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Technology for rehabilitation of Yamuna ravines – cost-effective practices to conserve natural resources through bamboo plantation

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The present study evaluated bamboo (*Dendrocalamus strictus*) based resource conservation in the Yamuna ravines at Central Soil and Water Conservation Research and Training Institute, Research Centre, Agra, Uttar Pradesh, India. Ravine lands are highly degraded dry lands and 3.97 m ha area is affected by ravines in India. One ravine micro watershed of 2.8 ha area was planted with two rows of bamboo in staggered manner as vegetative barrier for the analysis of hydrological and economic aspect of bamboo plantation. Hydrological results showed that runoff has been reduced from 9.6% to 1.8% and soil loss from 4.2 to 0.6 t/ha/year in the last 4 years. Based on bamboo growth performance, average value of culm height and culm collar diameter have been recorded as 3.80 m and 22.50 mm, the value of average crown size and number of culms per clump being 3.93 m and 18 numbers respectively. Further, the soils under bamboo plants improved in terms of decreased pH and enhanced soil organic carbon. The economic analysis suggested a cash outflow of Rs 48,000 ha^{-1} from 7th year onwards to the stakeholders in the region, in addition to the benefits accrued to society at large in terms of value of nutrient (Rs 2125–5555 ha^{-1}) saved through soil conservation. This study recommends bamboo plantation for productive and protective utilization of such degraded lands. It also suggests that the high cost of establishment for individual stakeholders can be met through subsidies and banks' financial inclusion programme in developing countries such as India. Further, public funding can also be routed through appropriate budgetary provisions in development plans of corporate entities involved in the rural development in the country.

Keywords: Bamboo plantation, degraded land, economic analysis, financial analysis, ravines.

RAVINE lands are highly degraded dry lands and 3.97 m ha area is affected by ravines in India. In Uttar Pradesh alone, 1.23 million ha (33.5%) of land is occupied by ravines, which are mainly found along the bank of river Yamuna and its tributaries. The severity of water erosion is found at the peak along the banks of Yamuna and Chambal rivers in the districts of Agra, Etawah, Kanpur, Fatehpur, etc. where terrain has completely deformed into ravines. Rao *et al.*[1] reported that stream bank erosion is a major cause of land degradation, leading to deteriorated drainage systems, which ultimately govern natural calamities in terms of floods, and non-point source pollution in ravine lands of India. Vegetation in these ravine regions suffers from a variety of unfavourable conditions such as nutrient deficiency, moisture stress and biotic interference. The inclement weather conditions coupled with very high summer temperature further aggravates the problem and makes farming uneconomical. In such situations, less water and nutrient demanding technologies hold a good promise to sustain the productivity and provide alternative source of income to the farmers. This vast tract of existing ravine lands poses potential threat to nearby productive lands because of overexploitation and poor management. Therefore, there is an urgent need to arrest degradation of these

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lands and protect both the arable and non-arable lands from further degradation. Since rain is a major source of water in the region, every drop of it must be conserved in the soil through *in situ* rainwater conservation.

Impacts of bamboo planting include raised groundwater level, increased land productivity, improved microclimate and improved socio-economic conditions. It is also seen that bamboo-based agroforestry models improve ecological parameters of a highly degraded basaltic tract of Jabalpur, Madhya Pradesh[2]. Similarly, Bahadur *et al.*[3] reported that improved farm practices and land treatment by bamboo, grasses and legumes on bunds, sloppy lands and terraced lands have been found to be effective means of soil and water conservation. Plantation of *D. strictus* was successful in increasing the economic productivity of gullied beds. About 4000–5000 mature culms/ha were harvested every year from the bamboo plantations on the gully beds[4]. Several scholars[5–9] have clearly established the importance of bamboo plant as an effective means of resource conservation. In comparison to deciduous and coniferous plantations, bamboo plants, are hydrologically best suited to degraded ravine lands[10]. Pande *et al.*[11] found bamboo plantation economically viable in ravines and suggested policy measures to development agencies and finance institutions for large greening of ravines in the country.

