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Biomass and carbon stock production using multipurpose trees for rehabilitation and resource conservation in deep Chambal ravines of Madhya Pradesh, India

Y.P. Singh[1], R.B. Sinha[2], Sudhir Singh[3], S. Kala[4,*], Ashok Kumar Singh[4] and A.K. Singh[3]

[1]*AICRP-IWM, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Morena, Madhya Pradesh;* [2]*Department of Agricultural Cooperation and Farmers Welfare, Ministry of Agricultural, Government of India, New Delhi;* [3]*College of Agriculture, Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior, Madhya Pradesh;* [4,5]*ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Kota, Rajasthan.*

**Corresponding author:*
E-mail: kalaforestry@gmail.com (S. Kala)

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ABSTRACT

Ravine lands are typical kind of degraded lands associated with several constraints for vegetation growth due to terrain deformation, poor soil fertility, low soil moisture, extreme variation in temperature, and heavy biotic pressure. An experiment site planted with different multipurpose trees and their impacts on biomass productivity, carbon stock, soil properties, runoff and soil loss were measured and analysed on regular basis for upto ten years. Based on overall growth on survival, biomass yield and C-stock production showed preferred ranking of tree species in the following order *viz., Acacia nilotica > Azadirachta indica > Prosopis juliflora > Leucaena leucocephala > Dalbergia sissoo > Balanitesa aegyptiaca > Acacia catechu.* Among all tree species, *A. nilotica* produced highest above ground biomass, root biomass (44.8 kg plant^{-1}) and above ground C-stock (9.2 kg plant^{-1}). The litter and pruned biomass C-stock was higher in *L. leucocephala* (1.4 kg plant^{-1}). The second best above ground and below ground carbon stock were recorded as 40.2 kg plant^{-1} and 1.2 kg plant^{-1}, respectively in *A. indica*, while *P. juliflora* had highest root biomass and root carbon stock (8.7 kg plant^{-1}) compared to all other species. Tree stand growth significantly improved the soil physico-chemical properties. Every drop of rainwater was harvested in treated ravine area using water harvesting structures like earthen embankments, earthen bunds, gully plugging and its utilization likely increased soil moisture retention capacity and facilitated tree growth compared to untreated ravines. *A. nilotica* tree stands recorded highest biomass and carbon stock production followed by *A. indica*. Thus, *A. nilotica* and *A. indica* species are most suitable multipurpose hardy tree species for rehabilitation of medium and deep ravines of Chambal ravines in India.

1. INTRODUCTION

The land degradation due to water induced erosion is a major global problem, and in India it affects more than 28% of total geographical area (TGA) of the country (Dhruva-narayana, 1993; ICAR, 2010). Among various forms of land degradation, rainwater erosion affects 1.37 Million ha (M ha) area under ravine (GoI, 2003; ICAR, 2010), and this occurs along several river systems in the alluvial zones of India. In Indian context, the word ravine refers to a network of gullies which are generally spread along any river system. The gully is an erosion channel developed by ephemeral streams with steep banks and a nearly vertical gully head deep enough to create hindrance to normal tillage operations. The rate of gully erosion depends on the runoff producing characteristics of the watershed which are governed by the size and shape of drainage area, soil characteristics, and the alignment, size, shape and gradient of the gully channel. The gullies are widening and ravines are extending at the rate of 8 m annum^{-1} to 9 m annum^{-1} with average soil loss of more than 17 t ha^{-1}yr^{-1} (Singh *et al.,* 2014b). It causes potential threat to nearby cultivated land, but also leads to other processes destructive to national economy, *viz*., floods in river basins, siltation in water reservoirs / tanks and the consequent loss in their storage capacity, choking of estuaries and harbors, damage to railway lines, roads and other public utility properties. In India, state of Madhya Pradesh alone has 0.68 M ha (Tomar *et al.,* 2015). These have encroached upon inhabited villages;

many of them had to be shifted to new sites to avoid loss of lives (Verma *et al.,* 2012). Research on very deep ravine (>10 m deep and slope >30%) lands (Kandrika and Dwivedi, 2013) was limited because according to land capability classification such lands are classed as unsuitable for farming (Verma *et al.,* 2018a). Highly suitable site specific technology was not readily available to manage medium to very deep ravine lands (Verma *et al.,* 2018a). The magnitude of this problem has been considered serious to get the attention not only of the State and Central Governments, but also of International Agencies, such as the World Bank, European Economic Community (now the European Union), German Technical Cooperation for International Development (GTZ, now GIZ) and others (Dagar and Singh, 2018). Because of the extreme form of erosion and loss of the entire topsoil and most of the soil solum, the exposed regolith is devoid of soil organic carbon (SOC) and is low in nutrient reserves. Lack of vegetation cover, coupled with none or minimal input of litter biomass carbon and high temperatures, the SOC stock is low and declining (Lal *et al.,* 2018).

