USE OF RHIZOSPHERE SOIL FOR RAISING *CEDRUS DEODARA* AND *QUERCUS SEMECARPIFOLIA* SEEDLINGS

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Received September 2006; Received resubmission July 2007

TAMTA, S., PALNI, L. M. S. & PANDEY, A. 2008. Use of rhizosphere soil for raising *Cedrus deodara* and *Quercus semecarpifolia* seedlings. Experiments were carried out in the nursery to develop a simple method to raise *Cedrus deodara* and *Quercus semecarpifolia* seedlings using their respective rhizosphere soil mixed with non-forest soil in various combinations. Different soil treatments, namely, control (non-forest soil); pure rhizosphere soil; rhizosphere soil, one part placed over nine parts of non-forest soil as top layer; and rhizosphere soil uniformly mixed with non-forest soil (1:9, v/v) were used in this study. Seeds were allowed to germinate in polybags. Observations were made on seed germination, seedling survival, rhizosphere microbial communities, nutrient status of soil as well as that of seedlings and overall growth of seedlings, six and twelve months after seed sowing. All treatments positively affected these parameters over the control. The treatment in which the rhizosphere soil was uniformly mixed in 1:9 ratio with the non-forest soil was most effective. The study has practical implications for raising healthy, vigorous seedlings for use in plantations, particularly in afforestation programmes.

Keywords: Nursery, afforestation, germination, microbial communities, biomass

TAMTA, S., PALNI, L. M. S. & PANDEY, A. 2008. Penggunaan tanah rizosfera untuk menanam anak-anak benih *Cedrus deodara* dan *Quercus semecarpifolia*. Kajian dijalankan di tapak semaian untuk membangunkan cara mudah bagi menanam anak-anak benih *Cedrus deodara* dan *Quercus semecarpifolia* menggunakan tanah rizosfera masing-masing bercampur dengan tanah bukan hutan dalam pelbagai kombinasi. Kombinasi rawatan tanah ialah kawalan (tanah bukan hutan); tanah rizosfera tulen; satu bahagian tanah rizosfera terletak di atas sembilan bahagian tanah bukan hutan dan tanah rizosfera digaul sekata dengan tanah bukan hutan (1:9 v/v). Biji benih dibiarkan bercambah di dalam polibeg. Percambahan biji benih, kemandirian anak benih, komuniti mikrob rizosfera, status nutrien tanah, status nutrien anak benih dan pertumbuhan keseluruhan anak benih dicerap enam bulan dan 12 bulan selepas penyemaian. Semua rawatan mempengaruhi parameter secara positif berbanding kawalan. Tanah rizosfera yang digaul sekata dengan tanah bukan hutan (1:9) merupakan rawatan paling efektif. Kajian ini mempunyai implikasi praktik dalam penghasilan anak benih yang sihat untuk digunakan dalam program penghutanan.

INTRODUCTION

While the importance of rhizosphere micro-organisms in plant growth is well known, plants also exert an influence on the soil microbial population (Curl & Truelove 1986, Fogel 1988). Consequently, a specific rhizoflora develop around plant roots and the degree of specificity of root-associated micro-organisms is likely to be more in trees due to their long life span (Shishido *et al.* 1995). Small amounts of rhizosphere soil can be a rich source of micro-organisms, which are beneficial for plant growth. They often contain microbes that are antagonists, phosphate solubilizers, nitrogen fixers and growth promoters, in addition to having mycorrhizal elements (Pandey *et al.* 1998). In contrast, soil from degraded sites may be devoid of appropriate and beneficial micro-organisms. Therefore, in raising plantations of forest species at such sites, the use of rhizosphere soil from the respective taxa as 'inoculum' appears to be an attractive and inexpensive proposition (Durgapal *et al.* 2002, Bisht *et al.* 2003). On the basis of these studies, the influence of rhizosphere soil on the production of healthy seedlings of deodar and brown oak, obtained from their corresponding forests, was investigated. Its effect on plant growth was evaluated in terms of seedling emergence, growth, biomass and nutrient status of the soil and plant parts.

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Cedrus deodara (deodar) and *Quercus semecarpifolia* (brown oak) are two important forest species of the Indian Central Himalaya. Deodar is an important timber tree of the Himalayan region. The wood is extensively used for the construction of buildings, bridges, railway sleepers and furniture making. The wood of deodar possesses diaphoretic, diuretic and carminative properties and is useful in fevers, piles, and pulmonary and urinary disorders. Brown oak plays a vital role in soil and water conservation and sustenance of the rural ecosystem. The wood is used for making agricultural tools and as fuel, leaves as fodder and leaf litter as cattle bedding. Production of healthy seedlings of these species for use in afforestation programmes and for replantation at degraded sites is an essential requirement.

