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Efficacy on Biomass and Carbon Stock Production by Different Silvipasture Systems in Chambal Ravines of South-Eastern Rajasthan (India)

S. Kala, A.K. Parandiyal, B.L. Mina, Ashok Kumar, H.R. Meena, S. Reeja, and I. Rashmi

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ABSTRACT: *Selection of species with high carbon sequestration potential becomes more important in the context of productive and effective utilization of degraded ravine lands. The protection of existing forests, reforestation of degraded forests and creation of new forestry and agroforestry plantations in India have been viable option for contributing to enhanced carbon stock production and atmospheric carbon balance management. The efficacy of carbon stock production depends choice of species, grow rate, age of tree, density of trees and other inherent wood forming traits. Maximum mean aboveground biomass (71.27 t ha^{-1}), belowground biomass (14.25 t ha^{-1}), litter biomass (2.39 t ha^{-1})and total biomass (85.76 t ha^{-1}) were recorded in the Acacia nilotica based silvipasture land use system. Total biomass production of different land use systems were categorized according the overall biomass and carbon stock productivity in the following order: Acacia nilotica > Aegle marmelos > Pongamia pinnata and Emblica officinalis respectively. Maximum soil organic carbon stock (18.92 t ha^{-1}) was recorded in Acacia nilotica based silvipasture land use systems, however lowest soil organic carbon value of 12.05 t ha^{-1} was observed in Pongammia pinnata compare to other systems. Soil organic carbon was decreased with increase in soil depth irrespective of the land use system. Biomass and carbon stock estimation results indicated that total carbon storage value was higher in Acacia nilotica followed by Aegle marmelos > Pongamia pinnata and Emblica officinalis. Acacia nilotica based silvipasture system has ranked first in larger biomass (AGB & BGB) as well as C-stock. Comprehensively, Acacia nilotica and Aegle maremelos would be appropriate hardy tree species for securing high efficacy on enhanced carbon sequestration in fragile chambal ravine ecosystems of south-eastern Rajasthan in India.*

1. INTRODUCTION

Agroforestry system based integrated land management, not only for renewable resource production, but also for climate change mitigation. The carbon storage capacity of agroforestry system mainly includes tree species and their geographical interaction effects. Further, the amount of carbon in any agroforestry system depends upon the structure and function of different components within the system. Tree biomass production in different forms plays important role in carbon sequestration under different LUS. The potential of forests to sequester carbon depends on the forest type, age of forest and size class of trees (Terakunpisut *et al.,* 2007). Carbon sequestration could be affected by plantation types and stand ages. It is urgent to assess the effects of forest types on carbon sequestration and carbon allocation in the, subtropical region. Ecosystem based options like ecological restoration, soil conservation afforestation, reforestation and agroforestry, mangrove conservation and replanting, green infrastructure (e.g., shade trees, green roofs), community-based natural resource management are the future strategies to mitigate climate change in a sustainable manner (Newaj *et al.,* 2012).

Above ground biomass, below ground biomass, dead wood, litter, and soil organic matter are the major carbon pools in any ecosystem. Selection of species with high carbon sequestration potential becomes more important in this context for utilization of these degraded areas especially like ravines (ie., ravines are the worst form of land degradation). The ravines are mainly adjoined with major river systems in the alluvial zones in India. These are the system of gullies running almost parallel to each other and draining in to a river after a short distance with the development of deep gorges. These may extend upto 2 - 3 km. in to the tablelands and vast areas go out of cultivation due to the process of degradation. Out of a total of 173.64 million ha degraded land reported in India, degraded forest lands comprising 19.49 million ha, 4.91 million ha land degraded due to shifting cultivation (MOA 1985). Recent estimates indicated that ravines occupy

✉ S. Kala
kalaforestry@gmail.com

Scientist (Forestry),
ICAR- Indian Institute of Soil & Water Conservation,
Research Centre, Kota- 324002, Rajasthan, India.

2.06 m ha in India and gully formation occurs in 8.31 million ha (35%) area (ICAR-NAAS 2010). Economic utilization of medium and deep ravine lands for recurring cultivation is challenging; however, these ravines can be potentially utilized for energy plantation, augmentation of fuel and fodder demands for local populace and production of hardy wood biomass producing tree/shrub species.