The restoration techniques like rehabilitation, afforestation, reforestation, natural regeneration of native species and adaptive conservation forestry approaches are more economically and ecologically sound in increasing the carbon storage capacity of the terrestrial ecosystems. IPCC (2007) also indicated in its special report that the conversion of wasteland and grassland to agroforestry has the best potential for carbon stock generation and other direct benefits. A systematic and science-based approach for restoration of ravine lands has the potential to increase C-stock in soil in the above and below-ground biomass. Increase in terrestrial C-stock of ravines has numerous benefits, including improvements in soil quality/health, renewability and purification of water, increase in the above and below ground biodiversity, increase in net primary productivity, and overall improvement in the environment quality (Somasundaram *et al.,* 2018; Dagar and Singh, 2018). Ravine-prone landscape has low SOC stocks compared with those of the un-eroded landscapes within the same biome. Therefore, degraded and depleted ravine lands have a large technical potential of C-stock through restoration and rehabilitation (Singh *et al.,* 2018a). Simultaneously, litter fall and fine root production is a major pathway for carbon and nutrient cycling in forest ecosystems, and their turnover depends on various factors such as species, age groups, canopy cover, weather conditions and biotic factors (Lodhiyal *et al.,* 2002; Stewart and Frank, 2008). Accordingly, a rehabilitation study was taken up in Chambal ravines during 2007-08 and impact was regularly monitored with standard protocols to identify the most suitable species. The objective of this study was to determine the success of reforestation with multipurpose trees for higher biomass production (above and below ground carbon stock) and improvement in soil properties.

2. MATERIALS AND METHODS

Study Site

Ravine lands, have strongly impacted economic, social, cultural, and environmental features of the region (Verma *et al.,* 2018b). Formation of ravine lands is triggered by tectonic activity, climate change, or drastic change in land use. In India, ravines are formed in the semi-arid climate with short monsoonal rains (3 months) and a long dry season. The details of various types of ravine formation, their classification, causes and reclamation measures have been compiled by Dagar and Singh (2018). The present study was carried out on land with very deep (>10 m deep gully) ravines in village Himmatpur (Ater block) situated at north-western part of district Bhind in Madhya Pradesh, India. The geographical location of study area is 25°54' N latitudes and 78°C 12' E longitudes with an altitude of 190 above mean sea level. The study area falls under the agro-climatic zone (ACZ), which is part of the vast Indo-Gangetic plains. The region has sub-tropical climate with three distinct seasons in the year, *viz*., hot and dry summer, cold and dry winters, and monsoon season. In summer, the maximum temperature reaches to 49°C and the minimum temperature is 0°C during winters. The high-temperature days in summer are longer than the low-temperature winter days. The average humidity in morning and evening ranges between 84% to 97% and 21% to 34%, respectively. Ten years (2007-2017) rainfall analysis is given in Fig. 1. The range of annual rainfall and number of rainy days during study period varied from 502 mm to 1250 mm and 33 days to 65 days, respectively. The average annual rainfall of the study site was 761 mm.

Basic Characteristics of Deep Ravine Soils

The region has alluvial soil, with very high dispersion coefficient and fragile nature. The slope of ravine land is 2% to 75% with an average value of 34% of study area. The soil texture of study area is sandy loam (55.1% sand, 33.2% silt and 11.7% clay). The soils are more or less neutral in reaction,

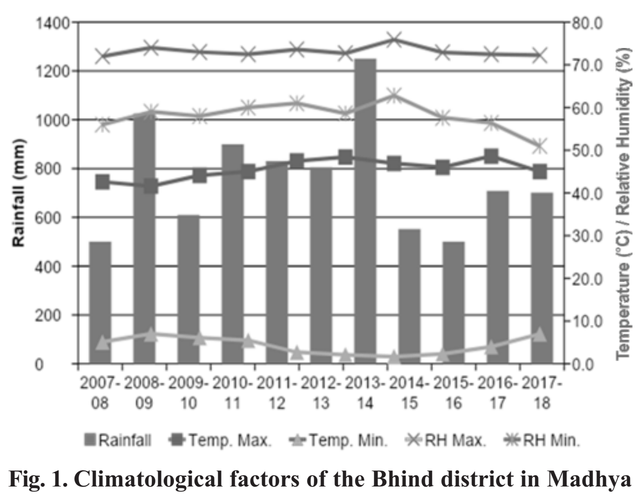


Fig. 1. Climatological factors of the Bhind district in Madhya Pradesh (India)

have normal salt content and are slightly calcareous in nature (containing 0.45% to 1.84% $CaCO_3$), and highly permeability having infiltration rate up to 33 mm hr^{-1}. The bulk density of soil varied 1.56 Mg m^{-3} to 1.60 Mg m^{-3} with an average value of 1.58 Mg m^{-3}.