MATERIALS AND METHODS

Study site

The study was conducted at the nursery of GB Pant Institute (Kosi-Katarmal, Almora) located at 29° 38' 15" N and 79° 38' 10" E at an altitude of 1150 m amsl.

Seed and soil collection

The rhizosphere soil and seeds were collected from well established stands of *C. deodara* and *Q. semecarpifolia* from Jageshwar (District Almora, 29° 35'–29° 39' N latitude and 79° 59' - 79° 53' E longitude, 1770–1920 m amsl, 45 km from the Institute) and Kilbury (District Nainital, 29° 24' 30" N–29° 27' N latitude and 79° 25' E–79° 29' 40" E longitude, 2100–2400 m amsl) forests respectively. Seeds of deodar were collected in October, stored for 1.5 months at 4 °C and sown in December. Oak seeds were collected in June and immediately sown. The soil treatments used were: (T1) control (non-forest soil, collected from a nearby site at Katarmal, District Almora); (T2) pure rhizosphere soil collected from underneath well-established trees of both species from their natural forests (deodar forest in Jageshwar and brown oak forest in Kilbury); (T3) rhizosphere soil (1 part) placed over 9 parts of non-forest soil as top layer; and (T4) rhizosphere soil uniformly mixed with non-forest soil (1:9). Rhizosphere soil from deodar forest was used for deodar seed germination, while rhizosphere soil from brown oak forest was used for oak germination. There were two separate experiments, one for each tree species and each with four soil treatments. The soil pH values were 7.6, 6.8 and 7.7 for T1, T2 and T4 respectively in the case of *C. deodara,* and 7.3, 5.3 and 7.4 for T1, T2 and T4 respectively in the case of *Q. semecarpifolia.* The initial pH values for the top and bottom soil layers in T3 were not recorded again.

Seed treatment

Seeds were rinsed in running water for 60 min, treated with bavistin (2% w/v, 20 min) and then washed thoroughly with water before sowing. Treated seeds were planted at a depth of 3 cm in polybags (16 cm height, 8 cm diameter, 1 kg soil per polybag). One seed was planted per polybag and 30 seeds were used per treatment. The polybags were kept in the nursery and watered regularly.

Seedling emergence and growth

Seed germination started after two months (in February for *C. deodara* and August for *Q. semecarpifolia*). After the emergence of the first seedling, observations on germination were recorded every seven days. Seeds continued to emerge till the end of April in *C. deodara* and up till the end of December in *Q. semecarpifolia.* Per cent seed germination and subsequent seedling survival were recorded. The monitoring of growth was done six till twelve months after germination. For this, three seedlings were carefully uprooted. They were chosen randomly from each treatment and observations were made on the number of lateral roots, root length, root diameter (10 cm below the collar region), collar diameter, shoot height, shoot diameter (10 cm above the collar), needle (*C. deodara*) or leaf (*Q. semecarpifolia*) numbers. For biomass estimation, seedlings were separated into root, stem and needle/leaf, and oven dried at 80 °C to constant weight.

Nutrient analyses

Soil organic carbon, nitrogen, phosphorus and potassium contents were analyzed at day zero and after six and twelve months. N, P and K content of the root, shoot and needle/ leaf were

analyzed after six and twelve months of seed sowing. Soil samples at day zero were taken from the polybags at the depth of 2.0–2.5 cm. On day zero, soil organic carbon, nitrogen, phosphorus and potassium contents were not analyzed for the top and bottom soil layers in T3 again. The rhizosphere soil samples surrounding the roots of the seedlings in different treatments were collected, dried at room temperature and passed through a 2 mm sieve. Dried root, stem and needle or leaf were ground separately and passed through a mesh of 0.5 mm size. Nitrogen was estimated by the Kjeldahl method using Kjeltec auto-analyzer. Phosphorus and potassium were analyzed by the acid digestion method (Allen 1989) using spectrophotometer and flame photometer respectively. Organic carbon was estimated by rapid titration method (Allen 1989).

