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Rehabilitation of Lignite Mine Spoils in the Indian Arid Zone-An Ecological Approach

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Abstract: Rehabilitation of barren lignite mined spoiled lands was carried out in the Barmer district of Indian arid zone following ecological approach. Being highly sodic in nature, the spoil surface was overlain with a layer of dune soil in varying thickness. The three treatments of thickness of topsoiling were 30, 45 and 60 cm. Landshaping of resultant surface with 5% slope was done to make micro catchment for water harvesting. Multipurpose species of trees, shrubs, creepers and grasses were selected. Woody perennial saplings were prepared for transplantation in 60×60×60 cm pits filled with a mixture of local soil and FYM in 2:1 ratio. Plantation was carried out in three seasons i.e., July, September and March. Results revealed that overall survival of species planted at lignite mine spoil was 85.28%. Maximum growth was observed in *Parkinsonia aculeata* followed by other species. Month of March has proved to be better plantation season than July and September in high sodium containing backfill. Micro catchments did not favour the growth of planted species. Thickness of 60 cm topsoiling emerged as most optimum for survival and growth of species. Monitoring of species growth and survival revealed that most suitable species for lignite mine spoil back fill in this area are *Parkinsonia aculeata, Acacia nubica, Circidium floridum, Acacia tortilis, Salvadora oleoides, Dichrostachys nutans, Acacia senegal* and *Tecomella undulata* in that order. Role of local people and NGO's for participatory mine rehabilitation has been highlighted as a major future requirement of these programs.

Key words: Mining, lignite mine spoil, rehabilitation, lignite backfill, woody perennials.

Opencast mining of lignite entails removal of uneconomic earth up to lignite seams which is then piled in the form of overburden dumps. As the mining pit advances, huge volume of solid waste comprising low quality mineral, murram and bentonite so excavated is refilled in the previously created abandoned mining pit to bring it to the level of adjoining land surface. This is called "Backfill". The overburden dumps due to stock piling of mineral waste occupy large areas of fertile land rendering them unfit for any economic activity. Mining muck heaps normally vary from place to place and type of mining in respect of height, slope, width, thickness, size of aggregates, voids besides their chemical constitution. In case of systematic dumping the height may range from 10 to 40 m. Final surface of backfilled pit is a result after many cycles of compaction of the mine waste by continuously rolling of heavy machinery. Uneven compaction results in highly compressed central area and loose periphery (Power *et al*., 1978). This causes uneven subsidence, undulating surface, differences in surface drainage and finally slope wash that adversely affects the adjoining land. This resultant surface is in fact a "spoil surface" and not the "soil surface" because it is completely devoid of fertile soil, flora and fauna. Both, overburden dumps and backfills have discontinuous rock-soil continuum (Harthill and Mckell, 1979) and thus represent drastically disturbed habitats that remain barren for years if left unattended. These barren landscapes of mining wastes are known to cause a large number of adverse ecological impacts which are both immediate and long term (Sharma *et al*., 2004). These immediate impacts trigger long term effects of declining productivity in adjoining lands, disrupting hydrological processes and enhancing erosional hazards culminating in water and soil pollution and occupational hazards affecting ultimately the human health. Thus, these drastically disturbed ecosystems are extremely vulnerable to future anthropogenic changes at both, local and global level (Peters, 1985). Bringing such lands to a form and productivity in conformity with the land use plan for the site is therefore, an essential requirement legally as well as environmentally. This includes isolation of disturbance impacts to the site, limiting

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contribution to environmental deterioration and making site amenable with surrounding aesthetic values by planting suitable species (Kumar and Praveen-Kumar, 2009).

Extent of mining in India and Rajasthan

India produces 89 minerals of which 48 are non metallic, 10 metallic and 24 minor minerals while 4 are fuel and 3 atomic minerals which all account for production value of Rs. 2,27,116 crores in the year 2013-14 (www.dmg. gov.in). Major mining companies were 3461 of which maximum are located in Andhra Pradesh (636) followed by Rajasthan (448). Rajasthan produces 58 different kinds of minerals and earning Rs. 3088 crores as annual revenue as of 2013-14. Rajasthan has been the sole producer of granite, jasper and wollastonite in the country, while most of zinc, calcite, asbestos and gypsum also come from Rajasthan. Some other minerals having higher production in Rajasthan are: ball clay (70%), feldspar (36%), fluorite (59%), kaolin ((44%), lead concentrate (89%), ochre (90%), phosphorite (90%), silver (81%), steatite (76%), barytes (32%), copper (32%), quartzite (33%) and silica sand (21%) (dmg-raj.org). India is ranked third in the world in the production of coal and lignite. Rajasthan has lignite reserves of 2208.74 million tons of which Giral has 101.90 million tons. In Barmer, lignite is mined in 7391.71 ha and in 2013-14 produced 49.64 lakh tons with the sale value of 335 crores and earning a revenue of 34 crore, which accounts for 70% total revenue from lignite in Rajasthan. Together, minor and major minerals provided direct employment to 35000 peoples and indirect employment to large majority of peoples (www.dmg-raj.org). At the same time mining of these minerals also brings out three times the quantity of overburden or mine waste which deteriorates environment . Hence, rehabilitation of lignite mine spoils assumes importance and priority in Barmer.

Need for Rehabilitation

Mining has been causing environmental concern by creating drastically disturbed lands on one hand but it also provides livelihood to millions of poor on the other hand. The huge revenue it provides makes it a social compulsion and political propriety to continue mining for providing livelihood to millions of people. But it becomes essential to find out techniques of rapid rehabilitation of mining of different minerals so as to minimize deleterious impacts of mining.

Efforts were therefore, initiated to rehabilitate lands spoiled due to lignite mining at a village Giral in Barmer district of Indian arid zone. The physical and chemical analysis of muck material following standard analytical tools revealed the limitations and possibilities of its rehabilitation. This helped in deciding three things: 1) The type of soil amendments to make it a growing media, 2) The type of soil and water conservation measures required and 3) The type of species suitable for rehabilitation of lignite spoils. Analysis of lignite mine backfill revealed that compared to normal soil, the backfill had high silt and clay, vary high sodium and high electrical conductivity (Praveen-Kumar *et al*., 2005). Since gypsum addition would require water in huge quantities for neutralizing high sodium, this option was not followed. Instead, simple layering with original top soil emerged as cheapest alternative. It was therefore decided that the best approach to rehabilitate these lands is to cover them with a layer of local soil and sand and then grow on them different species (Kumar and Praveen-Kumar 2009, Sharma *et al.,* 2004). This also fills the voids to make a perfect rooting medium. Further, seed bank in soil would help regenerate the natural weed flora. Their short duration growth would give anchorage to soil with their shallow root system. Almost all the muck heaps are deficient in nitrogen, phosphorus and potash. Hence for successful establishment and reasonable growth of transplanted material, farmyard manure (FYM) together with chemical fertilizer, etc. could also be used. Of these many options we describe here the woody perennials selected and planted on the modified lignite mine spoil surface aimed to answer following questions

i. Which is the most optimum thickness of soil re-spread over the surface of spoil of lignite backfill for sustainable revegetation?

ii. How does surface water harvesting affect the survival and growth of planted saplings ?

iii. What are the most suitable woody perennials species for plantation?

iv. Which is the best season of plantation of woody perennials?

v. Of the planted species, which are the best performers to be taken up for large scale plantation and their validation in the field?

Aim was to control erosion through plant cover in the short term and development of a self sustaining community through colonization of native species in the long term (Mitchell, 1987).

Such augmentation of biological activity of the soil surface horizon was expected to ensure the success of plantation in the long term. Restoration of physical structure, chemical composition and biological functioning of mine spoils by restructuring the vegetation was the final goal (Packer and Aldon, 1978). Therefore treatments were successively refined to narrow down the selection of soil layer thickness, type of species, season of plantation and water harvesting treatments.