Despite advances towards technological remedies for ravine reclamation through bamboo plantation, only a few attempts have been made regarding socio-economic aspects of plantation[12]. A policy debate covering government vis-à-vis individual decision about large-scale bamboo cultivation warrants that bamboo plantation must be economic (per unit land area). At least, it must complement crop production without reducing farm household income[13]. An economic analysis of bamboo plantation, therefore, shall not only help a large section of stakeholders at local, regional and national levels but also prove beneficial to policy makers, funding agencies and non-government organizations embarking upon ravine reclamation programmes. This study examines the hydraulic and economic aspects of bamboo plantation for ravine reclamation with policy implications for converting large-scale utilization of degraded ravine lands into productive land in Yamuna ravines. Hence, a study was carried out at Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Research Centre, Agra, on hydrologic and economic evaluation of bamboo plantations in gullied lands. This article presents some salient findings of the experimental studies on bamboo plants with conservation techniques in Yamuna ravines.

The experiments were conducted at CSWCRTI, Research Centre, Agra, located at 23°52′–31°28′N lat. and 77°06′–84°37′E long. and 168 m amsl. The study area is the representative site of major Yamuna ravine system in Uttar Pradesh (UP) which covers 1.23 m ha (33.5%), out of the 3.67 m ha ravine area in the country. Nearly 389,000 ha area is affected along the Yamuna in southern UP[14]. The climate of the ravine area of the state is tropical, continental and monsoonal with mild and dry winter and hot summer. Average rainfall is 755 mm. During summer, hot winds (Loo) blow from the west. At the study location, May is the hottest month with mean maximum temperature of 41°C and January is the coldest month with mean minimum temperature ranges from 6.5°C to 10°C. Relative humidity is least (21–27%) during summer. Thus, it makes the summer dry and hot. It is high during June–September (70–85%), whereas it remains between 50% and 70% during the remaining parts of the year. The predominant vegetation comprises Vilayati Babul (*Prosopis juliflora*) followed by Babul (*Acacia nilotica*), thorny legumes, Euphorbias and dwarf grass species. There is occasional occurrence of Neem (*Azadirachta indica*), Papdi (*Holopteila integrifolia*), Shisham (*Dalbergia sissoo*), Karanj (*Pongamia glabra*) and Chonkra (*Prosopis cineraria*).

One micro ravine watershed of 2.8 ha size was selected for this study. A gauging structure with triangular weir was constructed at the outlet of the watershed to collect data on runoff and soil loss of every runoff producing rainfall event when ravine beds were planted with two rows of bamboo in staggered manner as vegetative barrier (4×4 m). The bamboo plantation was supported with soil and water conservation measures such as trenches, bunding, etc.

The study is based on both primary and secondary data. The secondary data were supported by primary data collected from fields in a research project carried out at the Research Centre, Agra. Four years (2010–2013) data of rainfall, runoff, soil loss and bamboo plant growth have been collected from the gauged ravines micro watershed and analysed. Daily rainfall chart from recording type rain gauge have been collected from the meteorology observatory, Chhalesar, Agra. Runoff charts of stage level recorders from runoff producing storm were analysed for runoff calculation. Runoff water sample (500 ml) was collected manually for calculation of soil loss. Plant growth parameters such as average culm height (cm), average culm diameter (mm), crown size (cm) and number of culms/clump were also recorded at an interval of 6 months. Soil samples from different places were collected before plantation of the bamboo and after 4 years from the same places and analysed to study the impact of bamboo plantation on soil properties.

The data includes conservation measures adopted prior to bamboo plantation and input and output details of bamboo plantation in ravines. The costs and benefits have been valued at 2010–2011 local prices in the regions. Bamboo has a long productive cycle in ravine lands; the present analysis has been conducted for a period of 20 years. The financial discount rate of 8% has been used[11], though its sensitivity is analysed using different discount rates. For economic analysis, a social discount rate of 5.9% has been considered[15].