Enumeration of rhizospheric microflora

Samples of soil closely adhering to the roots of *C. deodara* and *Q. semecarpifolia* seedlings were collected 12 months after seed sowing for determination of microbial communities. To estimate the number of soil micro-organisms (bacteria, fungi and actinomycetes), the microbial counts, in terms of colony forming units (cfu), were calculated on the basis of per gram of oven dry soil using 10-fold serial dilution method (Johnson & Curl 1972). The plates were incubated at 28 °C and cfu were recorded after one week. Nutrient broth, potato dextrose agar, actinomycetes isolation agar and Jensen agar were used.

Statistical analyses

Data were subjected to statistical analyses and least significant differences (LSD) were calculated at p = 0.05 for different growth parameters according to Snedecor and Cochran (1967).

RESULTS

Seedling emergence

Seedling emergence started two months after seed sowing in both the species. The final seedling emergence values were highest in T4 in case of *C. deodara* (Figure 1a) and in T2 in *Q. semecarpifolia* (Figure 1c). T4, where the rhizosphere soil and non-forest soil were uniformly mixed in 1:9 ratio, was most effective in both species with regard to seedling survival (Figures 1b and 1d).

Seedling growth

The influence of rhizosphere soil on seedling growth was visually distinct eight months after sowing, and became very clear after 12 months in these two species (Figure 2). T2, T3 and T4 positively influenced all growth parameters. Increment in shoot height, compared with the control, was recorded in all treatments after six months and the differences were statistically significant (p = 0.05) after 12 months (Table 1). Root length and root diameter were higher than the control in pure rhizosphere soil treatment (T2) except for root diameter of *Q. semecarpifolia* after six months. T4 gave better results in comparison with others with regard to root length, shoot height, shoot, collar and root diameters, needle/leaf number (Table 1) as well as shoot, root and needle/leaf biomass (Table 2), except that the main root biomass values in both species and needle biomass value in *C. deodara* after 12 months were higher in T3.

Nutrient analyses

Nutrient content in soil

Pure rhizosphere soil of *C. deodara* was found to be rich. Particularly, the N, K and organic carbon values were greater than those recorded for the control and mixed soil treatments, both after six and twelve months of seed sowing (Table 3). The N, P, K and C values were significantly different from the control at 0 day and after 6 and 12 months. At day zero soil organic C, N, P and K were not analyzed for the top and bottom soil layers in T3 again for both species. In the case of *Q. semecarpifolia,* N, K and organic C were significantly higher (p = 0.05) in the rhizosphere as well as mixed soil treatments.

Nutrient content in seedlings

The trend of nutrient concentration was found to be more or less similar in both species. Rhizosphere soil inoculation improved the nutrient status of plant components. Nutrient status of seedlings improved due to soil treatments on the basis of nutrient