Soil Sampling and Analysis

Soil samples were collected upto depth of 0-30 cm from surface for determining soil physico-chemical properties at different periods under random sites of different tree plantations. The samples were air-dried and ground to pass through a 2 mm sieve. Analysis of soil for sand, silt and clay fraction was carried out as suggested by Gee and Bauder (1986). Soil pH and electrical conductivity (EC) in soil: water ratio of 1:2 were determined by following standard methods (Jackson, 1973). The oxidizable SOC was determined using wet oxidation method (Walkley and Black, 1934). Soil bulk density and water holding capacity were measured using method described by Black (1965). Infiltration rate was measured by method suggested by Page *et al.* (1982). Available N, P, K and S were determined as per methods described by Jackson (1973). SOC stock was calculated for 0-150 cm (30 cm intervals) soil depth by using the equation:

$$C\text{-}stock\ in\ soil = C\ content \times Bulk\ density \times Soil\ depth \quad ...(1)$$

Where, C content is given in g C kg^{-1}, BD in Mg m^{-3}, soil depth in m and C-stock in Mg ha^{-1}.

Water Harvesting Structures (WHS)

The construction of anicuts and afforestation had a great impact on the economy of both these villages. The impact was assessed by collecting socio-economic data through pre-tested questionnaires and interviews. As a result of the project work, the net cultivated area increased 13% in Bindwa village and 6.5% in Himmatpur in Madhya Pradesh (Singh *et al.,* 2018a). In order to utilize rainwater, under this rainfed situation, few water harvesting structures were constructed to capture available rainwater over planted area. Total twelve earthen embankment type structures in gullies were constructed in the project area covering 83 ha land. Earthen bunds across the slope in series were constructed in gullies based on analysis of hydrological data of the locality of past 20 years rainfall; calculated data pertains to peak runoff volumes. These structures were designed and spaced suitably in a micro-watershed to retain the entire amount of runoff in gullies. The average size of a water harvesting structures in this project was 14.5 m long, 10.5 m height, 6.0 m width at the top and 12.0 m width at the bottom. The average capacity of these structures varied from 1500 cum to 2500 cum. The structures were big enough to hold all the runoff water. Therefore, no waste-weir was provided in gully infested areas due to the fragile nature of soil. Gully plugs were constructed above each structure to retain some runoff against them. In all, 150 gully plugs were provided on all structures in the entire project area. They were observed, monitored and reshaped every year for purpose of maintenance.

Rehabilitation by Planting of Selected Tree Species

The project area includes 83 ha. One year old saplings of difficult species were planted in 63 ha, divided in three blocks represented as replications, and remaining 20 ha area was under water harvesting structures. Saplings of tree species were planted at a spacing of 6 m × 6 m *viz*., Babool / Kikar (*Acacia nilotica*), Shisham (*Dalbergia sissoo*), Vilayati babul (*Prosopis juliflora*), Neem (*Azadirachta indica*), Hingota (*Balanitesa aegyptiaca*), Kutch/Kheir (*Acacia catechu*) and Subabool (*Leucaena leucocephala*) during month of July, 2007. The tree species were facilitated with stored rainwater during initial 3 years by life saving irrigation in pits through PVC pipes. The number of life saving irrigation for survival applied were two times in winter season (November to March) and four times during summer (April to June). Plant growth in terms of survival (%), height and diameter of plants were properly recorded at regular intervals for assessment for the period of ten years from 2007-2017.

Data collection

At end of 10 years after plantation, survival rate, tree height and diameter at breast height (DBH) of the trees were taken for analysis. The above ground biomass (AGB) was measured for 5 trees by random selection and cutting at ground level in all three replications using Fisher's Random table (Panse and Sukhatme, 1954). The harvested tree was separated into bole, branches twigs and leaves. Each component was weighed separately for fresh weight. From all components, one kg of fresh sample was drawn, and dry weight was measured after oven-drying at 70°C to a constant weight. Total dry weight of each bole, branches, twigs plus leaves was determined for each tree separately, and the total above ground dry weight of each tree was computed by summation. Overall, total tree biomass was calculated on defined unit area basis (*i.e.* per hectare). Analysis of variance and significance test was done to determine differences in biomass, C-stock and soil properties under investigation.

Above ground, root and litter C-stock estimation of trees

Total tree biomass was obtained by adding above ground biomass including pruned leaf litter and root biomass. Tree biomass values were converted to tree C-stock (kg ha^{-1}) using a multiplication factor of 0.5 as recommended by IPCC (2003), Brown *et al.* (2005) and Ekoungoulou *et al.* (2015). The estimation of below ground biomass of forest trees was calculated with the equation proposed by Cairns *et al.* (1997). The C-stock (ABG + RB) calculated for selected tree species were inferred to hectare level with multiplication with the number of trees ha^{-1}. C-stock of the tree species were converted to Mg C ha^{-1}. The total C-stock of tree species in ha^{-1} was calculated with the addition of C-stock of tree species (ABG + RB) and soil. The accumulation rates of total C-stock were calculated through the equation:

Total C-stock accumulation rate (Mg ha^{-1}yr^{-1}) = Total C-stock ha^{-1} / Age in years of plantation ...(2)

