Binding capacity and root penetration of seven species selected for revegetation of uranium tailings at Jaduguda in Jharkhand, India

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Uranium from ores mined at the three mines – Jaduguda, Bhatin and Narwapahar (Jharkhand) – is processed in the mill and the waste emerges as tailings. The recorded radioactivity level in these tailings is very low, but to avoid any long-term effect of these tailings on the atmosphere, humans, cattle as well as native flora and fauna, the tailings are covered with 30 cm layer of soil. This reduces the gamma radiation and radon emission levels. However, to consolidate the soil covering the tailings on a sustainable basis, the area needs to be revegetated by plant species having shallow root systems, good conservation value and low canopy cover. Another important criterion for selection of species is that they should not have any ethnobotanical relevance to the surrounding villages. Considering these criteria, seven native plant species of forestry origin, viz. *Colebrookea oppositifolia*, *Dodonaea viscosa*, *Furcraea foetida*, *Imperata cylindrica*, *Jatropha gossypifolia*, *Pogostemon benghalense* and *Saccharum spontaneum* have been selected for experimental trials. We describe here the strategies adopted for consolidation of radioactivity in tailings, revegetation practices used and the ecological role of the selected species in consolidating the tailings.

Keywords: Binding capacity, conservation, revegetation, root penetration, uranium tailings.

MOST uranium mines in the world usually produce low grade ores containing 0.1–0.3% U_3O_8. Mines in India produce grades lower than these. Thus, the uranium industry generates large quantities of waste. Almost the entire mined ore comes out as waste after recovery of small amounts of uranium.

Australia has large reserves of uranium with significant deposits in northern Australia. The abandonment of uranium mines developed in the 1950s and 1960s is examples of major environmental insults[1,2]. Another abandoned uranium mine, the Rum Jungle in the Northern Territory was subjected to the costliest rehabilitation programme ever undertaken on an Australian mine (approximately A$ 20 m). Uranium and copper ore concentrates were produced between 1954 and 1971 from five open-cuts in close proximity. After mine closure, no rehabilitation was required or undertaken[2]. The mining and processing operations resulted in the pollution of the nearby East Fitness River with acid mine drainage resulting from oxidation of pyrite in the mine waste and overburden causing elevated levels of aluminum, iron, copper, zinc, cobalt and manganese.

During 1982–1986, the overburden heaps and tailings dam were rehabilitated, and 4 million m^3 of acid water in pits was treated. The pollutants resulting from the tailings were removed by excavating the material (approximately 330,000 m^3) and then dumped into one of the existing open-cuts. The floor of the original tailing dam was treated with hydrated lime, covered with 330 mm of topsoil, fertilized and seeds of a mixture of tropical grasses (*Chloris gayana*, *Cynodon dactylon*, *Brachiaria decumbens*, *Urochloa mozambicensis* and *Paspalum notatum*), legumes (*Stylosanthes hamata* and *Stylosanthes guianensis*) and native shrub and tree species (*Acacia* and *Eucalyptus*) were sown.

In India, it is from the depths of the arid tribal belt of mineral-rich Singhbhum district of east Bihar, Jaduguda that India's nuclear programme had its beginning and still gets sustenance. This is the principal and almost only major source of uranium in India, giving it complete independence in nuclear fuel fabrication for its 10 existing nuclear reactors. Uranium recovery from the ore at Jaduguda involves a number of steps including change in physicochemical characteristics of the bulk ore and steps like oxidation, leaching, ion-exchange and precipitation as magnesium di uranate (MDU). Though a major portion of uranium present in the ore is extracted, a fraction though quantitatively small, remains unextracted and is finally discharged with the tailings. The unextracted fraction may be either soluble hexavalent complexes of uranium or its insoluble tetravalent form. Even radiological exposure in the tailing ponds is negligible as the waste has very low level of activity concentration. However, to prevent long-term consequences of the exposure to radioactivity, these tailings have been covered with 30 cm of soil to consolidate the radioactivity under the ground. This is to prevent any gaseous emission from the tailing ponds and to avoid direct exposure to cattle or human beings living in the vicinity.