Material and Methods

Environmental setting

Study area is situated in village Giral of Barmer block some 45 km north west of Barmer town in Barmer district (24°58′ and 26°32′ N and 70°5′ and 72°52′ E). Maximum temperature during summer often touches 48°C which declines to 2°C in winter. Average annual rainfall and potential evapo-transpiration are 268 mm and 1857 mm, respectively. Most of the rainfall is received during July to September.

Soil layering treatments on backfilled spoil surface

The mine waste excavated from the advancing face of the mining pit is filled up in those mine pits where economically viable extraction of lignite has been completed. These backfilled areas were compacted and leveled. Physico-chemical properties of this spoil surface and non mined adjoining soil are detailed in Praveen-Kumar *et al*. (2005) and are also mentioned elsewhere in this issue. As emerged from that study,the leveled spoil was covered with a layer of locally available sand, soil from nearby dune landscape. In order to find out optimum thickness of re-spread soil layers following three treatments were designed:

- 30 cm thick soil spread
- 45 cm thick soil spread
- 60 cm thick soil spread

Land shaping for water harvesting

Micro catchment for water harvesting were created by giving 5% slope to the land in the 9 m width between two plantation rows so that rain water flows to the plant pits. Microcatchments were made in treatments of 30 and 45 cm layer soil spread only. However after initial experiment micro catchments were discontinued in further experments. Instead pit plantation was carried out.

Excavation of planting pits

The operation was started well in advance before rainy season. Planting pits (60x60x60 cm) excavated at 3 m spacing in rows 9 m apart, were filled up with necessary growing medium, consisting of mixture of fine sand / farm soil and farmyard manure in 2:1 ratio.

Selection of plant species

Based on bio-climatic conditions, soil type and desirable post mine use the species selected should have following characteristics:

- It can be propagated easily.
- It may be established successfully.
- It should be compatible with other species.
- It should be able to provide quick vegetative cover of pioneer species.
- It should be able to afford revival and growth of other desirable species, can be called also as nurse crops.
- It is a succession facilitator species.
- It should have desired rooting habit.
- It should serve as feed for wildlife and/or livestock.
- It should have tolerance to utilization.
- It should possess strategic adaptations in the phenological cycle and morphology so as to be able to evade/adapt critical periods of extremes of temperatures, drought and salinity.
- It should have competitive edge over invaders.
- It should be reasonably resistant to pest and microbial infections.
- It should have minimum or no requirement of externally added fertilizers.

- It should have rapid seedling growth and seedling drought/frost tolerance.
- It should have overall wide ecological amplitude in its life cycle strategy.

Table 1. Suitable plant species for revegetating lignite mine spoils

Type of vegetation	Plant species
Trees	*Acacia senegal, Acacia tortilis Azadirachta indica, Leucaena leucocephala, Parkinsonia aculeata, Prosopis cineraria, Salvodora oleoides, Tecomella undulata*
Shrubs	*Cassia angustifolia, Circidium floridum, Dichrostachys nutans, Tamarix aphylla, Ziziphus rotundifolia, Acacia nubica Colophospermum mopane*
Grasses	*Cenchrus setigerus, Cenchrus ciliaris, Lasiurus sindicus*
Crops	*Pennisetum glaucum*
Medicinal plants	*Cassia angustifolia*
Vegetables	*Cucumis callosus* var. Agrestis, *Cucumis callosus* var. Momordica, and *Citrullus fistulosus*

Using a combination of above criteria multipurpose native species of trees, shrubs, and perennial grasses for arid and semi-arid areas were selected for revegetation. Some of the exotic species, whose performance have been well established in arid tract, were also included (Table 1). Since majority of lands prior to mining in arid tract are grazing ground or rainfed agriculture, development of agroforestry and/or silvi-pasture system was finalized as post mine land use.

In this paper we report the results of survival and growth of only woody perennials, i.e., trees and shrubs.

Planting on spoils overlain with soil

Healthy seedlings of carefully chosen species were prepared in nurseries in poly bags in advance. Four months to an year old saplings were kept ready for planting at the mining site with suitable soil working for increasing water availability. Trees and shrubs were planted at 3 m plant to plant in a row which were 9 m apart. Planting was tried in three seasons viz., July, Sept. and March. Final treatments combinations involving soil layer thickness, water harvesting treatment and season of plantation are given in Table 2. The interspaces can be planted with annuals, grasses, legumes or crops. Weeding, soil working and watering (15 l/plant) in first three years are done as per requirement. No watering was done from June end to October.

Trees and shrubs of fifteen species adapted to this region were planted to study their survival and growth in backfill area. In all 3935 saplings were planted between 1999 to 2003 (Table 3). Besides, saplings were also planted at unmined site in five rows as green belt near the Giral village. The plantation pit and potting medium were same as on backfill (Table 3).

Post plantation care

Besides watering at the time of plantation and at regular intervals, weeding and hoeing was done to ensure its proper growth. The young sapling's leaves were much liked by

Table 2. Treatment combinations of soil layering thickness with land shaping and season of plantation

Aim	Treatment (Sites)	Thickness of layer of native soil and murram spred over backfilled spoil surface (cm)	Micro-catchment for water harvesting (MCWH) by making 5% slope	Season of plantation
To see the effect of soil layer thickness and MCWH	T-1	30	None	September 1999
	T-2	30	Yes	September 1999
	T-3	45	Yes	July 2000
	T-4	60	None	March 2001
To see the effect of season of planting	T-5	60	None	July 2001
	T-6	60	None	September 2001
	T-7	60	None	March 2002
Validation of above	T-8	60	None	March 2003
	T-9	60	None	July 2003

Table 3. Species planted at backfill and green belt at Giral

Type	Backfill		Green belt	
	Name	No. of saplings planted	Name	No. of saplings planted
Trees	*Salvadora oleoides*	739	*Salvadora oleoides*	104
	Azadirachta indica	116	*Azadirachta indica*	100
	Acacia tortilis	660	*Acacia tortilis*	102
	Tecomella undulata	256		
	Prosopis cineraria	136		
	Acacia senegal	73		
	Parkinsonia aculeata	732		
	Leucena leucocephala	135		
Shrubs	*Dichrostachys nutans*	468	*Dichrostachys nutans*	104
	Cassia angustifolia	Seedlings	*Cassia angustifolia*	103
	Acacia nubica	145		
	Colophospermum mopane	11		
	Tamarix aphylla	60		
	Ziziphus rotundifolia	67		
	Circidium floridum	337		
Total no of saplings plated		3935		513

squirrels, rabbits, peacocks, chinkaras and stray domestic livestock. A protection of thorny sticks as canopy was provided over saplings to act as deterrent to animals. This canopy was removed when plant attained 50-70 cm height. Lower branches were cut to train saplings into a single stem tree.

Observations and data analysis

In all the treatments in each rows 40-50 saplings were planted. Every fifth individual was regularly measured for height, collar diameter with vernier calliper, cover across two diagonals of the canopy and number of branches on yearly basis. Species wise data was analysed for mean, range and SD. This was used for arriving at yearly growth rate in each species in each treatment.