In fact, ravines are the most fragile ecosystems that have very low carbon content due to their light texture and poor aggregate stability. Thus, there is need to manage and restore these lands with suitable cultural and management involving practices that enhance carbon input through above- and belowground biomass help in improving soil organic matter and promote favourable changes in soil physical and chemical and biological properties. This ecosystem needs a surface cover against direct impact of raindrop that causes detachment of soil particles. There is also a need for slope stabilization through locally adapted grasses and shrubs during rainy season. The lower regions of the ravines are capable enough to produce annual crops. These practices and measures not only hold promise in conserving this natural resource but also help in enhancing carbon input into the soil through crop residue, roots and leaf fall under different vegetation, which in turn would help increase the C turnover in soil. Over a period, this carbon input would help in restoring the soil carbon in these fragile ravine ecosystems. In this line, Jha *et al.* (2014) reported that fine roots of *Azadirachta indica* have greater carbon stabilization potential than other species such as *Leucaena leucocephala* and *Prosopis juliflora* in the Yamuna ravine region. Deep and narrow gullies are stabilized by putting them under permanent vegetation of grasses and trees especially with bamboo plantations (Singh *et al.*, 2014 and Singh *et al.*, 2015). However, the indiscriminate land-use practices leading to a disturbance of the hydrological balance is one of the reasons. The major variables that affect upland soil erosion by water in the catchment of ravines are climate, inherent soil characteristics, topography, type of landuse and runoff management practices. The Kyoto protocol proposed carbon (C) reduction through decreasing fossil fuel emission or accumulating C in vegetation and soil (Oelbermann *et al.*, 2004). The protection of existing forests, regeneration of degraded forests and rising of forest plantations in India have been contributing to enhanced carbon stock (Ravindranath *et al.*, 2008). The most reliable technique for estimating forest carbon stock is through forest inventories followed by developing allometric relationships between the aboveground biomass (AGB) of a tree and its trunk diameter (Brown 1997; Brown *et al*., 1989; Clark *et al.* 2001). Chaturvedi *et al.* (2016) reported that the percentage contributions of bole, branch and leaf were 65-76, 14-19, 3-12 for fast growing tree species. In case of other tree based systems stem contributed about 76 to 80%, branch 11 to 29% and leaves 3 to 14% of aboveground biomass. A tree allocates on an average 81.89% to above ground biomass (stem, branch, leaves and litter) and 18.11% to below ground biomass (roots).

In this paper, an attempt has been made to assess the carbon stock production potentials four different silvipasture systems with different tree species by composition, density, growth performance and carbon sequestration under stress influenced ravine ecosystems. In the scenario of climate change, it is necessary to assess the biomass production and carbon sequestration using non-destructive techniques through developing multiple regression equations. Four silvi-pastoral systems belonging to dryland farming systems are commercially important and adopting throughout the greater part of the country. The present paper deals with the biomass accumulation and carbon stock / carbon density of tree based production systems in Chambal ravine of Kota district in Rajasthan, India.

2. MATERIALS AND METHODS

The present study was undertaken in four existing silvipasture systems at ICAR-IISWC, Research Centre, Kota in Rajasthan, India during 2011-16 (Fig.1). The study area is located in Kota district of south-eastern Rajasthan, lies between Latitude - 25°13′29″ to 25°14′18″ N; Longitude -75°52′18″ to 75°52′44″ E. 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 of 0 °C is noted during winters. The average humidity in the mornings and evenings range between 84 to 97% and 21 to 34% was recorded, respectively. During study period (2011-2015), the average 732 mm annual rainfall was received. The research farm comprises of two distinct landscapes, the agricultural table lands (34 ha) and ravine infested lands (34 ha) adjoining Chambal river. Soils of the research farm are classified under Kota series. These soils are deep to very deep soils occurring on flat gently sloping land with less than2% slope. The $CaCO_3$ layer generally occurred below 100 cm (Verma *et al.*, 1986). Soils are dominantly fine textured (>35% clay) belonging to hyperthermic family of Typic Chromusterts. Soil samples were collected from four quadrants in each of seven different land uses. Carbon sequestration potential of four different existing pastoral systems namely Beal + Dhaman (*Aegle marmelos* + Cenchrus *ciliaris*), Amla + Dhaman (*Emblica officinalis* + *Cenchrus ciliaris*), Desi babool + Dhaman (*Acacia nilotica* + *Cenchrus ciliaris*) and Karanj + Dhaman (*Pongamia pinnata* + *Cenchrus ciliaris*) were studied. For the quantitative analysis, four different silvipasture systems with same age (6 years old) were taken random sampling method was used for sampling the above ground biomass and below ground biomass to determine/check carbon stock production potential of species. Periodic observations on the biomass growth and litter production characteristics of the tree species were recorded. Standard 100 m x 100 m size quadrat sampling method adopted for tree biomass estimation, in each quadrat where non-destructive method were used collect biometric information about trees, in sub-quadrat of 1 m × 1 m plots were designed for collection of grass data and litter traps were installed entire study period to sum-up litter data into their biomass estimation.