Sustainable consolidation of radioactivity in these tailings to avoid migration of the unextracted fraction of uranium from tailings to plants and further into the food chain is the subject matter of our study. Species of plants that are not used by the local people for their fuel, fodder, food or other requirements have therefore been selected and used for experimental trials to cover the soil over the tailings. All these native terrestrial species are of forest origin[3–5].

Jaduguda is famous for its uranium ore deposits and mining. Geographically, it is located between lat. 22°30′N and long. 85°40′E. The distance from the Tatanagar station to Jaduguda is 24 km. The area around the mines is mountainous. Currenlty, two more uranium mines are

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*For correspondence. (e-mail: lalsingh82@gmail.com) being operated at Bhatin and Narwapahar, located in this area. These mines are managed by UCIL (Uranium Corporation of India Limited), an enterprise of the Government of India. The distance from Narwapahar to Jaduguda is only 10 km. The grade of the uranium ore in these mines is remarkably low; the average being about 0.06%. In Jaduguda, uranium ore from these three mines is processed in a smelter. The smelter in Jaduguda is capable of processing about 1000 tonnes ores per day; and about 600 kg per day, i.e. 200 tonnes per year uranium is produced resulting in 300,000 tonnes per year mill tailings. It is being released into tailing pond by pipeline in the liquid form[6].

The present study was undertaken at one of UCIL's tailing ponds located in Jaduguda, Singhbhum District of Chota Nagpur Plateau in Jharkhand.

The work presented and discussed here is part of an ongoing project to consolidate the radioactivity in the tailings using native primary colonizing plant species. The tailings pond has been covered with a 30 cm layer of soil. Seeds of the selected plant species were sown in it to study the radionuclide uptake (*in situ* trials). An attempt was also made to grow the same species under *ex situ* conditions in 200 litre experimental containers in the Health Physics Unit (HPU), Jaduguda. These experimental containers were filled with tailings and then covered with 30 cm soil as in the field trials and then the plants were grown. These experimental trials have been conducted to compare the binding capacity and root penetration of selected species under both *ex situ* as well as *in situ* conditions. Species selection for these experimental trials has been made after surveying five tribal villages surrounding the tailing pond to ascertain the non-usability of the species. The other important criteria for selection are their growth form, viz. perennials with low crown cover, shallow root system and their conservation value. Seven species have been selected and tried for *in situ* as well as *ex situ* experiments (Table 1).

Root excavations of selected species were done by carefully working sideways and downwards till the root tips were exposed[7]. The roots thus excavated were cleaned in water and separated for data recording. The roots of selected species were sampled from the quadrats, which were clipped for estimation of above the ground biomass. A soil monolith of 25 × 25 × 25 cm was removed. The dug out monolith was carried to the laboratory and flooded with water. Large roots were separated by hand and floating roots were separated using 0.5 mm mesh sieve[8].

Table 1. Selected plant species for experimental trials

Plant species	Family	Common name	Plant form
Colebrookea oppositifolia	Lamiaceae	Binda	Shrub
Dodonaea viscosa	Sapindaceae	Wild Mehandi	Shrub
Furcraea foetida	Agavaceae	Furcaria	Shrub
Imperata cylindrica	Poaceae	Phoola	Grass
Jatropha gossypifolia	Euphorbiaceae	Red Jatropha	Shrub
Pogostemon benghalense	Lamiaceae	Phangla, Julata	Shrub
Saccharum spontaneum	Poaceae	Kans	Grass

After excavation and washing, the roots of each plant were separated and divided into four categories, viz. main, primary, secondary and tertiary roots. The diameter of all the four categories was taken as three points along the length with the help of digital calipers and the average diameter of each category of roots was worked out[9] (Tables 2 and 3).

The length of all the four categories of roots was measured in centimetre to the nearest millimetre with tape and with the help of magnifying glass in case of fine roots[6] (Tables 4 and 5).

Roots were excavated mechanically[7]. Total number of lateral roots, length and diameter of tap root, average root diameter, total root weight and volume of total root system was recorded. Volume of the pit after excavation of complete root system was also calculated. Length and diameter of the roots and root volume were estimated.