3. RESULTS AND DISCUSSION

Growth Parameters

The survival percentages of different tree species under deep ravine lands ranged from 78% to 93% (Table 1). The significantly higher survival rate of 93% was observed in *P. juliflora* followed by *A. nilotica* (88%), *A. indica* (86%), *B. aegyptiaca* (84%), *D. sissoo* (82%), *A. catechu* (81%) and *L. leucocephala* (78%). At end of 10 years, DBH of trees significantly varied among tree species (Table 1). The observed range variations were found between 89 mm to 165 mm at planting sites. The average range of DBH was maximum of *A. nilotica* (165 mm plant^{-1}), followed by *A. indica* (163 mm plant^{-1}), *P. juliflora* (153 mm plant^{-1}), *D. sissoo* (141 mm plant^{-1}), *L. leucocephala* (132 mm plant^{-1}), *B. aegyptiaca* (126 mm plant^{-1}) and the lowest of *A. catechu* (89 mm plant^{-1}). Over all, growth assessment parameters confirmed that *L. leucocephala* and *A. nilotica* were the fastest-growing species, and *A. catechu* was a slow growing species at ravine rehabilitated sites. *L. leucocephala* attained a height of 9.36 m and *A. catechu* 4.39 m. The height range of different trees species greatly varied in the following order: *L. leucocephala* followed by *A. nilotica, P. juliflora, A. indica, D. sissoo, B. aegyptiaca* and *A. Catechu.*

Carbon Stock of Tree Species

The carbon stock for each tree species also significantly varied in different carbon pools *i.e.* the above ground, root and litter and pruned biomass (L&PB) in treated ravine land (Fig. 2). The significantly highest carbon stock in AGB was recorded in *A. nilotica* (44.8 kg plant^{-1}). Similar to AGB, in the root biomass (RB), C-stock was found to be significantly higher in *A. nilotica* compared to the other tree species. The maximum AGB and RB C-stock plant^{-1} was recorded in *A. nilotica*, while least values were found in *A. catechu*. Similarly, there was a significant difference in the C-stock in L&PB across the 7 tree species. The highest C-stock in L&PB was found in *L. leucocephala* (1.4 kg plant^{-1}) and lowest in *A. catechu* (0.8 kg plant^{-1}). The total biomass (TB) C-stock plant^{-1} was significantly highest with *A. nilotica* (55.2 kg plant^{-1}) followed by *A. indica* (49.6 kg plant^{-1}), *P. juliflora* (42.4 kg plant^{-1}), *L. leucocephala* (38.9 kg plant^{-1}), *D. sissoo* (32.7 kg plant^{-1}), *B. aegyptiaca* (27.0 kg plant^{-1}) and lowest in *A. catechu* (24.5 kg plant^{-1}).

Table: 1
Growth parameters of trees species established in ravine land after 10 years

Name of species	Survival (%)	DBH (mm tree^{-1})	Height (cm)	Dry biomass (Mg ha^{-1})
A. nilotica	88	165	882	23.5
D. sissoo	82	141	563	12.2
P. juliflora	93	153	752	17.8
A. indica	86	163	729	20.2
B. aegyptiaca	84	126	481	10.6
A. catechu	81	89	439	8.4
L. leucocephala	78	132	936	15.3
S Em±	0.7	4	23	0.6
LSD (p≤0.05)	2.2	12	69	1.9

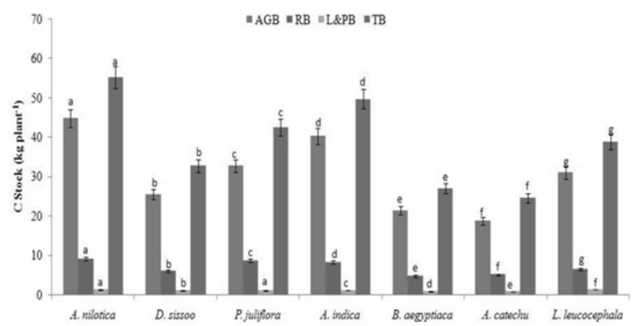
DBH: diameter at breast height

Soil C-stock Under Different Tree Stands

The soil C-stock was measured up to 30 cm soil depth under different tree plantation (Fig. 3). Among all tree species higher total soil C-stock was recorded under *A. nilotica* (5.02 Mg ha^{-1}) followed by *L. leucocephala* (4.77 Mg ha^{-1}), *A. indica* (4.46 Mg ha^{-1}), *P. juliflora* (4.34 Mg ha^{-1}), *D. sissoo* (4.19 Mg ha^{-1}), *B. aegyptiaca* (4.04 Mg ha^{-1}) and lowest value was recorded in *A. catechu* (3.58 ha^{-1}).