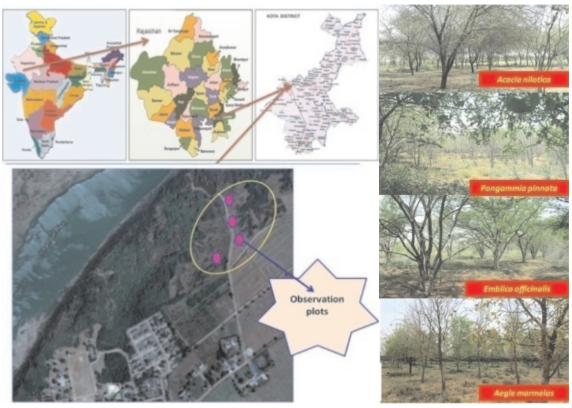

Fig. 1. Location Map and selected silvipasture systems for study in chambal ravines in Kota (Rajasthan)

Tree aboveground biomass (AGB) distribution and carbon storage in four different silvipasture systems under ravine localities were compared unmanaged open jungles in Chambal ravine belt. The rate of carbon sequestration depends on the growth characteristics of the tree species, the conditions for growth where the tree is planted, and the density of the tree's wood. They are five steps:

1. Determine the total (green) weight of the tree.
2. Determine the dry weight of the tree.
3. Determine the soil organic carbon status.
4. Determine the weight of carbon dioxide sequestered in the tree
5. Determine the weight of CO_2 sequestered in the tree per year.

So, determine the total (green) weight of the standing trees measured based on tree species, the algorithm to calculate the weight of a tree is:

W = Above-ground weight of the tree in kgs;

D = Diameter of the trunk in diameter;

H = Height of the tree in Meter

For trees with $D < 11$; $W = 0.25D^2H$; For trees with $D >= 11$; $W = 0.15D^2H$

The aboveground biomass carbon stock was calculated by assuming that the carbon content is 50% of the total aboveground biomass (Brown & Lugo 1982; Cannel *et al*., 1995; Dixon 1994; Ravindranath *et al*., 1997; Richter *et al*., 1995; Schroeder 1992). The average carbon content is generally about 50% of the tree's total volume. The coefficient of 0.55 was adapted for the conversion of biomass to carbon, offered by Winrock (1997). Therefore, to determine the weight of carbon in the tree, multiply the dry weight of the tree by 0.47 (IPCC default value). Soil samples were collected upto the depth of 0-30 cm from surface for determining soil physicochemical 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. The oxidizable soil organic carbon (SOC) was determined using wet oxidation method (Walkley and Black, 1934). Soil bulk density and water holding capacity were measured using method as described by Black (1965). SOC stock was calculated for 0 - 150 cm (30 cm intervals) soil depth by using the equation:

C-stock in soil = C content x Bulk density x Soil depth------------ (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}.

Belowground biomass was estimated 20% of the aboveground biomass (Cairns *et al.*, 1997; Mokany *et al.*, 2006) and 15% of aboveground biomass was considered for litter biomass estimation (Achard *et al.*, 2002). To determine the total carbon stock of the tree, multiply the Weight of carbon in the tree by 3.67. 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 landuse… (2)

Divide the weight of carbon dioxide sequestered in the tree by the age of the tree.