The binding capacity of the root was calculated by the formula

$$F = V/R^2,$$

where F is the binding factor; V the volume in ml; R the average radius of the roots in mm.

Root penetration and binding capacity of selected species was evaluated under natural and field conditions and in experimental containers annually[10] (Tables 6 and 7).

Plant samples of selected species (both root and shoot) from the revegetated tailing pond area and experimental containers have been collected for two years (1st and 2nd age group plants). Five replicates were collected at random from each site. The data obtained/recorded for various parameters was analysed by adopting three-way analysis of variance (ANOVA). The data was collected under the influence of three factors, viz. site, plant species and depth. Their individual and interactive effect was explored. The critical difference (CD) was calculated using Scheffe's method[11,12].

The analysis of data on binding capacity shows variation between the two age group data, between the two sites of experimentations, viz. *in situ* and *ex situ* experimental sites, and among the seven species. In short, all these factors show significant variations with respect to binding capacity (conservation value). It can be seen that the binding capacity in the 2nd age group plants is more (95.30) than the first age group plants (94.48). Analysis shows that this difference is significant. Hence, it is clear that the binding capacity has increased (Table 6).

The average binding capacity in experimental containers is 100.80, which is significantly more than that of tailing

Table 2. Root diameter (mm) of selected plant species in *in situ* experimental trials

Species	Main roots	Primary roots	Secondary roots	Tertiary roots	Average root diameter
Colebrookea oppositifolia	34.27	5.58	2.39	1.11	10.84
Dodonaea viscosa	13.53	3.29	2.09	0.00	4.73
Furcraea foetida	6.86	3.33	2.19	1.10	3.37
Imperata cylindrica	2.74	1.17	1.00	0.67	1.39
Jatropha gossypifolia	17.61	8.87	4.04	0.00	7.63
Pogostemon benghalense	14.99	6.04	3.75	1.00	6.45
Saccharum spontaneum	2.45	1.81	1.25	0.93	1.61

Table 3. Root diameter (mm) of selected plant species in *ex situ* experimental trials

Species	Main roots	Primary roots	Secondary roots	Tertiary roots	Average root diameter
Colebrookea oppositifolia	34.65	5.63	2.48	1.14	10.98
Dodonaea viscosa	13.57	3.34	2.11	0.00	4.75
Furcraea foetida	4.99	3.40	2.22	1.10	2.93
Imperata cylindrica	2.77	1.20	1.00	0.67	1.41
Jatropha gossypifolia	17.66	8.86	4.05	0.00	7.64
Pogostemon benghalense	15.02	6.07	3.77	1.00	6.47
Saccharum spontaneum	2.47	1.87	1.27	0.93	1.64

Table 4. Root penetration (cm) of selected species in both *ex situ* and *in situ* experimental trials in both ages

		Species								
Age	Sites	*Colebrookea oppositifolia*	*Dodonaea viscosa*	*Furcraea foetida*	*Imperata cylindrica*	*Jatropha gossypifolia*	*Pogostemon benghalense*	*Saccharum spontaneum*	Mean	Mean site
1st age (one year old)	Exp. container	20.00	21.40	16.00	18.90	20.00	22.00	15.00	19.043	Exp. container 19.064***
	Tailing pond	20.00	20.00	16.00	20.00	18.00	22.00	15.00	18.714	
	Mean	20.00	20.70	16.00	19.45	19.00	22.00	15.00	18.979**	
2nd age (two year old)	Exp. container	20.20	21.40	16.00	19.00	20.00	22.00	15.00	19.086	Tailing pond 18.971***
	Tailing pond	20.00	21.00	16.00	20.80	19.40	22.40	15.00	19.229	
	Mean	20.10	21.20	16.00	19.90	19.70	22.20	15.00	19.157	
	Mean	20.05	20.950	16.00	19.67	19.35	22.10	15.00	19.02**	
CD	Age = 0.3622 Age * site = 0.5122 Age * site * species = 1.3551			Site = 0.3622 Age * species = 0.9582		Species = 0.6775 Site * species = 0.9582				