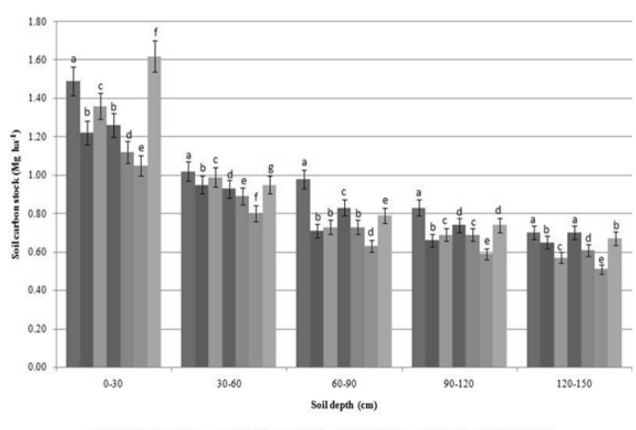
Total Production of C-stock

The calculation of estimated C-stock within four storing compartments (AGB, RB, L&PB and soil) of tree



The bars represent standard error of mean and the similar letters for AGB, RB, L&PB and TB of various trees are not significantly different at LSD (p≤0.05).

Fig. 2. Biomass and carbon stock per tree of different tree species at age 10 years after planting in Chambal ravines



The bars represent standard error of mean and the similar letters for various soil depths of tree species are not significantly different at LSD (p≤0.05)

Fig. 3. Soil carbon stock at different soil depths under various tree plantation after 10 years of planting in Chambal ravines

species on hectare basis revealed that more C (46-60%) was stored in AGB, followed by soil (26-39%), RB (11-15%) and lowest in L&PB (1-3%) in all the tree species (Table 2). The C-stock of different tree species in AGB ranged between 4.23 Mg ha^{-1} and 11.75 Mg ha^{-1} (Table 2), whereas it was significantly higher in *A. nilotica* compared to other species. The maximum C-stock in AGB was recorded in *A. nilotica* (11.75 Mg ha^{-1}) followed by *A. indica* (10.1 Mg ha^{-1}), *P. juliflora* (8.92 Mg ha^{-1}), *L. leucocephala* (7.65 Mg ha^{-1}), *D. sissoo* (6.09 Mg ha^{-1}), *B. aegyptiaca* (5.31 Mg ha^{-1}) and *A. catechu* (4.23 Mg ha^{-1}). Like-wise trend of C-stock in RB followed the order: *A. nilotica* (2.36 Mg ha^{-1}) >*P. juliflora* (2.35 Mg ha^{-1}) >*A. indica* (2.0 Mg ha^{-1}) >*L. leucocephala* (1.58 Mg ha^{-1}) > *D. sissoo* (1.39 Mg ha^{-1}) > *A. catechu* (1.29 Mg ha^{-1}) > *B. aegyptiaca* (1.17 Mg ha^{-1}).

The overall total C-stocks within the main four storing compartments (AGB, RB, L&PB and soil) ranged from 9.29 Mg ha^{-1} to 19.45 Mg ha^{-1} (Table 2). Among total C-stock of different trees observed after 10 years of plantation, maximum C-stock was recorded in *A. nilotica* (19.45 Mg ha^{-1}) followed by *A. indica* (16.76 Mg ha^{-1}), *P. juliflora* (15.89 Mg ha^{-1}), *L. leucocephala* (14.33 Mg ha^{-1}), *D. sissoo* (11.94 Mg ha^{-1}), *B. aegyptiaca* (10.83 Mg ha^{-1}) and *A. catechu* (9.29 Mg ha^{-1}).The man annual carbon sequestration rate in form of total C-stock (biomass + soil) varied significantly in different tree species ranging from 0.93-1.95 Mg $ha^{-1}yr^{-1}$ (Table 2). The highest C-stock was recorded in *A. nilotica* (1.95 Mg $ha^{-1}yr^{-1}$) and least in *A. catechu* (0.93 Mg $ha^{-1}yr^{-1}$). The C-stock was in the order of *A. nilotica* > *A. indica* > *P. juliflora* > *L. leucocephala* > *D. sissoo* > *B. aegyptiaca* > *A. Catechu.*

Table: 2
Difference in biomass and carbon stock production rate of tree species at ten year old plantations in ravine lands

Name of species	C-stock (Mg ha^{-1})				C-stock rate Mg C $ha^{-1}yr^{-1}$
	AGB	RB	L&PB	Soil	Total
A. nilotica	11.75	2.36	0.32	5.02	1.95
D. sissoo	6.09	1.39	0.27	4.19	1.19
P. juliflora	8.92	2.35	0.28	4.34	1.59
A. indica	10.1	2.00	0.20	4.46	1.68
B. aegyptiaca	5.31	1.17	0.31	4.04	1.083
A. catechu	4.23	1.29	0.19	3.58	0.93
L. leucocephala	7.65	1.58	0.33	4.77	1.43
S Em±	0.23	0.05	0.01	0.05	0.034
LSD (p≤0.05)	0.72	0.14	0.02	0.16	0.09

ABG - above ground biomass, RB - root biomass, L&PB - litter and pruned biomass, soil C-stock within 0 to 150 cm

Changes in Physico-chemical Properties of Soil

Consequently, changes were inflicted in basic physico-chemical properties of the soil due to litter residue increases and moisture retention, and due to their downward movement. The availability of organic matter and water holding capacity increased by 57-148% and 20-58%, respectively, in the treatment imposed area as compared to untreated ravines, where they scored 2.1 g kg^{-1} and 20.7%, respectively. As a result of rehabilitation, addition cum decomposition of leaf litter might increase soil fertility in the study sites (Table 3). There was significant variation observed in available nitrogen, phosphorus, potassium and sulphur under different tree stands. Under experimental sites of various tree, plantations enhanced the additional total availability of nutrients from 125 kg ha^{-1} to 265 kg ha^{-1} as compared untreated ravine land. Data indicated that total availability of macro-nutrients under different plantations was in the order *viz., L. leucocephala* > *A. nilotica* > *A. indica* > *D. sissoo* > *P. juliflora* > *A. catechu* > *B. aegyptiaca*. The highest nutrient mobilization was observed in the plot of *L. Leucocephala*.