3. RESULTS AND DISCUSSION

Silvipasture is a most promising alternate land use system which integrates multipurpose trees, shrubs, legumes and grasses, mostly on non-arable, degraded lands for optimising land productivity. It mimics a natural forest and helps in conservation of vegetation, soil and nutrients and provides forage, timber and fire wood on a sustainable basis. Trees in silvipasture systems tolerate extreme soil and climatic conditions, whereas grasses provide good ground cover to check soil erosion. The system provides resilience by ensuring continued and sustainable multiple outputs such as forage, fuel, fibre and industrial raw material, besides other positive environmental effects including carbon build up. The significance of biomass, fodder and wood production had long been recognized, but very little attempts have been made to estimate the carbon biomass accumulation and carbon sequestration especially in chambal ravine lands of Rajasthan. Selection of ideal species for carbon sequestration is very important step for restoration of stress influenced ecosystem like ravines. The carbon allocation patterns of above-CS and below-ground CS were mainly influenced by age of tree, types of tree species and growth traits. A significant positive relationship was observed between biomass, litterfall and total carbon stock. The four different silvipasture systems had good amount of undecomposed litter and the peak of litter production was observed in April month. Litter decomposition rate and pattern among various landuse systems were studied and given in table-1. Hence, this is a benchmark parameter for determination of carbon sequestration assessment. Maximum mean aboveground biomass (71.27 t /ha), belowground biomass (14.25 t/ ha), and total biomass (85.76 t /ha) were recorded in the Acacia nilotica based silvipasture land use system. Total biomass production of different land use systems followed the order: *Acacia nilotica* > *Aegle marmelos* > *Pongamia pinnata* and *Emblica officinalis* respectively. The higher values of biomass and carbon stocks observed in silvipastoral systems, it might be due to more stand density and uniform age structure.

Implementing more and more tree-based land use systems like agroforestry is one alternative to deal with problems related to land use and global warming (Albrecht and Kandji, 2003; Li *et al*., 2012). Maximum aboveground biomass (84.65 t ha^{-1}) was recorded in the *Acacia nilotica* based silvipasture system, followed by *Aegle marmelos*. Similarly, maximum belowground biomass (19.50 t ha^{-1}) was also in *Acacia nilotica* based silvipasture system which was found significantly higher than all other land use types. The results of the our present study indicates that total biomass production is influenced by the tree density, fast growing nature of tree species and wood specific gravity components (strong wood value) and is supported by the findings of Rajput *et al.* (2015, 2017). Similarly, Mangalassery *et al.* (2014) also reported highest total plant biomass in the silvipastoral system involving *Acacia* + *C. ciliaris* followed by *Acacia* +*C. setegerus*. Management practices, input components, disturbance levels and site quality may have influenced the variability in the carbon density of different LUS. The high values of biomass and carbon stocks in *Acacia nilotica* due to its stress tolerance capacity, fast growing nature, high stand density, and nitrogen-fixing cum residual soil nutrient build-up which have directly and indirectly beneficial in soil aggregation and nutrient enrichment. Silvipastoral systems help in greater accumulation of soil organic matter and thus more carbon storage when compared to grassland alone or plantation alone (Kaur *et al.,* 2002). The plant component of the silvipastoral system invests higher proportion of growth into the development of the root system compared to those growing singly (Swamy and Puri 2005).

Litterfall is a more important resource of soil organic matter and maintaining the key process in determines the carbon and nutrient cycling of forest floor and the magnitude of litterfall regulates the rate of respiration, decomposition, soil organic carbon content directly. Litterfall can also characterize the properties of the underlying surface by changing the hydraulic conductivity and terrestrial ecosystem dynamics (Zhang *et al.,* 2014). In fact, litter fall and pruned twig root biomass addition are the crucial agents of nutrient recycling in forest ecosystems under ravine lands. It was evident from there and present studies higher C-stock from leaf litterfall and twig biomass from *Acacia nilotica* followed by *Aegle marmelos, Pongammia pinnata* and least with *Embalica offcicinalis* (Fig.1). Our study results were corroborated with similar kind litterfall study result that 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 (Jha and Mohapatra, 2009).