Results

Survival of woody perennials

Survival of different plant species varied in different treatments; the overall average being 85.28% in backfill plantation (Fig. 1). The minimum survival was 50% in *Tamarix aphylla*. Species showing over 80% survival included *Salvadora oleoides, Acacia nubica, Tecomella undulata, Prosopis cineraria, Azadirachta indica, Colophospermum mopane, Acacia senegal, Parkinsonia aculeata, Circidium floridum* and *Leucaena leucocephala*. Low survival of plantation in the green belt was due to browsing of plants by animals and lack of watering. The maximum survival (97.66%) was observed in the site-4 (60 cm, March-01) plantation, followed by almost similar per cent (71.85 to 93.22%) survival in the remaining season sites and minimum survival (45.07%) in the site- 6 (60 cm, Sept. 01 plantation).Based on above, it can be concluded that

- Most of the trees transplanted at backfill showed a high degree of survival (63-100%). Similar survival values of trees planted at east Jharia coal mine spoil were reported by Srivastava and Ram (2009).
- Water harvesting did not result in significant improvement in survival of the plants compared to those without water harvesting.
- Survival of most tree species was higher on 60 cm thick layer of sand spread over backfill.

Growth of woody perennials

In the control plot, site-1, the maximum growth in four years was observed in *Azadirachta indica* [235.0 cm height and 36.42 mm collar diameter (CD)] followed by *Acacia nubica* (198.63 cm height and 43.3 mm CD), *Dichrostachys nutans* (128.43 cm height and 20.95 mm CD) (Fig. 2), *Salvadora oleoides* (89.39

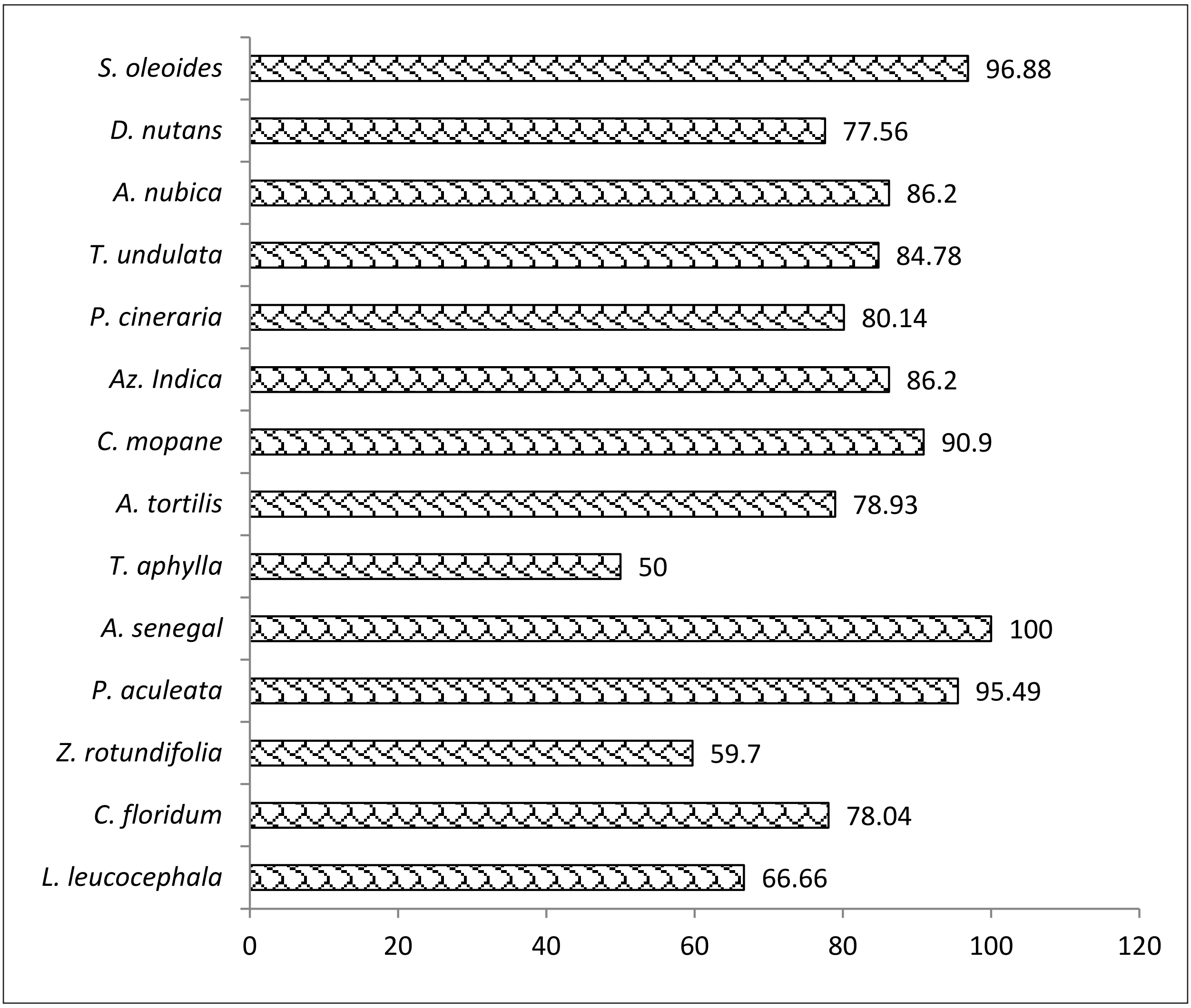

Fig. 1. Overall survival of different species at backfill.

cm height and 20.87 mm CD), *Prosopis cineraria* (76.57 cm height and 18.30 mm CD) and *Tecomella undulata* (63.57 cm height and 14.52 mm CD), respectively (Table 4). Per cent yearly increase in height was maximum in *Azadirachta indica* (83.59%) followed by *Prosopis cineraria* (68.77%), and *Colophospermum mopane* (67.40%), Increase in collar diameter was maximum in *Prosopis cineraria* (112.05%) followed by *Azadirachta indica* (105.76%) and *Acacia nubica* (55.59%), *Salvadora oleoides* (51.01%), *D. nutans* (36.68%) and *T. undulata* (36.59%) (Table 5).

In site-2, there was a layer of 30 cm native soil on backfill surface and it was shaped to have slope of 5% microcatchment for water harvesting. In this site the highest growth in four years was attained by *Tamarix aphylla* (192.0 cm height and 44.19 mm CD) followed by *Azadirachta indica* (186.75 cm height and 27.17 mm CD), *Acacia tortilis* (123.5 cm height and 24.99 mm CD) , *Dichrostachys nutans* (100.88 cm height and 23.64 mm CD), *T. undulata* (59.13 cm height and 16.67 mm CD) and *Prosopis*

Fig. 2. Dicrostachys nutans (3 years old) at backfill control site overlain with soil.

Table. 4. Growth of different species at back fill site in phase 1 (Thickness of soil layer and water harvesting), Giral, Barmer