Discussion

As a result of longer duration of the plantation, water harvesting structures availability in the area improved moisture regime throughout the year and consequently reduced the rate of runoff and soil erosion. The installation

Table: 3
Soil physico-chemical properties (0-30 cm depth) under different tree species after 10 years of plantation

Tree species	pH_2	EC_2 (dS m^{-1})	OC (g kg^{-1})	BD (Mg m^{-3})	IR (mm hr^{-1})	Available macro-nutrients (kg ha^{-1})		
						N	P	K
Ravine land	8.11	0.24	2.1	1.58	33	79	11.2	295
A. nilotica	7.71	0.36	4.5	1.44	31	219	18.5	374
D. sissoo	7.90	0.33	3.7	1.48	25	208	20.1	351
P. juliflora	7.84	0.38	3.8	1.45	22	185	17.9	368
A. indica	7.89	0.34	4.2	1.45	19	194	19.4	382
B. aegyptiaca	7.94	0.28	3.5	1.48	16	174	16.1	311
A. catechu	8.02	0.30	3.3	1.51	17	165	17.5	332
L. leucocephala	7.83	0.41	5.2	1.42	29	221	20.4	394
S Em±	0.02	0.01	0.13	0.02	1	3	0.5	4
LSD (p≤0.05)	0.05	0.02	0.41	0.05	3	8	1.5	13

PH and EC - Electrical Conductivity (1:2 soil water ratio), OC - Organic Carbon, BD - Bulk density, IR - Infiltration rate of anicuts gave additional benefits of providing water for life saving irrigation for survival of tree saplings. There was a significantly higher survival rate of *P. juliflora* followed by *A. nilotica* and lowest in *L. leucocephala*. *L. leucocephala* is fast-growing and high biomass producing crop. It was found after successful field survival that, *L. leucocephala* has full capacity to grow under harsh ravine condition as a legume crop with the highest growth of *L. leucocephala* among other tree species in our study. This was validated with report of Fagbola *et al.* (2001) which reported that *L. leucocephala* is a leguminous fast-growing tree for eroded land management with quick green cover. *A. catechu* was found to be hardy tree, but slow growing in the ravines compared other tree species

The survival and growth of plants usually get reduced under water stress influenced ravine ecosystem. The best rehabilitation success can be achieved through choice of species or species selection for planting. In the present study, the tree species were critically ranked based on their survival, and vigour (height × stem diameter) in terms of stand vigour. Following this procedure, the tree species ranking were carried out with plant quality traits. Based on assessment, the choice of the tree species were given in the following order *viz., A. nilotica* > *A. indica* > *P. juliflora* > *L. leucocephala* > *D. sissoo* > *B. aegyptiaca* > *A. catechu* (Table 4).

The mean annual carbon stock production rate influenced by different tree species ranged from 0.93-1.95 Mg C ha^{-1} yr^{-1} depending upon their growth and biomass production capacity under this stress condition. *A. nilotica* with maximum biomass production was found to be most efficient tree species for degraded ravine lands development. The C-stock production followed the order of *A. nilotica* > *A. Indica* > *P. juliflora* > *L. leucocephala* > *D. sissoo* > *B. aegyptiaca* > *A. catechu*. Similarly, Jha *et al.* (2014) reported that fine roots of *A. indica* have greater carbon stabilization potential than other species such as *L. leucocephala* and *P. juliflora* in the Yamuna ravine region. Lal (2018) reported that carbon sequestration in degraded soil had a technical potential of 2.6–5.3 Tg C yr^{-1} under best management practices for both preventative and control

Table: 4
Rank the tree species by their suitability under ravine land

Tree species	Ranking of tree species based on			
	Survival (A)	Height × DBH (B)	Biomass (cm)	Overall (A+B+C)
A. nilotica	2	1	1	1
D. sissoo	5	5	5	5
P. juliflora	1	4	3	3
A. indica	3	2	2	2
B. aegyptiaca	4	6	6	6
A. catechu	6	7	7	7
L. leucocephala	7	3	4	4

measures. Enhancing carbon input through above and below ground biomass helps in improving soil organic matter and promotes favourable changes in soil physical and chemical properties. Singh *et al.* (2015) reported that planting of bamboo *(D. strictus)* with suitable moisture conservation practice proved as a viable alternative on ravine lands for gully beds stabilization, and controlling sloping land erosion through good soil binding effect and fast growing vegetative cover. The bamboo based bio-engineering technology might reduce soil erosion, runoff, soil pH and nutrient losses considerably by imposition of trenches, basins and vegetative barriers due to improvement in infiltration rates resulting in higher water use efficiency (Singh *et al.,* 2014b).