The surface bulk density under different silvipasture systems/plantation was lower than natural unmanaged degraded ravine land soil layers due to lack of ground cover (Table-4). Hence, an addition of leaf litter and organic residue, deep root penetrations which improved soil organic carbon and enhance soil porosity and reduce bulk density. Similar kind of report on lower bulk density under tree plantation was reported by Kumar *et al.,* (2009). Litter fall addition and fine root production is a major pathway for C 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). The soil organic carbon increased upper layers of 0-30 cm soil depth irrespective of the tree species due to litter fall addition and better moisture management practices, there was an increase in organic matter influenced the soil fertility and reduction in soil erosion compare to unmanaged degraded ravine lands (Table-4). The availability of macro-nutrients increased due to an increase in soil organic matter content through litter addition and partly due to the reduction in nutrient loss by soil erosion. The result from the present study also demonstrates that maximum accumulation of soil organic carbon is in the surface layer and decreased with increase in soil depth. Gradual decline in the availability towards lower soil layers could be due to more accumulation and mineralization and reduced root biomass in deeper soil layers. The other reason may be cycling of nutrients and depositing them in surface soils (Shah *et al*., 2013).

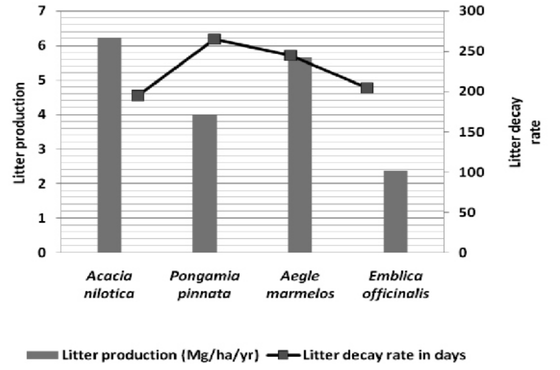

Fig 1. Rate of litter fall addition and decomposition in different silvipasture systems

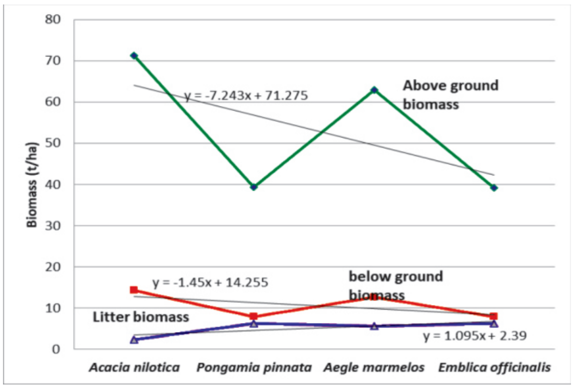

Fig 1: Biomass accumilation rate by different silvipastue systems in Chambal ravines

Table 1. Litter accumulation rate and leaves contribution to litter by different species

Sl.No.	Silvipasture systems	Litter production (Mg/ha/yr)	Leaves as % of total litter
1	*Acacia nilotica*	4.39	70.03
2	*Pongamia pinnata*	6.23	72.40
3	*Aegle marmelos*	5.66	76.62
4	*Emblica officinalis*	5.23	69.12
	Mean	4.56	4.88
	SE.d	1.74	0.96
	CD (0.05)	3.01	1.87

Table 2. Total Biomass and carbon stock production under different silvipasture systems in Chambal Ravines

Sl.No.	Different silvipasture systems	Above ground Biomass (t/ha)	Below ground Biomass (t/ha)	Litter biomass (t/ha)	Total biomass (t/ha)
1	*Acacia nilotica*	71.27	14.25	4.39	89.91
2	*Pongamia pinnata*	39.25	7.85	6.23	53.33
3	*Aegle marmelos*	62.91	12.58	5.66	81.15
4	*Emblica officinalis*	39.24	5.84	5.23	54.60
	Mean	53.17	10.13	4.88	69.75
	SEd	6.23	1.84	0.96	8.83
	CD (0.05)	12.49	3.52	1.87	15.02

Table 3. Total Biomass, carbon stock and carbon sequestration rate by different silvipasture systems in chambal ravines