Plant Species		Plant Height (cm)			Collar Diameter (mm)			Canopy Cover (sqm)			No of branches		
		Mean	±SD	Range	Mean	±SD	Range	Mean	±SD	Range	Mean	±SD	Range
Salvadora oleoides	T1	89.39	36.59	45-177	20.87	10.48	8.75-45.56	1.084	0.869	0.083-2.909	21	11.32	8-45
	T2	84.6	49.01	26-155	28.86	14.77	9.76-51.61	0.797	0.585	0.073-1.650	15	8.87	4-37
	T3	85.5	40.14	38-175	20.28	10.24	8.64-36.44	0.866	0.847	0.216-3.046	14	6.89	6-27
	T4	146.7	55.29	47-246	36.22	12.34	12.36-59.99	1.879	1.082	0.616-3.889	14	5.18	7-26
Dichrostachys nutans	T1	128.43	24.33	72-150	20.95	10.28	13. 16-41.06	0.923	0.777	0.259-2.009	14	5.97	7-23
	T2	100.88	31.42	65-160	23.64	7.63	16.29-40.82	1.171	1.193	0.347-4.063	18	12.58	7-45
	T3	112.6	21.41	82-140	28.18	10.69	15.13-52.04	1.006	0.352	0.407-1.409	7	2.67	9-17
	T4	131.14	25.00	71-162	27.92	6.82	14.99-40.89	1.882	0.877	0.801-4.027	9	2.52	6-13
Acacia nubica	T1	198.63	62.62	119-270	43.3	24.86	17.36-86.85	5.807	3.599	1.572-10.315	39	16.76	12-65
	T3	119.6	24.38	94-165	38.18	7.58	29.98-51.38	3.09	1.53	1.420-5.936	22	8.37	13-35
Tecomella undulata	T1	63.57	17.65	39-86	14.52	5.19	9.46-22.34	0.421	0.412	0.083-1.296	7	4.06	3-14
	T2	59.13	12.02	35-70	16.67	4.14	13.20-25.64	0.362	0.271	0.059-0.874	7	3.60	4-15
	T3	56.33	14.85	42-85	14.44	2.14	10.80-17.34	0.167	0.058	0.088-0.242	5	2.09	3-9
	T4	78.27	34.99	40-172	16.18	7.61	6.92-32.83	0.725	0.712	0.196-2.878	9	3.18	4-15
Prosopis cineraria	T1	76.57	29.09	40-124	18.30	10.03	5.47-31.06	0.496	0.359	0.073-1.093	9	3.86	5-14
	T2	48.57	20.38	27-75	11.19	6.26	5.98-22.84	0.280	0.337	0.049-0.985	7	2.61	4-12
	T4	76.4	47.33	48-160	17.88	8.81	11.77-32.36	0.462	0.385	0.200-1.130	10	3.56	6-15
Azadirachta indica	T1	235.00	-	-	36.42	-	-	0.413	-	-	7	-	-
	T2	186.75	43.27	152-250	27.17	7.06	22.12-37.54	0.093	0.059	0.012-0.152	3	0.95	2-4
Colophospermum mopane	T1	24.5	3.53	22-27	14.09	0.56	9.70-14.49	0.019	0.024	0.002-0.036	3	0.70	2-3
	T2	37.14	14.24	23-59	10.74	2.36	7.24-14.61	0.144	0.108	0.019-0.297	4	1.72	3-8
Acacia tortilis	T1	36.75	12.82	25-55	7.28	2.36	4.37-9.41	0.070	0.042	0.018-0.110	5	2.16	3-8
	T2	123.5	38.61	68-187	24.99	9.58	15.57 -40.77	1.799	1.719	0.385-5.307	12	5.01	6-22
	T4	199.2	99.46	91-425	46.45	27.89	19.12-96.52	3.069	2.18	0.762-9.075	15	10.46	5-40
Parkinsonia aculeata	T4	274.33	37.93	210-325	57.91	10.32	40.77-77.59	4.920	1.893	2.487-8.942	15	5.05	9-28
Acacia senegal	T4	76.9	35.0	20-134	22.87	9.21	11.62-43.25	1.288	1.00	0.278-3.283	16	8.91	7-35
Tamarix aphylla	T2	192.0	98.72	88-325	44.19	22.34	13.33-66.63	3.402	2.758	0.777-6.948	16	12.30	6-33

T1=Plant growth in four years after plantation in September, 1999 in backfill with 30 cm layer of native soil.
T2=Plant growth in four years after plantation in September, 1999 at back fill having 30 cm layer of native soil with micro catchment water harvesting treatment.
T3=Plant growth in three years seven months after plantation in July, 2000 at back fill having 45 cm layer of native soil with micro catchment water harvesting treatment.
T4=Plant growth in two years ten months after plantation in March, 2001 at back fill having 60 cm layer of native soil .

cineraria (48.57 cm height and 11.19 mm CD), respectively (Table 4). Per cent yearly increase in height was maximum in *Acacia tortilis* (33.22%), followed by *D. nutans* (26.89%), *P. cineraria* (23.27%), *Tamarix aphylla* (17.57%) and *Tecomella undulata* (2.35%). Per cent yearly increase in collar diameter was maximum in *S. oleoides* (114.41%), followed by *Acacia tortilis* (62.06%), *T. aphylla* (54.51%), *T. undulata* (54.49%), D. *nutans* (47.11%), *A. indica* (45.33%) and *Prosopis cineraria* (39.87%) (Table 5).

In site-3 there was 45 cm thick layer of native soil and land shaping with 5% microcatchment for water harvesting. Here, the maximum growth after three years seven months was observed in *Acacia nubica* (119.6 cm height and 38.18 mm CD), followed by *D. nutans* (112.6 cm height and 28.18 mm CD), *Salvadora oleoides* (85.5 cm height and 20.28 mm CD) (Fig. 3) and *T. undulata* (56.33 cm height and 14.44 mm CD), respectively (Table 4). Per cent yearly increase in height (Table 5) was

Fig. 3. Salvadora oleoides at backfill overlain with 45 cm soil with microcatchment water harvesting.

maximum in *A. nubica* (36.13%), followed by *S. oleoides* (28.19%) *Tecomella undulata* (16.02%) and *Dichrostachys nutans* (11.59%). Per cent yearly increase in collar diameter (CD) was maximum in *A. nubica* (167.55%), followed by *D. nutans* (101.43%), *S. oleoides* (96.89%) and *Tecomella undulata* (80.27%).

In site-4 (March 2001, plantation), there was 60 cm layer of native soil spread over backfilled soil. The highest growth after two year ten months was attained in *Parkinsonia aculeata* (274.33 cm height and 57.91 mm CD) (Fig. 4) followed by *Acacia tortilis* (199.2 cm height and 46.45 mm CD), *S. oleoides* (146.7 cm height and 36.22 mm CD) , *D. nutans* (131.14 cm height and 27.92 mm CD), *T. undulata* (78.27 cm height and 16.18 mm CD), *A. senegal* (76.9 cm height and 22.87 mm CD) and *Prosopis cineraria* (76.4 cm height and 17.88 mm CD), respectively (Table 4). Per cent yearly increase in height (Table 5) was maximum in *Acacia tortilis* (57.51%), followed by *P. aculeata* (51.55%) (Fig. 5), *S. oleoides* (47.46%), *P. cineraria* (30.96%), *Acacial senegal* (26.48%) and *T. undulata* (8.92%), respectively. Per cent yearly increase in collar diameter (CD) was maximum in *P. aculeata* (141.4%), followed by *P. cineraria* (82.82%), *A. tortilis* (69.03%), *A. senegal* (51.29%), *S. oleoides* (39.74%), *D. nutans* (37.72%), and *T. undulata* (23.32%).

In site-5 (July 2001, plantation), there was 60 cm layer of native soil spread over backfill soil. Here, the maximum growth after two years five months was shown by *P. aculeata* (228.73 cm height and 45.05 mm CD) and per cent yearly increase in height and CD was maximum in *P. aculeata* 25.88% and 63.82%, respectively (Table 6).

In site-6 (September 2001, plantation), there was 60 cm layer of native soil spread over backfill soil. Here, the highest growth after two years three months was shown in *Acacia tortilis* (86.75 cm height and 19.50 mm CD), followed by *D. nutans* (73.83 cm height and 17.00 mm CD) (Table 6). Per cent yearly increase in height was maximum in *D. nutans* (106.33%), followed by *A. tortilis* (81.33%). Per cent yearly increase in CD was maximum in *Acacia tortilis* (123.88%) followed by *D. nutans* (102.62%).

In site-7 (March 2002, plantation), there was 60 cm layer of native soil spread over backfilled soil. The maximum growth after one year ten months was attained in *S. oleoides* (40.39 cm height and 10.34 mm CD), followed by *Ziziphus rotundifolia* (38.87 cm height and 7.74 mm CD) (Table 6). Per cent yearly increase in height was maximum in *Z. rotundifolia* (25.99%) followed by *S. oleoides* (8.08%) and per cent yearly increase in CD was maximum in *Ziziphus rotundifolia* (101.56%), followed by *S. oleoides* (8.96%).