Litterfall and fine root production is a major pathway for carbon and water holding capacity in forest ecosystems, and their turnover depends on a variety of factors such as species, age groups, canopy cover, weather conditions and biotic factors (Lodhiyal *et al.,* 2002; Stewart and Frank, 2008). In the present study, availability of organic matter and water holding capacity increased by 57-150% and 20-58% under tree plantations compared with initial values 2.1 g kg^{-1} and 20.72%, whereas there was decrease in bulk density and infiltration rate by 4-9% and 12-52% corresponding with initial values 1.58 Mg m^{-3} and 33 mm hr^{-1}, respectively. The clay and silt got deposited against earthen check dams and in the ring trenches, consequently decreasing infiltration rate in treated areas of ravine land. Due to better management practices, there was an increase in organic matter which influenced soil fertility and reduction in soil erosion. The availability of macro-nutrients increased due to increase in soil organic matter content through litter addition and partly due to reduction in nutrient loss by soil erosion. The variations in available nutrients in different species were observed due to different amount and quality of litter falls and fine root development. Jha and Mohapatra (2009) also gave a similar report of leaf litter fall, fine root mass, production and turnover rate in the upper soil (0–30 cm) under four locally dominant tree species such as *L. leucocephala*, *A. nilotica*, *A. indica* and *P. juliflora* in Yamuna ravine region of India. It also justified our results that there is higher C-stock from leaf fall and pruned biomass from *L. leucocephala* followed by *A. nilotica, D. sissoo, A. indica, P. juliflora, B. aegyptiaca* and least with *A. catechu.* Rainwater was harvested in treated ravine area using water harvesting structures like earthen embankments, earthen bunds, gully plugging. Its utilization might increase soil moisture retention capacity and facilitate tree growth compared to untreated ravines. Our study results suggested that construction of anicut on very deep gully as per hydrological analysis and establishment of tree species play an important role in rehabilitation of ravine lands. The extremely eroded deep ravine lands could be utilized sustainably with permanent tree based production systems with suitable species selection in appropriate densities.

4. CONCLUSIONS

The conclusion of our study results indicated that *Acacia nilotica* (Babul) was the most promising tree species followed by *Azadirachta indica* (Neem). Simultaneously, development of above ground vegetation canopy due to tree suitable planting influence on addition of letter residues, decomposition of leaf litter and fine roots turnover may cause improvement in soil physio-chemical properties in long run. Thus, the ravine lands of India have a huge potential for biomass production, livelihood security, C-stocking, improvement in soil environment by adopting improved bioengineering technologies to achieve both economic and ecological aim of quick green cover, ecological restoration, and carbon balance in sustaining economic and environmental benefits.

REFERENCES

Black, C.A. 1965. Methods of soil analysis. Part I, American Society of Agronomy. Madison, Wisconsin, USA. 1572 p.

Brown, S., Pearson, T., Moore, N., Parveen, A., Ambagis, S. and Shoch, D. 2005a. *Impact of selective logging on the carbon stocks of tropical forests: Republic of Congo as a case study*, Deliverable 6 to USAID, Cooperative Agreement No. EEM-A-00-03-00006-00, Winrock international, Arlington, VA, USA.

Cairns, M.A., Brown, S., Helmer, E.H. and Baumgardner, G.A.1997. Root biomass allocation in the world's upland forests. *Oecologia,* 111: 1-11.

Dagar, J.C. and Singh, A.K. 2018. Ravine lands: greening for livelihood and environmental security. *Springe Nature*, Singapore Pvt. Ltd, 636p.

Dhruvanarayana, V.V. 1993. Soil and water conservation research in India. *Directorate for Information and Publications of Agriculture,* ICAR, KAB-II, Pusa, pp 1–454.

Ekoungoulou, R., Shukui, N., Loumeto, J.J., Ifo, S.A., Bocko, Y.E., Fleury Mikieleko, F.E., Guiekisse, E.D.M., Senou, H., Liu, X. 2015. Evaluating the C stock in above and below ground biomass in a moist central African forest. *Appl. Ecol. Environ. Sci.,* 3: 51–59, doi: 10.12691/aees-3-2-4.

Fagbola, O., Osonubi, O., Mulongoy, K., Odunfa, S.A. 2001. Effects of drought stress and arbuscularmycorrhiza on the growth of *Gliricidiasepium* (Jacq). Walp, and *Leucaenaleucocephala* (Lam.) de Wit. in simulated eroded soil conditions. *Mycorrhiza,* 11: 215–223.

Gee, G.W. and Bauder, J.W. 1986. Particle size analysis. In: Klute, A. (ed). Methods of Soil Analysis. *Part 1: Physical and Mineralogical Methods.* Monograph No. 9, (2nd edition) ASA, Madison, WI.