**Significance at 5% level; ***Significance at 0.1% level; CD, Critical difference.

pond, where the binding capacity is 88.99. It is observed that soil under the species *Pogostemon benghalense* showed the highest binding capacity (111.50), whereas *Furcraea foetida* showed the least binding capacity (73.85) among the seven species. Species *Dodonaea viscosa* and *Jatropha gossypifolia* show equal binding capacity (107.70 and 107.09). The agewise averages of sites show that binding capacity of experimental containers is higher than the tailing pond and more in the second age group plants. On comparison, it is seen that the binding capacity of all the species improves in the second age group plants. In *Pogostemon benghalense* binding capacity remains high and is lowest in *Furcraea foetida* in both the age group of plants (Table 6).

When sitewise binding capacity of species is compared, it is observed that species perform significantly better in experimental containers than the tailing pond, i.e. the binding capacities of all the species in experimental containers are better than those observed in the tailing pond. The combined effect of the three factors on binding capacity shows that all the species in experimental containers show higher binding capacity, which increases

Table 5. Root penetration (cm) of selected species in experimental containers (*ex situ*), tailing pond (*in situ*) and natural habitat

	Species							
Sites	*Colebrookea oppositifolia*	*Dodonaea viscosa*	*Furcraea foetida*	*Imperata cylindrica*	*Jatropha gossypifolia*	*Pogostemon benghalense*	*Saccharum spontaneum*	Mean
Exp. container	20.10	21.40	16.00	18.95	20.00	22.00	15.00	19.06**
Tailing pond	20.00	20.50	16.00	20.40	18.70	22.20	15.00	18.97**
Natural habitat	22.80	23.50	16.60	22.60	24.40	24.50	18.00	21.77**
Mean	20.97	21.80	16.20	20.65	21.03	22.90	16.00	19.94**
CD	Sites = 0.579	Species = 0.884	Sites * species = 1.532					

**Significance at 0.1% level; CD, Critical difference.

Table 6. Binding capacity (conservation value) of selected species in both *ex situ* and *in situ* experimental trials in both ages

		Species								
Age	Sites	*Colebrookea oppositifolia*	*Dodonaea viscosa*	*Furcraea foetida*	*Imperata cylindrica*	*Jatropha gossypifolia*	*Pogostemon benghalense*	*Saccharum spontaneum*	Mean	Mean site
1st age (one year old)	Exp. container	82.64	109.57	92.45	102.56	111.11	117.64	86.00	100.28	Exp. container 100.80***
	Tailing pond	69.44	105.00	55.00	99.44	102.00	104.93	85.00	88.69	
	Mean	76.04	107.28	73.72	101.00	106.55	111.28	85.50	94.48	
2nd age (two year old)	Exp. container	84.44	110.22	92.94	104.00	112.64	118.44	86.50	101.31	Tailing pond 89.99***
	Tailing pond	70.44	106.00	55.00	100.00	102.60	105.00	86.00	89.28	
	Mean	77.44	108.11	73.97	102.00	107.62	111.72	86.25	95.30	
	Mean	76.74**	107.70**	73.85**	101.50**	107.09**	111.50**	85.87**		
CD	Age = 0.639 Age * site = 0.904 Age * site * species = 2.392		Site = 0.639 Age * species = 1.691			Species = 1.196 Site * species = 1.691				

**Significance at 5% level; ***Significance at 0.1% level; CD, Critical difference.

further in the second age group. Tailing ponds in both ages show lower binding capacity in all the species (Table 6).

Hossner and Hons[13] worked on the selection of appropriate plant species for reclamation and concluded that the most important criteria are chemical and physical properties of disturbances, their elevation, geographic location, compatibility with other vegetation and above all the climatic characteristics of the area. In the absence of one or more of these criteria, the revegetation effort is likely to fail. Soni *et al.*[14] prepared a detailed inventory of species suitable for planting in rock phosphate and limestone mines at Dehradun. Recent vegetation programmes on disturbances have begun to emphasize the use of native vegetation. Soni *et al.*[14] attempted to revegetate a rock phosphate mine with various native trees, shrubs and grasses. They reported that the mixture of natives has improved the soil fertility status and productivity capacity of the spoil material besides favouring the biological invasion of various natural invaders.