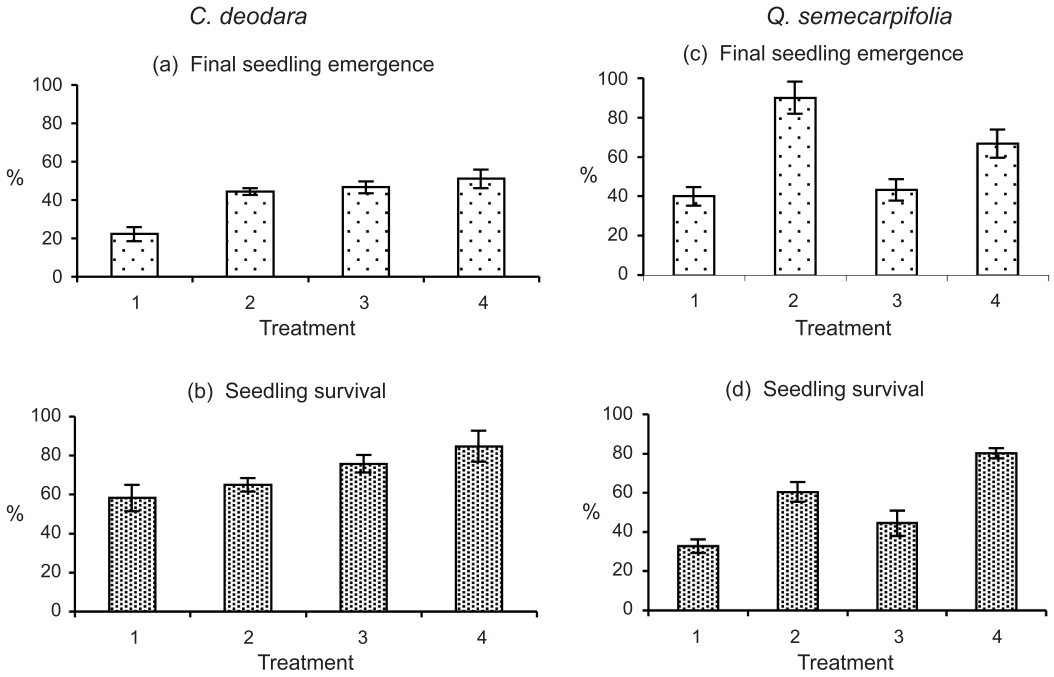

Figure 1 Effects of soil treatment on final seedling emergence and seedling survival of *C. deodara* and *Q. semecarpifolia* seedlings. Data for seedling survival were recorded 12 months after seed sowing. Vertical bars represent SE.
T1 = control, T2 = pure rhizosphere soil, T3 = rhizosphere soil (1 part) placed over 9 parts of non-forest soil as top layer, T4 = rhizosphere soil uniformly mixed with forest soil (1:9)

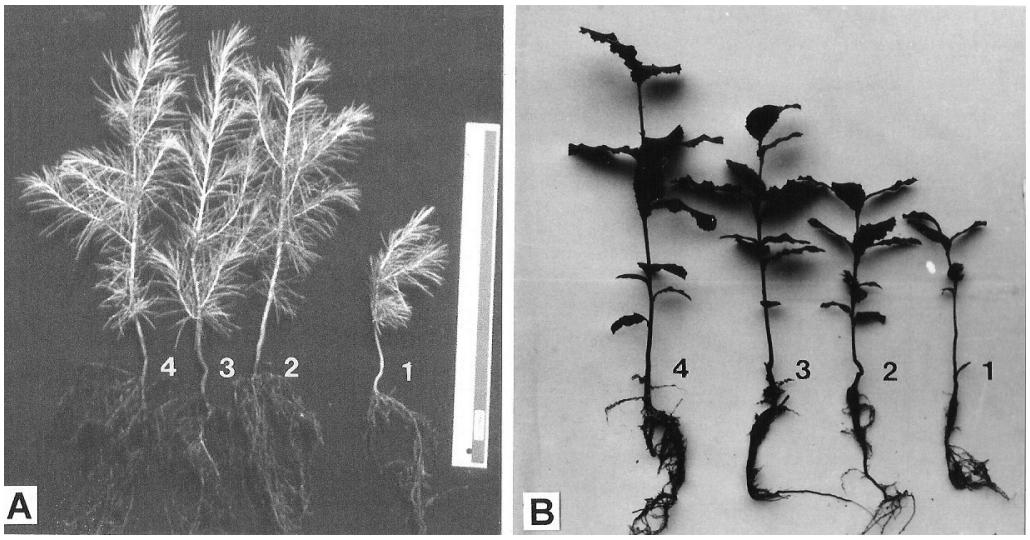

Figure 2 Effects of soil treatments on general growth and vigour of 12-month-old *C. deodara* (A) and *Q. semecarpifolia* (B) seedlings. Plants have been kept in the following order (right to left): seedlings subjected to soil treatments T1, T2, T3 and T4.

concentration (Table 4). Both the mixed soil treatments increased N, P, K concentrations in root, shoot and needle ($p = 0.05$). In both species, the N, P, K concentrations were more in the needles/leaves compared with the other plant parts.

Rhizosphere microbial communities

The soil treatments stimulated various groups of microbial populations in comparison with the control in both the species (Table 5). Bacterial population was highest in T2. In the case of *C.*

Table 1 Effects of soil treatment on selected growth parameters in *C. deodara* and *Q. semecarpifolia* after 6 and 12 months of seed sowing