Economic benefit–cost analysis is helpful in assessing the economic efficiency, from society's point of view, of a production system. It attempts to identify and quantify costs and benefits to society (not just individuals) by utilizing resources over a specified time period. The output (benefit) considers values for such things as increased or decreased soil erosion, reduced unemployment and improved foreign exchange earnings. This type of analysis is useful where the objective is to develop and implement techniques for environmental soil and water conservation, soil improvement and carbon sequestration as is the case with bamboo plantation. In ravines, bamboo not only provides the much needed timber but can also be used as soil conservation measure. The costs and benefits of those objectives are not only shared or consumed by specific individuals but by 'society' or groups within society. This analysis calculates the 'net benefit' or 'return' to society employing alternative bamboo techniques.

Financial benefit–cost analysis calculates the costs and benefits to individuals and organizations using market prices only. The discounted (over time) cash flow method is also used; however, the focus is on calculating the net benefit and return to the capital invested in the production system. In the case of bamboo, this type of analysis can, for example, be used where the objective is to maximize economic output per unit time by a group of farmers in ravines.

In both forms of benefit–cost analyses, there are three main criteria by which a single or set of techniques can be assessed and compared. These are: (i) Benefit–cost ratio is simply the total of the present worth of expected benefits divided by the total of the present worth of expected costs. A production system with a ratio of greater than 1 is economically efficient in terms of resource use. (ii) Net present value (NPV) is simply the difference between the present value of the expected benefits and expected costs. Production systems which result in a positive net present value are economically efficient in terms of resource use. (iii) Internal rate of return is defined as the average earning power of the value of resources used in the production system. A production system that gives a rate of return higher than the existing market interest rate is resource efficient.

The formal mathematical statements of these criteria are as follows:

$$\text{Benefit}-\text{cost ratio} = \frac{\sum_{t=1}^{n} B_t (1+r)^t}{\sum_{t=1}^{n} C_t (1+r)^t}.$$

$$\text{Net present value} = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+r)^t}.$$

Internal rate of return is that discount rate r such that

$$\sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+r)^t} = 0,$$

where B_t = benefits in each year, $t = 1, 2, \ldots, n$; C_t = costs in each year, $t = 1, 2, \ldots, n$; n = number of years and r = discount rate.

Intangible benefits of soil conservation due to plantation are assessed from different points of view depending upon the context. Soil erosion affects downstream reservoir, commercial fish production pond and recreational lake downstream. The damage function approach can be used for modelling erosion's impact on soil productivity. Similarly, replacement cost approach has been used to impute resource value to soil erosion[16,17]. Replacement cost approach has been used here to estimate the resource value of soil conserved with bamboo plantation. The soil loss from degraded ravine lands moves to adjacent Yamuna river in Agra. It is assumed that the productivity of soil can be maintained if the lost nutrients and organic matter are replaced artificially. This justified the use of replacement cost approach. Moreover, this approach is easier if data on nutrient loss and market price of nutrient is readily available[18].

The carbon build-up in soil under bamboo plantation was estimated with a scenario that the degraded ravine land with no plantation would not only have lost the soil nutrients but also lost the opportunity of building soil carbon under the plantation. Therefore, the intangible benefit of the carbon build-up justifies the utility of bamboo plantation in degraded ravines to national and international stakeholders and the policy makers.

Soil carbon build-up under plantation is valued using an estimate of the shadow price of carbon drawn from the climate change damage literature. This price reveals the present value of (future) damages caused by a tonne of carbon (equivalent) emissions[19]. A value of US$ 20/tC is used as the social cost of carbon. Sensitivity analysis is performed with estimates of US$ 5/tC and US$ 40/tC (ref. 15).