Munshower[15] emphasized that native species were less competitive and can be used in rehabilitation and the disturbances permit the germination and development of non-seeded species. Development of the ecosystem was accompanied by improvement in soil characteristics. Some species play a key role in nutrient conservation and were thus important in all rehabilitation programmes. Significant improvement in chemical and physical properties like carbon, nitrogen, cation exchange capacity, total porosity and bulk density of soil takes place with the age of reconstruction[16]. Dadhwal and Singh[17] studied the rooting behaviour of five trees, two shrubs and six grass species. The best root growth, soil binding capacity and nodulation were found in *Leucaena leucocephala*, *Bauhinia retusa*, *Pennisetum purpureum*, *Eulaliopsis binata* and *Cymbopogon fulvus*. The present study on the

Table 7. Binding capacity (conservation value) of selected species in experimental containers (*ex situ*), tailing pond (*in situ*) and natural habitat

Sites	Species *Colebrookea oppositifolia*	*Dodonaea viscosa*	*Furcraea foetida*	*Imperata cylindrica*	*Jatropha gossypifolia*	*Pogostemon benghalense*	*Saccharum spontaneum*	Mean
Exp. container	83.54	109.89	92.69	103.28	111.87	118.04	86.25	100.80**
Tailing pond	69.94	105.50	55.00	99.72	102.30	104.96	85.50	119.99**
Natural habitat	97.90	174.00	160.00	111.10	104.00	104.90	88.00	88.89**
Mean	83.79	129.80	102.57	104.70	106.06	109.30	86.58	103.26**
CD	Sites = 0.877		Species = 1.340		Sites * species = 2.321			

**Significance at 0.1% level; CD, Critical difference.

comparative growth behaviour and soil binding capacity of roots of selected plant species on revegetated tailing pond (*in situ* experimental trial) and experimental containers (*ex situ* experimental trial) has been evaluated at HPU, Jaduguda. The competitive interactions of plants in any area appear to be strongly influenced by root growth. Formation of an adequate spreading root system vertically and laterally on the one hand assists in the absorption of the soil moisture and nutrients from the deeper strata and on the other hand it binds the loose overburden due to its high soil binding capacity. Binding capacity of *Jatropha gossypifolia*, *Dodonaea viscosa* and *Pogostemon benghalense* was comparatively higher than that of other selected species. However, *Imperata cylindrica*, *Saccharum spontaneum*, *Colebrookea oppositifolia* and *Furcraea foetida* were also moderately effective soil binders (Table 6).

An analysis of binding capacity data showed (Table 7) variations in the three experimentations sites, viz. *in situ*, *ex situ* and natural habitat, and among the seven species. In short, all these factors showed significant variations in their binding capacities (conservation value).

Soil binding capacity of the roots among the seven species has been found to vary significantly. In *ex situ* experimental trials, it is found that the species *Pogostemon benghalense* (118.04) has the maximum soil binding capacity in its roots whereas the species *Colebrookea oppositifolia* (83.54) is found to possess the least soil binding capacity. In *in situ* experimental trials, it is found that *Dodonaea viscosa* (105.50) has the maximum soil binding capacity, whereas *Furcraea foetida* (55.00) has the least soil binding capacity. In natural habitat, *Dodonaea viscosa* (174.00) has the maximum amount of soil binding capacity, whereas *Saccharum spontaneum* (88.00) has the least soil binding capacity (Table 7). Soil binding capacities of the roots have been found nearly the same in *ex situ* and *in situ* experimental trials, but in natural habitat it was statistically significant. Soil binding capacity in natural habitat was much higher than that in *ex situ* and *in situ* experimental trials (Table 7). The higher values of binding capacity of species may be because of their well developed lateral roots and higher root volume. The production of greater number of lateral roots not only increases biomass and binding capacity of roots but also takes up the task of absorption of water under moisture stress conditions. Many authors have determined the binding capacity of various species to assess their suitability for revegetating the unstable degraded ecosystem. Evaluation of the suitability of some species has demonstrated that *Wendlandia exserta*, *Buddleja asiatica* and *Trema politoria* are highly valued species for reclamation of phosphate and limestone mined degraded lands[18].

