⁻¹ was through regeneration promoted through RWH and protection measures.**

Table 1. Carbon stock (tone ha⁻¹) and sequestration (tone ha⁻¹ year⁻¹) in vegetation and soil (0-40 cm soil layer) in different slopes and the RWH treatments during rehabilitation of degraded hills.

Slope	Treatment	Vegetation				Soil			Total sequestered amount (t C ha ⁻¹)			Sequestration (t C ha ⁻¹ y ⁻¹)	
		June 2005	Dec. 2010	June 2005	June 2010	June 2005	June 2010	June 2005	June 2010	Veg.	Soil	Total	Veg.
<10%	Control	0.37	7.41	11.31	28.13	7.04	16.82	23.86	1.30	3.37			
	Contour trench	0.25	8.58	6.69	33.74	8.33	27.05	35.38	1.54	5.41			
	Gradonie	0.19	8.84	10.64	30.87	8.64	20.23	28.87	1.60	4.05			
	Box trench	0.30	9.83	7.34	29.62	9.55	22.28	31.83	1.76	4.45			
	V-ditch	0.21	10.68	7.12	26.36	10.46	19.19	29.65	1.93	3.84			
10-20%	Control	0.17	2.74	6.29	29.42	2.57	23.13	25.70	0.48	4.62			
	Contour trench	0.19	6.79	6.16	24.87	6.61	18.72	25.33	1.22	3.74			
	Gradonie	0.28	4.26	7.14	29.57	3.99	22.43	26.42	0.74	4.49			
	Box trench	0.22	5.45	9.24	34.81	5.23	25.56	30.79	0.97	5.11			
	V-ditch	0.38	5.53	9.63	34.10	5.97	24.47	30.44	1.10	4.89			
>20%	Control	0.20	2.64	6.08	29.92	2.45	23.86	26.31	0.45	4.77			
	Contour trench	0.22	4.30	8.99	41.86	4.07	32.87	36.94	0.75	6.58			
	Gradonie	0.18	5.71	5.83	35.86	5.53	30.04	35.57	1.02	6.01			
	Box trench	0.17	4.86	8.78	39.37	4.70	30.59	35.29	0.87	6.12			
	V-ditch	0.19	4.33	3.69	35.83	4.15	32.14	36.29	0.77	6.42			
Average		0.23	6.13	7.67	32.29	5.95	24.62	30.57	1.10	4.93			

In addition, there was turnover of about 1.60 t C ha⁻¹ in herbaceous vegetation harvested per year, though its root added to the soil organic carbon pool. It ranged from 1.53 t C ha⁻¹ in >20% slope to 1.62 t C ha⁻¹ in <20% slope. Among RWH treatments, it ranged from 1.47 t C ha⁻¹ in CT plots to 2.16 t C ha⁻¹ in VD plots (as compared to 1.26 t C ha⁻¹ in the control plots).



Restoration efforts at the Bara Nandra Kho site generated significant carbon benefits in vegetation as well as in soils. Rainwater harvesting, afforestation and protection measures generated carbon benefits (net sequestration) of about 519.69 tones (17 × 30.57 t C ha⁻¹) at 65 months across the slopes and RWH treatments. It means net removal of atmospheric CO₂ in this area equals about 1905.53 tonnes (519.69×44/12). However, the amount of carbon sequestered in soil is about four times to that sequestered in vegetation. Net amount of carbon sequestered in soil was highest in contour trench plots, followed by Box trench plots, whereas the amount of carbon sequestered in vegetation was highest in V-ditch plots, followed by Box trench plots.

Conclusively, rainwater harvesting, afforestation and protection measures help in conservation of soil and water that improves microclimate and favour restoration process. By this way it facilitates regeneration and help in climate change mitigation, i.e. carbon sequestration in vegetation as well as in soil. Contour trench and V-ditch found the best and can be replicated in other similar areas. Let us come to replicate this model suitably for degraded hills/lands restoration, biodiversity improvement and conservation and climate change mitigation.

By: Dr. G. Singh, Scientist F
E mail: gsingh@icfre.org

Published by: Director, AFRI, Jodhpur

For details Contact:

Group Coordinator Research

Arid Forest Research Institute

P.O. Krishi Upaj, Mandi, New Pali Road, Jodhpur-342005,
Rajasthan, India

Visit us at: www:afri.res.in

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Front cover photos: Degraded hill in May 2005 (top),
Emblica officinalis in 2006 (Middle) and a mixed
vegetation in October 2010 (Bottom).