Four years (2010–2013) runoff and soil loss data collected from the ravinous micro watershed planted with bamboo as a vegetative barrier in staggered manner have been analysed and presented (Table 1). Average seasonal rainfall during the study period was recorded as 427 mm. Results showed that runoff was 9.65% in the first year of plantation which was reduced to 1.81% in the fourth year due to vegetative growth of bamboo plantation in ravine bed. Similarly, soil loss was also reduced from 4.27 to 0.60 t/ha/year over the period of 4 years. Reduction in runoff and soil loss was attributed to influence of bamboo vegetation on soil in terms of increased permeability of the soil and thereby allowed better water penetration into soil and increased drainage capacity of soil. This has resulted in reduced surface runoff, soil loss and evaporation from the area.

Table 1. Runoff and soil loss under bamboo plantation

Year	Seasonal rainfall (mm)	Runoff from bamboo planted area (mm)	Runoff (%)	Soil loss (t/ha/year)
2010	456	44	9.65	4.27
2011	226	6.04	2.67	0.66
2012	531	14.50	2.73	0.78
2013	494	8.96	1.81	0.60

Table 2. Mean value of growth parameters of bamboo plants at Research Farm, Agra

Growth parameters of bamboo plants	Values
Average culm height	3.80 m
Average culm collar diameter	22.50 mm
Average crown size	3.93 m
Number of culms/clumps	18.02

Table 3. Basic data for working out cost of cultivation of bamboo in Yamuna ravine

Description	Yamuna ravine
Spacing (m)	4 × 4
Number of plants/ha	625
Mortality replacement (%)	30
Manure required (kg per plant per year)	10
Fertilizer required (kg per plant per year)	0.02
Cost of fertilizer (Rs/kg)	9.5
Irrigation cost/number (Rs)	100
Number of irrigations/year	21
Seedling price (Rs/seedling)	6.5
Labour wages (Rs/manday)	150
Number of harvestable plants per ha (%)	
Initial 4 years	30
Fifth year onwards	40
Sale price per bamboo pole (Rs)	40

Soil loss decreased considerably and has brought change in moisture and silt retention owing to the growth of a dense vegetative cover in the gully beds. Bamboo (*D. strictus*) plant roots play an effective role in protecting soil from gully beds and reduced runoff by increasing infiltration of soil. A similar study was reported by Sharda *et al.*[20], on effect of plantation of *Cenchrus ciliaris* along with contour trenching on runoff and soil loss from 0.2 ha watershed at Agra. The runoff was brought down by the above treatment from 25% to almost nil. Sharma *et al.*[21] have also reported that bamboo plantation conserves soil moisture and mitigates the adverse drought effects on flora and fauna. Further, bamboo acts as good soil binder owing to its dry and hardy nature, peculiar dense clump formation and extensive interlocking fibrous root systems, natural capacity to regenerate through its rhizomes which play an important role in preventing erosion, increasing water holding capacity and nutrient cycling under gully beds.

The mean value of bamboo growth parameters after 4 years of plantation in gully bed, viz. average culm height (m), average culm collar diameter (mm), average crown size (m) and number of culms/clumps were recorded and analysed (Table 2). Average value of culm height and average value culm collar diameter have been recorded as 3.80 m and 22.50 mm; the value of average crown size and number of culms per clump were recorded as 3.93 m and 18 numbers.

The results of this treatment have been found to be promising in biomass productivity and enhancing the *in situ* moisture use efficiency. Through this finding, we could reclaim major ravine land ecosystem using *Dendrocalamus strictus* along with recommended moisture conservation measures. *D. strictus* has been identified for protective and productive use in ravine lands and this is a potential species for efficient resource utilization in non-arable lands, livelihood support systems, etc. This technology is applicable to light textured well-drained soils including reclaimed ravine land where moisture and nutrient resources are scarce. The technology can suitably be adopted on the cultivable wastelands distributed in north-western India and in other areas having similar agro-climatic and soil conditions. The growth of bamboo plantation and reclamation of degraded ravines are shown in Figure 1.