Sl.No	Silvipasture systems	Total biomass (t/ha)	Total carbon stock (t/ha)	Total SOC (t/ha)	Total CO^2 seq. (t/ha)
1.	*Acacia nilotica*	89.91	49.45	18.92	250.92
2.	*Pongamia pinnata*	53.33	29.33	17.52	171.94
3.	*Aegle marmelos*	81.15	44.63	18.25	230.78
4.	*Emblica officinalis*	54.60	30.303	12.08	154.54
	Mean	69.75	38.43	16.69	202.04
	SEd	8.83	5.72	1.71	27.21
	CD (0.05)	15.02	11.02	3.46	43.63

The total SOC stored in soil was found higher in *A.nilotica* and least in *Pongammia pinnata* i.e., 18.92 t C/ha and 5.07 t C/ha, respectively. Among four systems studied, the total biomass (85.76 t/ha), total carbon stock (47.17 t/ha) as well as total CO_2 sequestration (66.09 t/ha) was highest in the *Acacia nilotica* based silvipastoral system and it could be attributed to the more uniform stand structure combined with high carbon density of trees (ie., more trees per unit area). This was followed by *Aegle marmelos* > *Pongammia pinnata* > *Emblica officinalis* (Fig.3). Terakunpisut *et al* (2007) reported that key factors responsible for such total AGB were different density, stages of forest growth cycle, habitat and species variabilities, and varying tree density. However, plantation forests with higher annual productivity were reported to be ideal for carbon storage and sequestration (Lal and Singh 2000; Annissa *et al.,* 2013). Uthappa *et al* (2016) reported that ravine rehabilitation requires an integrated approach of treatment of table and marginal lands contributing runoff to the gullies and gullies proper on watershed basis. The carbon biomass density per unit area in silvipasture landuse types is especially higher compare to monocropping agriculture and grasslands. Continuous capturing and accumulation of carbon units in trees are regular and accelerated based on fasting growing tree physiological and functional traits. Some of the tree species make continuous littering make soil into nutrient rich which helps build-up more carbon in soil layers compare to monocropping/agriculture systems.

As a result, creation of new plantation with hardy legume tree species on degraded lands is a better option for higher carbon storage when these can planted and harvested periodically and used as a source of timber pole, fuelwood and fodder purposes in resource poor lands people livelihood generation with minimum effort. Attention must be paid to soil and water conservation techniques in relation to agroforestry based interventions for better resource utilization, besides exploring unexploited and under-exploited trees and grasses of high economic values such as tree borne oil seeds and utilizing them in silvipasture systems. The study revealed that the significantly highest amount of carbon sequestrated by *Acacia nilotica* in soil. Further, study confirms that *A.nilotica* and *Aegle marmelos* species provides a substantial role through carbon sequestration. Our findings made great implication on choice of tree species selection for afforestation /reforestation in terms of biomass and carbon stock production are important /valuable for decision making process in sustainable ravine watershed management.

4. CONCLUSION

Therefore, the ravine lands of India have a huge potential for biomass production, livelihood security, C-stocking, improvement in soil environment. Species composition and vegetation structure had significant impacts on the biomass, carbon stock and improvement in soil nutrients in ravine lands. The carbon biomass density per unit area in silvipasture landuse types is especially higher compare to monocropping agriculture and grasslands. Continuous capturing and accumulation of carbon units in trees are regular and accelerated based on fasting growing tree physiological and functional traits. Maximum mean aboveground biomass (71.27 t ha^{-1}), belowground biomass (14.25 t ha^{-1}), litter biomass (2.39 t ha^{-1})and total biomass (85.76 t ha^{-1}) were recorded in the *Acacia nilotica* based silvipasture land use system. Total biomass production of different land use systems were categorized according their biomass and carbon productivity in the following order: *Acacia nilotica* > *Aegle marmelos* > *Pongamia pinnata* and *Emblica officinalis* respectively. Simultaneously, tree Canopy raindrop interception, control of surface flow velocity by grass, formation underground root network by grass and trees, deposition of litter residues, decomposition of leaf litter and fine roots turnover may causes in reduction of soil erosion through soil surface improvement and nutrient buildup through soil physio-chemical modification by trees and grasses. Silvipasture systems with fast-growing tree species, such as Desi babool (*Acacia nilotica*) and Bael (*Aegle marmelos*) would be appropriate Multipurpose tree species along with suitable soil moisture conservation measures were found most suitable form of scientific land use for rehabilitation of ravine humps under chambal ravines in India.

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