Fig. 4. Parkinsonia aculeata after 2 years and ten months of plantation at backfill overlain with 60 cm soil.

Fig. 5. Close up of 34 months old Parkinsonia aculeata at backfill overlain with 60 cm soil planted in March, 2001.

Table 5. Survival (%), Increase in height (%) and increase in collar diameter (CD) of different species in phase 1 of plantation trial

Treatments	T1			T2			T3			T4		
Soil layering thickness	30 cm			30 cm			45 cm			60c m		
Microcatcment for water harvesting	None			5% slope			5% slope			None		
Species	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)
Salvadora oleoides	93.68	1.93	51.01	100	0.475	114.41	100	28.19	96.89	100	47.76	39.74
Dichrostachys nutans	83.67	2.74	36.68	96.36	26.89	47.11	91.22	11.59	101.43	96.29	13.23	37.72
A. nubica	80.85	28.65	55.59	-	-	-	72.5	36.13	167.55	-	-	-
Tecomella undulata	52.17	32.05	36.59	94.33	2.35	54.49	72.22	16.02	80.27	96.69	8.92	23.32
Prosopis cineraria	70.83	68.77	112.05	74	23.27	39.87	-	-	-	100	30.96	82.82
Azadirachta indica	100	83.59	105.76	100	16.43	45.53	-	-	-	-	-	-
Colophospermum mopane	100	67.4	15.49	88.8	-51.76	3.77	-	-	-	-	-	-
Tamarix aphylla	-	-	-	50	17.57	54.51	-	-	-	-	-	-
Acacia tortilis	-	-	-	99.4	33.22	62.06	-	-	-	94.89	57.51	69.03
Parkinsonia aculeata	-	-	-	-	-	-	-	-	-	98.47	51.55	141.4
Acacia senegal	-	-	-	-	-	-	-	-	-	100	26.48	51.29

(a) = % Survival; (b) = % Yearly increase in Height; (c) = % Yearly increase in CD.

T1, T2, T3 and T4 are same as in Table 4.

Table 6. Growth of different species at back fill site in phase 2 and 3 (season of plantation and validation), at Giral, Barmer

Plant species	Treat-ments	Plant height (cm)			Collar diameter (mm)			Canopy cover (sqm)			No of branches		
		Mean	±SD	Range	Mean	±SD	Range	Mean	±SD	Range	Mean	±SD	Range
Acacia tortilis	T5	52.2	11.43	34-65	13.26	3.73	7.69-17.87	0.366	0.224	0.159-0.739	7	1.14	6-9
	T6	86.75	35.65	41-200	19.50	8.92	7.50-51.70	0.939	1.044	0.033-3.921	11	5.43	3-25
Parkinsonia aculeata	T5	228.73	66.53	117-370	45.05	18.72	17.32-88.19	4.503	3.732	0.307-16.25	12	7.30	3-40
	T8	180.02	50.17	100-330	31.47	11.78	15.52-61.26	2.25	2.105	0.169-8.038	7	3.66	3-20
Dichrostachys nutans	T6	73.83	20.09	46-105	17.00	5.98	11.58-26.08	0.648	0.210	0.352-0.976	12	4.71	7-18
Salvadora oleoides	T7	40.39	16.35	13-88	10.34	3.96	2.36-19.58	0.288	0.328	0.003-1.539	13	7.65	2-35
Ziziphus rotundifolia	T7	38.87	7.92	29-55	7.74	2.42	5.31-12.87	0.077	0.052	0.047-0.169	6	1.51	4-9
Acacia nubica	T8	132.6	48.38	54-190	24.55	7.43	15.30-35.78	4.560	2.322	1.011-7.302	23	10.96	12-40
Circidium floridum	T8	118.0	41.01	43-214	25.06	7.99	9.04-39.48	1.772	1.150	0.057-4.887	10	5.03	2-20
	T9	89.67	24.71	40-147	19.33	6.02	9.97-29.42	1.039	0.835	0.049-3.299	8	3.21	4-15
Azadirachta indica	T9	94.77	22.06	59-133	16.99	5.72	6.26-29.82	0.268	0.223	0.006-1.084	4	1.31	2-7
Leuceana leucocephala	T9	57.32	26.46	15-130	13.39	4.59	6.10-25-45	0.192	0.162	0.006-0.541	6	2.48	2-12

T5=Plant growth in two year five months after plantation in July, 2001 at back fill having 60 cm layer of native soil.
T6=Plant growth in two year three months after plantation in September, 2001 at back fill having 60 cm layer of native soil.
T7=Plant growth in one year ten months after plantation in March, 2002 at back fill having 60 em layer of native soil.
T8=Plant growth in ten months after plantation in March, 2003 at back fill having 60 cm layer of native soil.
T9=Plant growth in six months after plantation in July, 2003 at back fill having 60 cm layer of native soil.

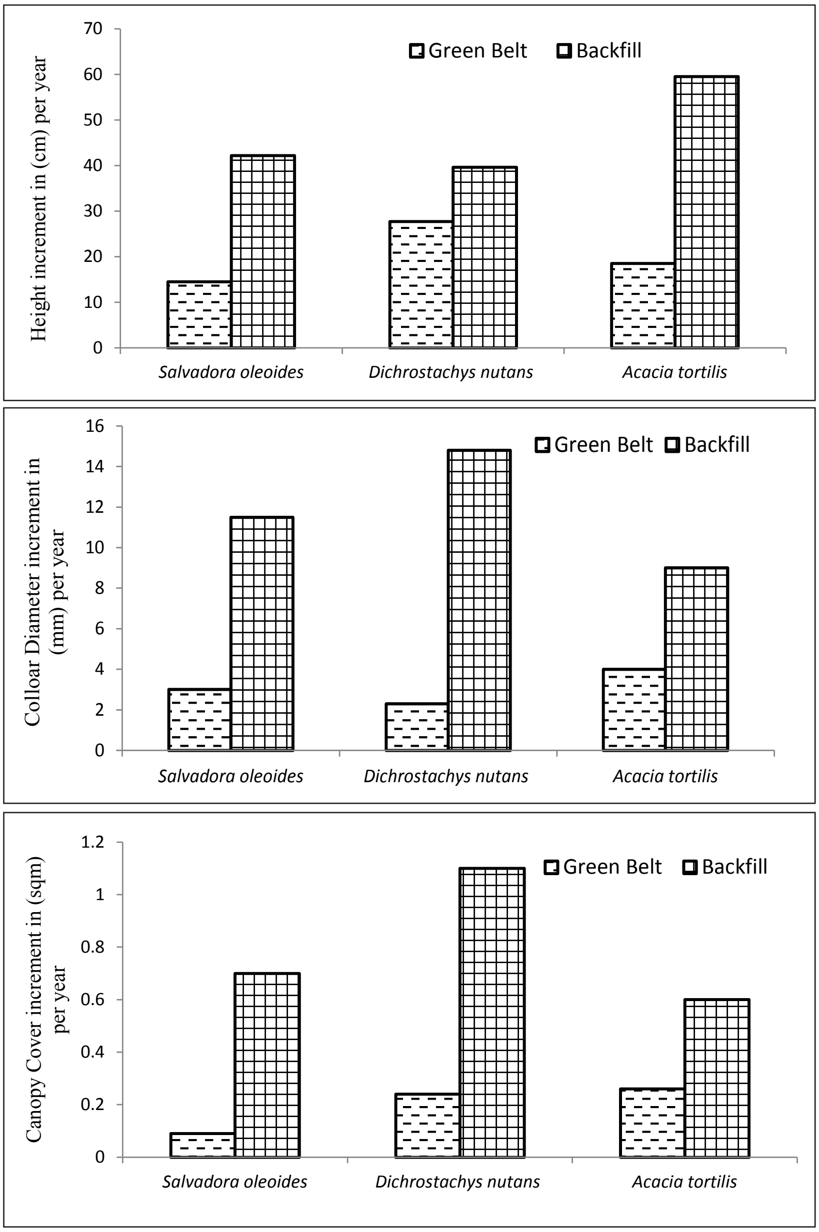

Fig. 6. Annual growth in height, collar diameter and canopy cover of different species at green belt and backfill, Giral.