GoI. 2003. Rehabilitation of gullied and ravine lands. *Technical brochure No-1/2003. Department of Land Resources.* Ministry of Rural Development, Government of India, New Delhi, 44p.

ICAR-NAAS 2010. *Degraded and wastelands of India: status and spatial distribution*. Directorate of Information and Publications of Agriculture, Indian Council of Agricultural Research, Krishi Anusandhan Bhavan I, Pusa, and National Academy of Sciences, New Delhi.

IPCC. 2003. In: Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. and Wagner, F. (eds.). Good Practice Guidance for Land Use, Land Use Change and Forestry. IPCC/OECD/IEA/IGES, Hayama, Japan.

IPCC2007. Special report, Intergovernmental Panel on Climate Change (IPCC), UNEP, New-York, USA.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, 498p.

Jha, P. and Mohapatra, K.P. 2009. Leaf litterfall, fine root production and turnover in four major tree species of the semi-arid region of India. *Plant Soil,*326(1): 481-491.

Jha, P., Mohapatra, K.P. and Dubey, S.K. 2014. Fine roots C mineralization and soil C stabilization under major tree species of the semi-arid region of India. *Nat. Acad. Sci. Lett*., 37: 413–418.

Kandrika, S. and Dwivedi, R.S. 2013. Reclamative grouping of ravines using Cartosat-1 PAN stereo data. *J. In. Soc. Remote Sens*., 41: 731-737.

Lal, R. 2018. Sequestering C in Ravine-prone and Eroded Landscapes. J.C. Dagar, A.K. Singh (eds.), *Ravine Lands: Greening for Livelihood and Environmental Security,* pp 445-454.

Lodhiyal, N., Lodhiyal, L.S. and Pangtey, Y.P.S. 2002 Structure and function of shisham forests in central Himalaya, India: dry matter dynamics. *Ann. Bot.,* 89: 41–54.

Page, A., Miller, R.H. and Keeney, D.R. 1982. Method of Soil Analysis. Part 2. Chemical and Microbiological Properties. 2nd ed. Agron. Monogr. 9. ASA, CSSA, and SSSA, Madison, WI.

Panse, V.G. and Sukhatme, P.V. 1954. Statistical method for agriculture workers. In Public. ICAR, New Delhi, pp 97-151.

Singh, A.K., Singh, Y.P. and Verma, S.K. 2018a. *Greening of ravines: A strategy for viable production and mitigation to climate change.* J.C. Dagar and A.K. Singh (eds.), Ravine Lands: Greening for Livelihood and Environmental Security, pp. 455-475

Singh, A.K., Kala, S., Dubey, S.K., Rao, B. Krishna, Gaur, M.L., Mahopatra, K.P. and Prasad, B. 2014b. Evaluation of bamboo based conservation measures for rehabilitation of degraded Yamuna ravines. *Indian J. Soil Cons.,* 42:80-84.

Singh, A.K., Kala, S., Dubey, S.K., Pande, V.C., Rao, B.K., Sharma, K.K. and Mahapatra, K.P. 2015**.** Technology for rehabilitation of Yamuna ravines cost-effective practices to conserve natural resources through bamboo plantation. *Curr. Sci.*, 108(8): 1526-1533.

Somasundaram, J., Parandiyal, A.K., Jha, P., Lakariya, B.L., Singh, R.K., Mina, B.L., Kala., S. and Ali, S. 2018. *Ravine: Prospective zone for C sequestration*. J.C. Dagar, A.K. Singh (eds.), Ravine Lands: Greening for Livelihood and Environmental Security, pp. 433-444, doi.org/10.1007/978-981-10-8043-2-1.

Stewart, A.M. and Frank, A.F. 2008. Short sampling intervals reveal very rapid root turnover in a temperate grassland. *Oecologia* 157: 453–458, doi: 10.1007/s00442-008-1088-9.

Tomar, V.S., Verma, G.P. and Singh, Y.P. 2015. Land degradation in India: Strategies to manage Chambal ravines in Madhya Pradesh. *JNKVV Res. J.,* 49: 366-373.

Verma, G.P., Singh, Y.P. and Dubey, S.K. 2012. *Watershed based reclamation and control of Chambal ravines.* Conservation of Natural Resources for Food and Environmental Security In: Dubey et al. (Eds), pp 329–341.

Verma, G.P., Singh, Y.P. and Singh, A.K. 2018b. Management of steep land. *Indian Farm.,* 68: 16-19.

Verma, G.P., Singh, Y.P., Singh, A.K. and Verma, S.K. 2018a. *Management of Chambal ravines for income enhancement*. J.C. Dagar, A.K. Singh (eds.), Ravine Lands: Greening for Livelihood and Environmental Security, pp. 253-277.

Walkley, A. and Black, I.A. 1934. An Examination of the Degtjareff Method for Determining Soil Organic Matter and a Proposed Modification of the Chromic Acid Titration Method. *Soil Sci.,* 37: 29-38.