The basic data used for estimating cultivation cost of bamboo in Yamuna ravines is presented in Table 3. Bamboo was planted in 4 × 4 m spacing in the ravines. This space is sufficient for bamboo clumps to grow in subsequent years. The field study at Yamuna ravines suggested a mortality replacement of 30%. Damage due to wildlife was the major factor; water stress and local management were the other factors. Similarly, the differential supportive irrigation in the ravines was explained in terms of rainfall and soil. Yamuna ravines are characterized by sandy to sandy loam soils.

The analysis relies on actual accrual of costs and bamboo output harvested from the fields in Yamuna ravine systems. The constant input and output prices for the year 2010–2011 were considered. The harvest price of bamboo at farm gate was considered as these were realized at the research farm in Yamuna ravine. This is justified since there is no organized market and identified marketing channel for bamboo sale in the ravines. A harvest cycle of 20 years has been considered with different financial and social discount rates.

Figure 1. Photographs showing the reclamation of degraded Yamuna ravines through bamboo plantation.

The total cost of bamboo plantation in Yamuna ravines is accounted for by land preparation; soil and moisture conservation measure (trench); plantation establishment including planting material and protection and maintenance, which includes irrigation, cleaning of bamboo clumps, etc. In the analysis, 35–46% of total cost is incurred in the first year. Major expenditures in the first year are for trench making, irrigation followed by plantation establishment (site preparation and planting). The remaining 54–65% is spread over the next 4 years, primarily for irrigation, cleaning of clumps and mortality replacement in the second year and carry-on plantation maintenance and protection from second to fifth year. Break-even is expected in the eleventh year, when maintenance and protection cost is offset by bamboo sales (Table 4).

Land preparation before bamboo plantation in ravines is required to remove obnoxious weeds. Competition for moisture otherwise would raise the expenditure on irrigation. Irrigation is one of the important cost items. The establishment cost items are spread over a period of 7 years. Only protection and harvest costs would occur beyond 7 years. Major costs accrue in the initial 4 years, the minor costs are spread over the subsequent years. The expenditure on cleaning of bamboo clumps is done in an interval of 2 years. The total cost over a period of 7 years works out to be Rs 117,248/ha in Yamuna ravines, out of which Rs 42,768/ha is spent in the first year (Table 4).

Harvesting commences from seventh year onwards. The minimum sale price per piece of green bamboo is Rs 40. On average, three to four good culms per clump of bamboo can be harvested from seventh year (Table 5). A net expected income of Rs 34,000/ha can be realized during seventh to tenth year. This would increase to Rs 48,000/ha from eleventh year onwards.

The financial indicators for bamboo plantation in ravines are given in Table 6. The net present worth (Rs/ha/year) is Rs 7031 in Yamuna ravines. Similarly, the benefit cost ratio works out to be around 1.89 in the Yamuna ravines. The internal rate of return reveals that bamboo performance in Yamuna ravines yields the best rate of return (19.3%).

While soil carbon has been recognized to benefit in improving soil structure, water retention and fertility, improved productivity, profitability and greater resilience to a warming, drying climate[22], bamboo plantation in ravine bed also checks soil erosion, thereby conserving the precious resource in degraded gullies. Carbon stock build-up under bamboo plantation has been extensively quantified[23–27]. Carbon stock comprises living biomass and soil organic matter. While the former is depleted with the harvest of bamboo, the latter is retained in the soil till the bamboo plantation lasts. Soil conservation benefits due to bamboo are a bonus in ravines, which are prone to soil loss but have not been much studied. Research studies in ravines have proved that bamboo is effective in conserving soil erosion[28]. This study values these benefits under bamboo plantation based on the field data collected from the research farm.