In site-8 (March 2003, plantation), there was 60 cm layer of native soil that was spread over backfilled soil. Here, the maximum growth after ten months was observed in *Parkinsonia aculeata* (180.02 cm height and 31.47 mm CD), followed by *Acacia nubica* (132.6 em height and 24.55 mm CD) and *Circidium tlotidum* (118.0 em height and 25.06 mm CD) (Table 6). Per cent yearly increase in height was maximum in *P. aculeata* (507.76%), followed *Acacia nubica* (316.98%) and *Circidium floridum* (240.06%) and collar diameter was maximum in *P. aculeata* (789.48%), followed by *Circidium floridum* (579.13%) and A. nubica (184.80%).

In site-9 (July 2003, plantation), there was 60 cm layer of native soil that was spread over backfilled soil. The highest growth after six months was attained in *Azadirachta indica* (94.33 cm height and 16.99 mm CD),followed by *Circidium floridum* (89.67 cm height and 19.33 mm CD) and *Leuceana leucocephala* (57.32 cm height and 13.39 mm CD) (Table 6).

Discussion

Growth at backfill versus green belt

Backfill and green belt represented two contrasting habitats: Drastically disturbed

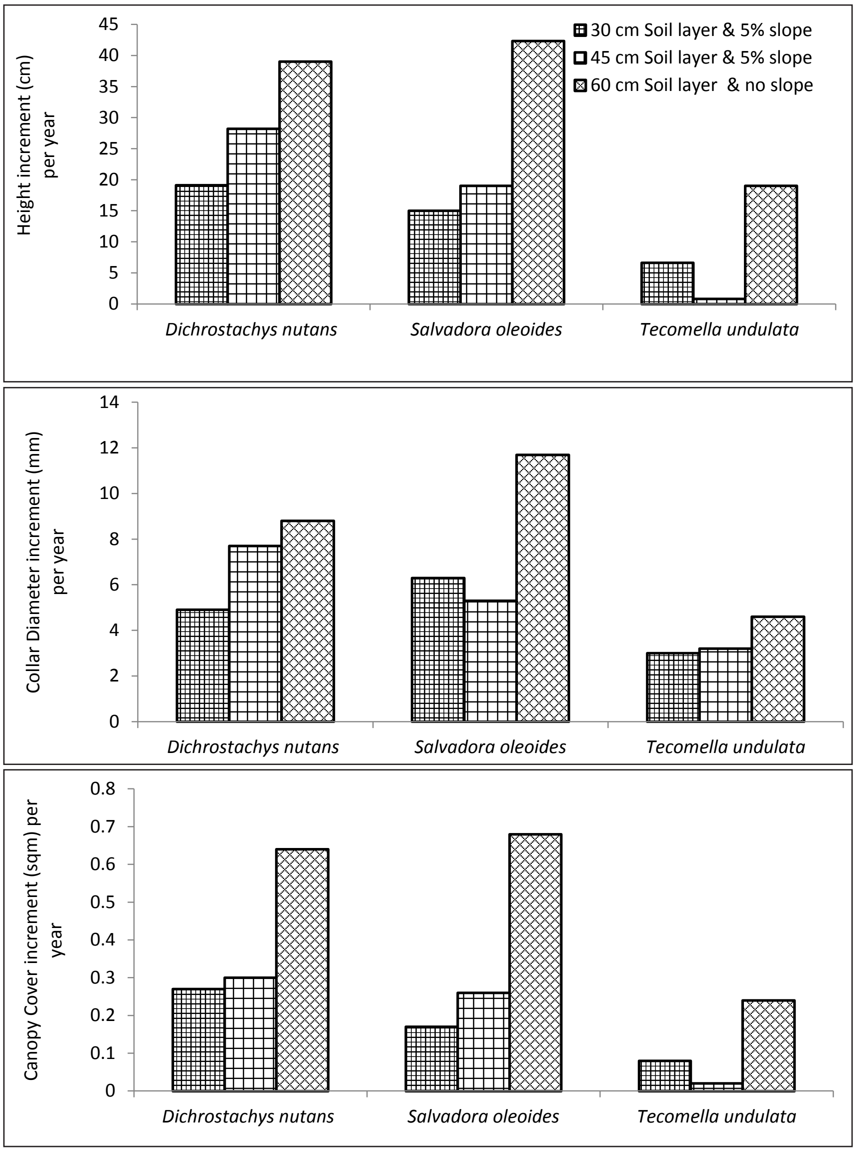

Fig. 7. Effect of thickness of soil and murram layer on annual growth in height, collar diameter and canopy cover of different species at backfill, Giral.

surface of backfill overlain with sand layer to make it as similar to natural surface of green belt as possible. The real confirmation of success of planted species on backfill would emerge by comparing their growth with those planted in green belt. All the three key species *Salvadora oleoides, Dichrostachys nutans* and *Acacia tortilis* on backfill showed many times more height, more collar diameter and more canopy cover gain per year than in those grown at green belt (Fig. 6).

Thus, not only these planted species have shown better survival, their growth on modified backfill was also consistently more throughout 3-4 years of plantation. This is despite the fact that high Na was a major limiting factor at backfill. Higher survival and better growth on modified backfills are reported by many workers in reclamation of coal mines in India and abroad (Singh,1993). These trends may be due to absence of the competition and availability of organic matter.

Effect of thickness of soil layer

Of the three thickness of soil layer respread on backfill spoil, the annual increment in height in respect of all the three species viz. *Dichrostachys nutans, Salvadora oleoides* and *Tecomella undulata* was maximum on backfill overlain with 60 cm thick layer, followed by

45 cm and 30 cm layer. Annual increment in collar diameter as well as canopy cover in these species also showed, by and large, the same trends (Fig.7). Hence it can be concluded that 60 cm layer of soil is most optimum for growth of planted species in these lignite mine spoils. Power *et al*. (1981) have also reported that over highly sodic fine textured spoil, crop yields improve with increasing thickness of soil layers from 75 to 150 cm, while in 30 cm layering it was not sustainable. In our experiments 60 cm thickness emerged as optimum thickness of soil layer. Sandoval and Gould (1978) also reported 70 cm thickness of overlain soil on spoil as most optimum in rehabilitation of coal mines in USA.