Soni *et al.*[19] prepared a seed mix of about 31 species for ecorestoration trials on benches and overburden dumps of iron ore mines in Jharkhand and Orissa. Seed mixes were prepared out of the locally collected seeds. Two separate mixes were prepared for mined out benches and overburden dumps and applied during restoration trials. They concluded that using these species for restoration of derelict lands may help in speeding up the succession process and the system may become stable, and match the undisturbed natural forests within a short span of time. The present study (Tables 6 and 7) revealed that all the seven species are able to revegetate tailing covered degraded land but *Pogostemon benghalense*, *Jatropha gossypifolia* and *Dodonaea viscosa* appeared to be the most efficient species in terms of their higher binding capacity and therefore can be used for faster stabilization of such degraded ecosystems (Tables 6 and 7).

Data on root penetration (cm) revealed that variations in the two age group data and the two sites of experimentations, viz. tailing pond and experimental containers, showed no significant variation, i.e. root penetration during both the years remains the same; also the sites showed equal average root penetration. But the variation in root penetration is highly significant among the seven species. In short, root penetration solely depends on the species. It can be seen that root penetration in the 2nd age group is 19.16 cm and in the first age group 18.88 cm, which are statistically equal as the difference is insignificant. The average root penetration in experimental containers is 19.06 cm, which is statistically the same as in tailing pond, where the root penetration is 18.97 cm (Table 4). Species is the only factor which has been found to vary significantly, it is observed that soil under the species *Pogostemon benghalense* shows the highest root penetration (22.10 cm), whereas *Saccharum spontaneum* shows the least root penetration (15.00 cm). *Imperata cylindrica* and *Jatropha gossypifolia* show equal root penetration (19.68 and 19.35 cm). The agewise averages of sites show that root penetrations in experimental containers and the tailing pond show no significant improvement in the second age group. It is seen that the root penetration of all the species remains nearly the same in the second age group. When the sitewise root penetration of the species is compared, it was observed that site to site difference is insignificant but species to species variation is significant. Root penetration of *Pogostemon benghalense* in experimental containers and tailing pond is the same but it is highest among the species.

The combined effect of the three factors on root penetration in all the species in experimental containers and tailing pond showed statistically equal root penetration in the second age group as well as the first age group (Table 4).

The analysis of data of root penetration (cm) showed variations among the three sites of experimentations, viz. *in situ*, *ex situ* experimental sites and natural habitat, and among the seven species. In short, all these factors showed significant variation in root penetration. Root penetrations (cm) in the soil of the roots among the seven species have been found to vary significantly. In *ex situ* experimental trials, it is found that *Pogostemon benghalense* (22 cm) shows maximum root penetration, whereas *Saccharum spontaneum* (15 cm) shows the least root penetration capacity among the seven species. In *in situ* experimental trials, it is found that *Pogostemon benghalense* (22.20 cm) has the maximum root penetration capacity whereas *Saccharum spontaneum* (15.00 cm) has the least root penetration capacity among the seven species. In natural habitat, it is found that *Pogostemon benghalense* (24.50 cm) has the maximum root penetration capacity, whereas *Furcraea foetida* (16.00) has the least root penetration capacity.

Root penetrations among the seven species have been found nearly the same in *ex situ* and *in situ* experimental trials but in natural habitat it was statistically significant. In natural habitat, soil root penetration was much more than in *ex situ* and *in situ* experimental trials (Table 5). The belowground competition and greater responsiveness of roots on restored site influence the stability of soils in the early stages of development[20]. The values of total root length recorded on both the sites are well within the ranges recorded by Carton *et al.*[21]. Due to the large network of roots, it appears that shrubs would occupy a major portion of the soil and thus their importance in soil physics is obvious. It is this network that has dramatically changed the edaphic factors on dry and infertile soils of mine sites. Improvement in soil characteristics with the addition of organic matter from root decay has been reported by several workers[22–24]. Generally, the higher root length in natural habitat soils may not be of considerable importance compared to its significance for plants grown in degraded habitats where soil moisture can be considered as the main factor inhibiting plant survival and growth. Thus, the aforesaid species with more number of lateral roots and higher root surface area values can absorb more water. Hence, these species are highly capable of growing in stressful sites. Because absorption of nutrients also depends on root length and root surface area, it can be assumed that these species with a large proportion of branched roots would absorb more minerals per unit weight than unbranched roots[25].