The conservation effects of bamboo studied at the Research Farm, Agra have shown that the bamboo

Table 4. Unit cost for raising 1 ha bamboo plantation in ravine land (2010–2011 prices), Yamuna Ravines

		Years							
Items	Units	1	2	3	4	5	6	7	Total
Material									
Planting material including 30% mortality replacement in second and third years		2,600	780	780					4,160
Manure and fertilizers (DAP)	50 g/plant	190							190
Plant protection	LS	2,228							2,228
Irrigation, 21 nos	Rs 100 per irrigation	2,100	2,100	2,100	2,100				8,400
Subtotal		6,018	2,880	2,880	2,100				14,978
Labour	Mandays								
Land preparation	LS	6,000							6,000
Digging of trench, refilling @ Rs 30 per trench	400 nos	12,000							12,000
Planting and staking	400 nos	14,000	4,200	4,200					22,400
Soil working and others	2		5,000	5,000	5,000	5,000	5,000	5,000	30,000
Watch and ward	LS	3,000	3,000	3,000	3,000	3,000	3,000	3,000	21,000
Harvesting – 7th year onwards	LS							6,000	6,000
Subtotal		35,000	12,200	12,200	8,000	8,000	3,000	9,000	97,400
Contingency	5%	1,750	610	610	400	400	150	450	4,870
Grand total		42,768	15,690	15,690	10,500	8,400	3,150	9,450	117,248

Table 5. Expected yield and income of bamboo plantations in different ravine systems

Year	Yield (poles no. ha^{-1}) in Yamuna	Net income (Rs ha^{-1}) in Yamuna
VII	1200	33,550
VIII to X	1200	34,000
XI year on wards	1600	48,000

Table 6. Financial analysis for cultivation of bamboo in ravines

Parameters	Yamuna ravines system
NPV (Rs/ha/year)	7031
Benefit cost ratio	1.89
Internal rate of return (%)	19.3
Payback period (years)	9

plantation retains 80–100% rainwater. This water is either used by the vegetation or recharges the groundwater strata. Sediment yield is reduced to 0.60 t/ha in a high rainfall year, which is 15–25 times less than an untreated watershed[29]. Further, the studies conducted at the farm also reported the conservation effect of bamboo plantation on improved soil health over a period of time[30]. Various approaches have been used to value the conserved soil. The nitrogen, phosphorus and potash content of soil in a degraded ravine land of this region ranges between 240–321, 6.5–9.70 and 510–658 kg/ha respectively. This works as a lower and upper bound for nutrients in the soil conserved as a result of bamboo plantation. In ravine land, farm yard manure is applied in small quantity prior to plantation but the quantity is too small to replace the nutrients lost through soil erosion. Hence, only chemical fertilizers are used for replacement of the last nutrients. Further, nitrogen is closely related to carbon in the soil under plantation. Since valuation of carbon is done separately, benefit of this nutrient is not summed in the nutrient saved. The border price of nutrients has been considered for economic benefit cost analysis. The value of nutrient, thus, saved through bamboo plantation is estimated to be Rs 2126–5555/ha.

Deep and narrow gullies are recommended to be put under permanent vegetation of grasses and trees. Bamboo plantation for productive and protective utilization of such degraded lands is not only a profitable option for local stakeholders but also financially and economically viable policy option for funding agencies and government and non-government agencies. Due to bamboo plantation runoff from the ravinous watershed has been reduced from 10% to 2% and soil loss from 4.2 t/ha/year to 0.6 t/ha/year. The analysis carried out using data from the Yamuna ravine system suggests a cash outflow ranging from Rs 33,550/ha to Rs 48,000/ha from seventh year onwards to individual stakeholders in the region, in addition to the benefits accrued to society at large in terms of enhanced soil health. Bamboo harvest cycle continues for a long time in ravines if a recommended practice of harvesting one-third culms per clump is followed. The soil carbon build-up would enhance with the age of plantation due to litter fall. Based on the evidence in ravines, this conservative value of enhanced soil carbon adds up to a net present value of benefits to the economy. Cost of bamboo plantation can be a constraint to small and medium local stakeholders located in the vicinity of the ravine lands. Initial high cost of establishment can be met through subsidies and banks' financial inclusion programme for such stakeholders. Government waste land development programme can be an appropriate mechanism to address this problem. The substantial amount of public funding can also be routed through appropriate budgetary provisions in the development plans of corporate entities involved in the rural development in country.

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