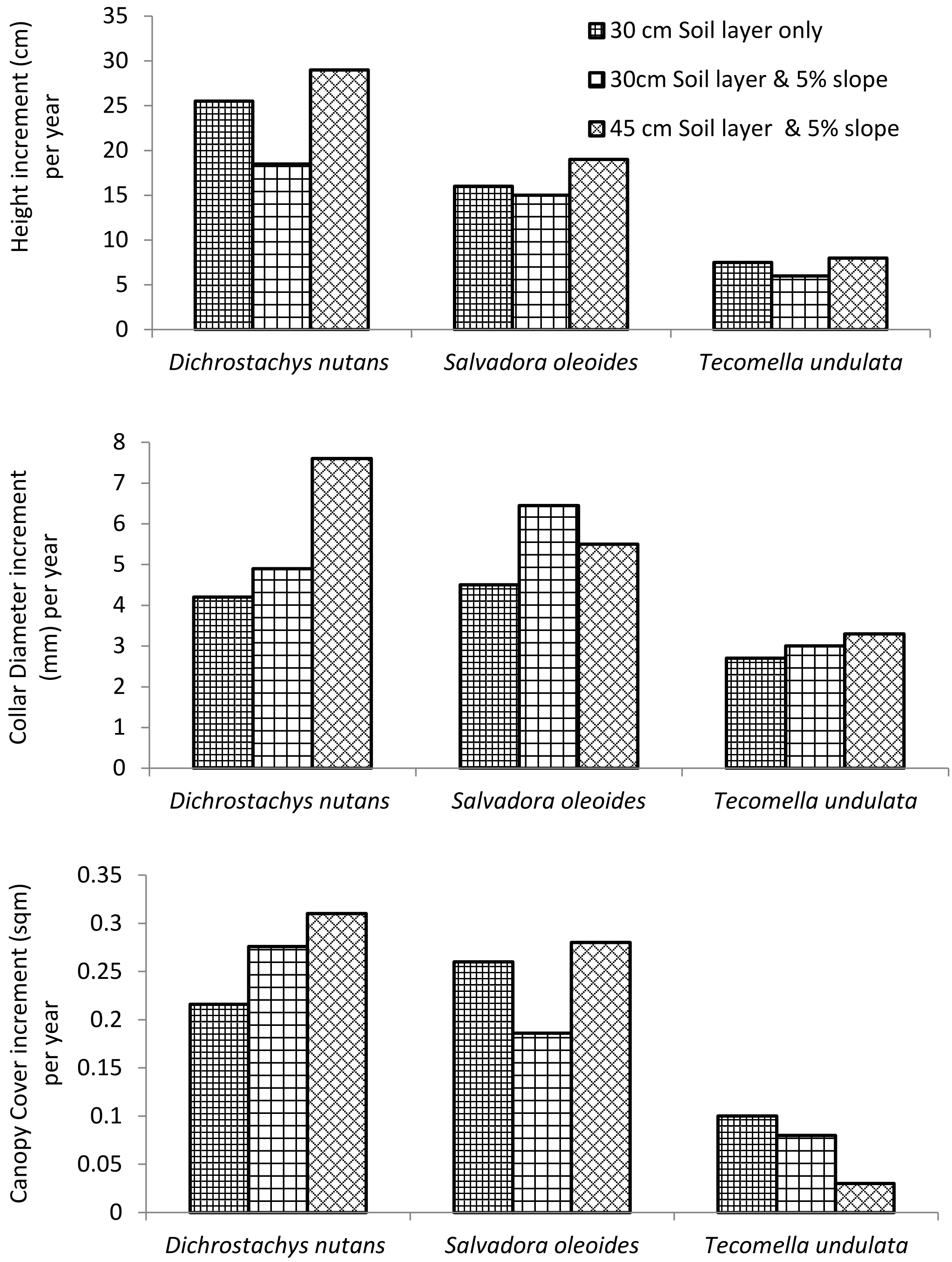

Fig. 8. Effect of microcatchment water harvesting on annual growth in height, collar diameter and canopy cover of different species at backfill, Giral.

Effect of land shaping for microcatchment water harvesting

All the three planted species *Dichrostchys nutans, Salvadora oleoides* and *Tecomella undulata* showed higher annual increment in height in plots without microcachments than that provided with microcatchment on 30 cm layer of soil over backfill (Fig. 8). Though, increment in collar diameter of 2 plants was more in plots having microcatchments, the difference was rather minor. Canopy cover increment was also more in plots having no microcatchment in respect of two out of three test species. It can be thus, concluded that land shaping to make microcatchment for water harvesting was not as effective as originally hypothesized. Hence, microcatchments could be avoided to save huge

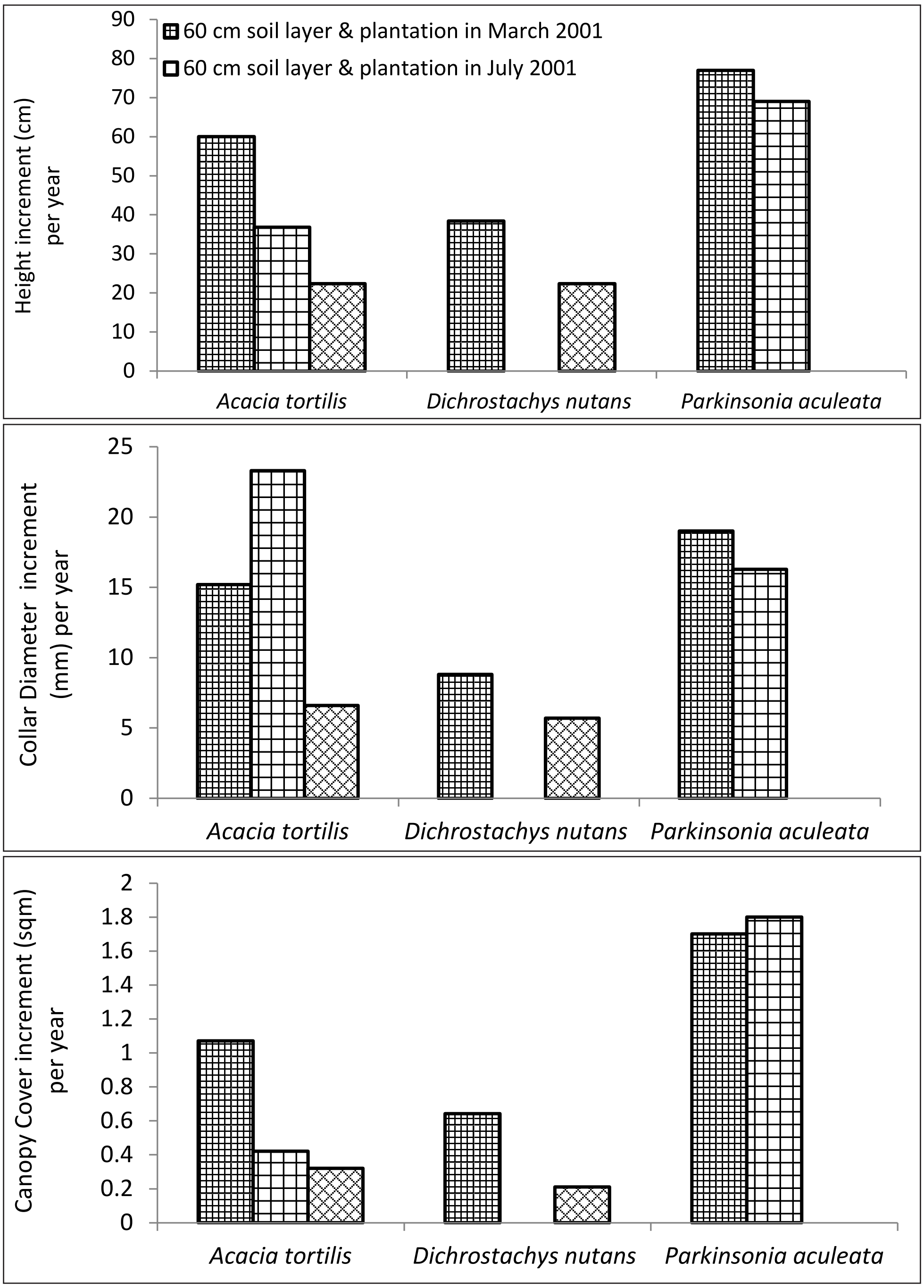

Fig. 9. Effect of season of plantation on annual growth in height, collar diameter and canopy cover of different species at backfill, Giral.

cost involved in their making. This is due to the fact that higher sodium content and higher clay in spoil absorb and retain water to create anaerobic conditions in the root zone so much so that plants growth slackened.