The comparative root length of plant species on revegetated tailing pond site (*in situ*) and experimental containers site (*ex situ*) is presented in Tables 4 and 5. The length of roots varied in both the species and between the two contrasting sites. *Pogostemon benghalense* proved to be superior in terms of its contribution to total root length on revegetated site and natural habitat. The extensive growth of this species was due to the presence of extensive network of fibrous roots.

It can therefore, be concluded that all the seven species were effective soil binders and suitable soil conserving species for tailing pond areas. The results reveal that all the selected species were good soil binders vis-à-vis fast growing in nature. It was, therefore recommended that these species should be given priority for soil conservation and revegetation purposes in degraded lands.

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1. Bastias, J. G., Retreatment of radioactive gold bearing tailings and rehabilitation of mill and tailings dump sites at Rockhole and Moline, Northern Territory (a personal view). Australian Mining Industry Council Environment Workshop Papers, Canberra, 1987, pp. 319–346.
2. Ryan, P., Rum Jungle Mine rehabilitation – Northern Territory. *J. Soil Conserv., New South Wales*, 1987, **43**, 18–27.
3. Singh, L. and Soni, P., Concentration of radionuclides in uranium tailings and its uptake by plants at Jaduguda, Jharkhand, India. *Curr. Sci.*, 2009, **98**(1), 37–49.
4. Singh, L., Soni, P. and Jha, V. N., Consolidation of radionuclides in uranium tailings at Jaduguda (Jharkhand) – a case study. *Int. J. Ecol. Environ. Sci.*, 2009, **35**(2–3), 255–260.
5. Singh, L. and Soni, P., Marketing and use of common wild plants of Jaduguda, Jharkhand, India. *Int. J. Forest Usufructs Management*, 2009, **10**(2), 1–10.
6. Jha, V. N., Sethy, N. K., Sahoo, S. K., Shukla, A. K., Tripathi, R. M. and Khan, A. H., A comparison of radioactivity level in discharge waste and natural sources in uranium mineralized area of Singhbhum, Jharkhand. In Proceedings of the 27th IARP National Conference of Occupational and Environmental Radiation Protection, BARC, Mumbai, 2005, pp. 284–286.
7. Bohm, W., *Methods of Studying Root System: Ecological Studies*, Springer-Verlag, Berlin, 1979, vol. 33, p. 188.
8. Lauenroth, W. K. and Whiteman, W. C., *J. Range Management*, 1971, **24**, 308–309.

9. Dittmer, H. J., A method to determine the length of individual roots. *Bull. Torrey Bot. Club*, 1959, **86**, 59–61.
10. Bhimaya, C. P., Rege, N. D. and Srinivasan, V., *J. Soil Water Conserv.*, 1956, **4**(3), 113–117.
11. Schaeff, H., *Analysis of Variance*, John Wiley and Sons, New York, 1959, pp. 168–231.
12. Snedecor, G. W., *Statistical Method*, Iowa State University Press, Iowa, 1956, pp. 171–188.
13. Hossner, L. R. and Hons, F. M., Reclamation of mine tailings. In *Advances in Soil Science* (eds Lal, R. and Stewart, B. A.), Springer-Verlag, New York Inc, 1992, vol. 17, pp. 311–350.
14. Soni, P., Vasistha, H. B. and Om Kumar, Surface mined lands: problems and prospectus. Report on eco-restoration of rock phosphate mined area, ICFRE Publ., 1992, pp. 18–30.
15. Munshower, F. F., *Practical Handbook of Disturbed Land Revegetation*, Lewis Publ., London, Tokyo, 1993.
16. Varela, C., Vazquez, C., Sangregorio, G. V. M., Leiros, C. M. and Sotres, G. F., Chemical and physical properties of open cast lignite mine soils. *Soil Sci.*, 1993, **156**(3), 193–204.
17. Dadhwal, K. S. and Singh, B., Rooting behaviour of different plant species in limestone mined area. *Indian For.*, 1993, **119**(2), 71–74.
18. Vasistha, H. B., Growth behaviour of some colonizing plant species of rock phosphate mine spoils areas of Doon Valley. Ph D thesis, H.N.B. Garhwal University, Srinagar, Garhwal, 1992.
19. Soni, P., Rawat, A. and Singh, L., Seed mix for ecorestoration trials on iron ore mines in Keonjhar District of Orissa, National Conference on Eco-Restoration of Derelict Mined Lands, Sponsored by UGC, 1 and 2 March 2007, p. 24.
20. Nambier, E. K. S., Ecological and physiological aspects of the development of roots: from nursery to forest. In Proceedings Australia Forest Nutrition Workshop, Productivity in Perpetuity, SIRO, Melbourne, Canberra, 1981, pp. 117–129.
21. Carbon, B. A., Bartle, G. A., Murray, A. M. and Macpherson, D. K., The distribution of root length, and limit to flow of soil water to root in a dry sclerophyll forest. *Forestry Sci.*, 1980, **26**, 656–664.
22. Thakur, C., Grassland in soil conservation. *J. Soil Water Conserv.*, 1957, **6**(1), 43–47.
23. Bhimaya, C. P. and Seri, D. N., Root system and root ecology. In *Environment and Root Behaviour Geobios International* (ed. Seri, D. N.), Jodhpur, 1980, pp. 1–24.
24. Singh, R. P. and Gupta, M. K., Root studies and soil binding capacity of some important grasses of temperate region, Kyaright, HP. *Indian J. Soil Conserv.*, 1983, **11**(1), 60–63.
25. Nye, P. H., The effect of nutrient intensity, buffering power of a soil, absorbing power and size of root, on hairs of a root and nutrient absorption by diffusion. *Plant Soil*, 1966, **25**, 82–85.

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Parallel response between gametophyte and sporophyte for *Fusarium* wilt resistance in the recombinant inbred lines of chickpea (*Cicer arietinum* L.)

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In the present communication, we study the possibility of screening of a large set of chickpea recombinant inbred lines (RILs) for wilt resistance through *in vitro* pollen tube growth inhibition in the presence of pathotoxin. Further, the number of alleles with resistance differs in their degree of resistance at both gametophytic and sporophytic phase. The RILs of cross JG-62 (highly susceptible) × WR-315 (resistant), segregate for both the loci of wilt resistance and molecular markers linked to the wilt resistance loci. The pollen grains of 43 randomly selected RILs were cultured in cavity slides in the laboratory. The addition of increased concentration of the pathotoxin to the pollen germination medium inhibited pollen tube growth of all the lines. The tube growth inhibition was not uniform across all the lines. It was highest in highly susceptible lines followed by susceptible lines. The degree of pollen resistance depends on the number of alleles/genes for resistance it carries and pollen resistance segregates with alleles for resistance. The study evidenced the parallel response between gametophytic and sporophytic wilt resistance. The toxin concentration required to inhibit 50% pollen tube growth was determined for all the lines. The resistant lines required significantly higher mean toxin concentration for 50% pollen tube growth inhibition, followed by susceptible and highly susceptible lines. The correlation between sporophytic wilt resistance and toxin concentration to inhibit pollen tube growth was highly significant. Higher the sporophytic resistance to wilt, higher was the concentration required to inhibit its pollen tube growth under *in vitro* conditions. Consequently, pollen response has a potential for rapid and inexpensive screening of a large set of genotypes for biotic stress tolerance.

Keywords: Chickpea, *Fusarium* wilt, gametophyte, *in vitro* pollen germination, sporophyte.

THE gametophyte has been the subject of intense studies not only for its importance as the male partner in plant reproduction, but also as a potential arena for selection in crop improvement programmes[1,2]. From pollen formation to successful fertilization, pollen grains experience vari-

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