Effect of season of plantation of saplings

Having confirmed that 60 cm layering of soil without any microcatchment favoured maximum annual growth in the planted species, it is important to analyze the effect of season of plantation to find out the optimum planting time. This can seen in treatments T5, T6 and T7. Three planting seasons were March, July and September in the year 2001 when saplings of two species were planted to see the seasonal effect. Height increment per year was more in species planted in March than that in July and September (Fig. 9). Collar diameter increment showed similar trend in respect of *Dichrostachys nutans* and *Parkinsonia aculeata* whereas in *Acacia tortilis* it was marginally more in July plantation. Canopy cover increment was also more in March planted saplings in respect of two species and was more or less same in March and July in *Parkinsonia aculeata* (Fig. 9). In view of overall better growth in saplings planted in March month, compared to that in July and September, March month i.e. Spring season can be said to be most optimum season for planting on sodium rich backfill.

Selection of suitable species of woody perennials based on their performance

Of different species planted on 60 cm and 45 cm layered backfill the annual increment in height, collar diameter and canopy cover was maximum in *Parkinsonia aculeata* followed by that in *Acacia nubica, Circidium floridum, Acacia tortilis, Salvadora oleoides, Dichrostachys nutans, Acacia senegal, Tecomella undulata* and finally *Prosopis cineraria* (Fig.10).Thus the desirable woody perennials in order of performance are as follows:

Desirable woody perennials

Parkinsonla aculeate → Acacia nubica → Circidium floridum → Acacia tortilis → Salvadora oleoides → Dichrostachys nutans → Acacia senegal →Tecomella undulata

In an exhaustive review, Datar *et al*. (2011) reported that in the Indian context 245 species have been used in 37 reclamation program across India. Frequency of using a species in reclamation was used to select species for adoption. However, this may not be a useful criteria in extreme agroclimates like hot deserts, cold deserts or saline lands, where only adapted species will be more successful than the four; Neem, *Dalbergia*, *Albizzia* and *Pongamia* emerging out of Datar's review. Accordingly, most successful fast growing species in this study are those adapted to high sodium in lignite spoil in the backfils in Indian arid zone. They absorb high sodium in their leaves and balance it with absorption of other elements. Thus this reclamation study provided permanent green cover, has restored the landscape much in conformity with Kuter (2013). Pecharova *et al*. (2011) also emphasized such a strategy of revegetation by growing target species and restoring or improving the sites. The success of above rehabilitation program was because of following ecological principles applied at Giral:

- Matching site - species suitability
- Adopting soil and water conservation measures
- Making available soil seed bank in the respread native soil
- Soil fertility was restored through addition of FYM
- Toxic effect of high sodium in spoil was minimized by top soiling
- Succession facilitator species were planted
- Density – dominance (vegetation ecology) of re-vegetated spoil was designed to match with that at naturally occurring grazing land.

Future strategies

Rehabilitation of lands disturbed by mining has become obligatory for both; the state owned corporations as well as private companies in view of environmental concerns and socio-economic compulsions. As newer and more areas will be brought under mining, the need for rehabilitation of these lands will become more obvious. Realizing this, such protocols of rehabilitation will have to be fine tuned as per bioclimatic conditions. In order to make rehabilitation program cost effective and people friendly, participation of local people in providing social fencing, as also generating employment for them should receive focused

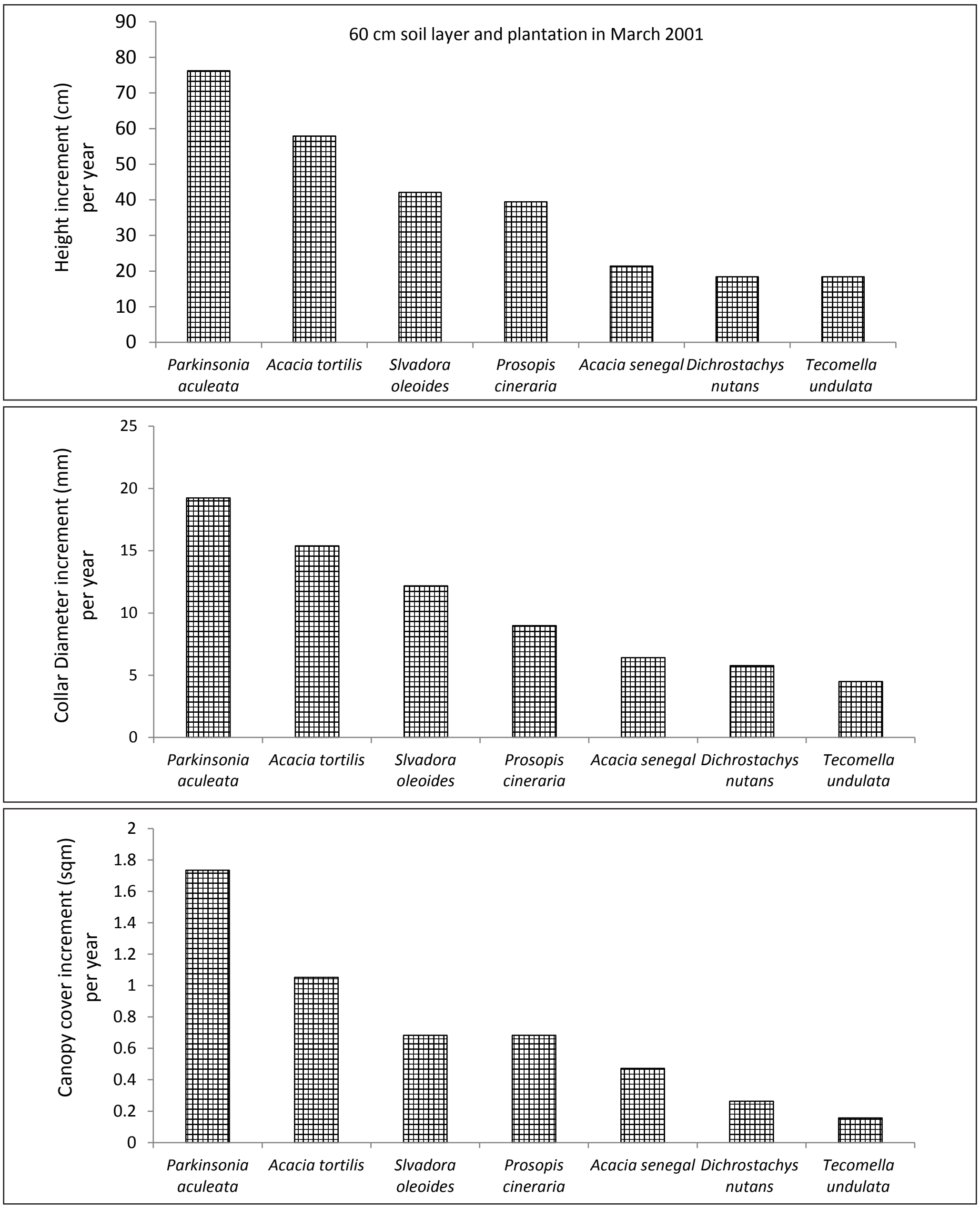

Fig. 10. Annual growth in height, collar diameter and canopy cover of different species planted in March 2001 on 60 cm layer of soil at backfill, Giral.

attention of our policy makers, miners and the NGOs.

Conclusion

- 60 cm layering is most optimum for effective survival and growth of planted species.
- Most desirable season for planting species is March (spring season) for obtaining best growth.
- Land shaping for microcatchment water harvesting are not needed. Pit plantation is equally successful.
- Most successful species are *Parkinsonia aculeata, Acacia nubica, Acacia tortilis, Dichrostachys nutans, Salvadora oleoides* and *Circidium floridum.*

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