Soil treatment	Age (months)	Shoot height (cm)	Root length (cm)	Shoot diameter (mm)	Root diameter (mm)	Collar diameter (mm)	Lateral root no.	Needle/leaf no.
C. deodara								
T1	6	7.00 ± 0.62	14.77 ± 1.25	0.86 ± 0.04	0.54 ± 0.04	1.49 ± 0.04	15.33 ± 0.27	154.00 ± 5.79
	12	17.17 ± 2.14	28.00 ± 1.41	2.22 ± 0.05	1.50 ± 0.03	3.70 ± 0.04	34.00 ± 2.83	392.67 ± 3.54
T2	6	11.30 ± 0.46	15.27 ± 0.53	0.94 ± 0.04	0.72 ± 0.04	1.54 ± 0.06	21.67 ± 0.98	443.00 ± 2.87
	12	29.33 ± 1.16	31.33 ± 0.98	2.50 ± 0.02	2.00 ± 0.03	5.00 ± 0.01	34.30 ± 0.98	1071.00 ± 9.27
T3	6	10.80 ± 0.41	10.10 ± 0.78	0.86 ± 0.04	0.53 ± 0.06	1.37 ± 0.08	9.67 ± 0.98	370.67 ± 5.26
	12	32.50 ± 0.62	34.33 ± 0.72	3.50 ± 0.06	2.20 ± 0.02	5.20 ± 0.03	28.00 ± 1.89	1220.67 ± 8.65
T4	6	10.70 ± 0.36	11.43 ± 0.44	0.84 ± 0.03	0.49 ± 0.07	1.36 ± 0.07	21.67 ± 1.44	379.67 ± 2.88
	12	35.03 ± 2.02	36.33 ± 0.59	3.80 ± 0.03	2.40 ± 0.02	5.40 ± 0.04	47.70 ± 1.19	1242.33 ± 6.44
LSD (p = 0.05)	6	1.90	3.25	0.16	0.21	0.27	4.04	17.60
	12	6.43	3.91	0.16	0.09	0.11	14.67	29.26
Q. semecarpifolia								
T1	6	10.03 ± 0.26	13.97 ± 2.28	1.40 ± 0.04	3.67 ± 0.11	2.01 ± 0.03	3.67 ± 1.66	5.00 ± 0.47
	12	13.10 ± 1.48	19.20 ± 1.19	1.61 ± 0.05	3.80 ± 0.34	2.47 ± 0.09	6.00 ± 1.70	8.00 ± 0.47
T2	6	16.67 ± 1.46	19.87 ± 1.86	1.36 ± 0.08	2.15 ± 0.56	2.26 ± 0.15	19.67 ± 0.98	4.00 ± 0.47
	12	19.90 ± 2.32	20.67 ± 1.11	2.30 ± 0.46	5.22 ± 1.26	2.91 ± 0.53	21.33 ± 4.91	10.00 ± 0.94
T3	6	12.60 ± 0.25	25.70 ± 1.93	1.59 ± 0.21	1.69 ± 0.38	2.02 ± 0.11	17.33 ± 7.14	3.33 ± 0.72
	12	24.80 ± 1.68	27.20 ± 1.61	2.33 ± 0.12	5.61 ± 0.36	3.70 ± 0.55	21.67 ± 4.28	12.00 ± 0.94
T4	6	12.10 ± 0.48	15.33 ± 1.66	1.46 ± 0.18	3.36 ± 1.29	2.21 ± 0.10	8.67 ± 1.19	5.33 ± 0.27
	12	30.86 ± 1.78	22.40 ± 0.36	2.89 ± 0.34	4.82 ± 1.06	3.94 ± 0.21	24.67 ± 5.19	13.33 ± 0.72
LSD (p = 0.05)	6	3.16	7.77	0.58	2.93	0.42	14.97	2.03
	12	7.36	4.64	1.18	3.44	1.57	16.97	3.16

T1 = control, T2 = pure rhizosphere soil, T3 = rhizosphere soil (1 part) placed over 9 parts of non-forest soil as top layer, T4 = rhizosphere soil uniformly mixed with forest soil (1:9)
All values are averages of three replicates ± SE.

Table 2 Effects of soil treatment on biomass (dry matter yield) of 6- and 12-month-old seedlings of *C. deodara* and *Q. semecarpifolia*

Soil treatment	Age (months)	*C. deodara*				*Q. semecarpifolia*				
		Shoot (g) ± SE	Main root (g) ± SE	Lateral root (g) ± SE	Needle (g) ± SE	Shoot (g) ± SE	Main root (g) ± SE	Lateral root (g) ± SE	Fine root (g) ± SE	Leaf (g) ± SE
T1	6	0.23 ± 0.01	0.17 ± 0.02	0.41 ± 0.003	0.90 ± 0.06	0.13 ± 0.01	0.95 ± 0.23	0.08 ± 0.04	0.01 ± 0.003	0.23 ± 0.04
	12	0.64 ± 0.01	0.32 ± 0.01	1.15 ± 0.01	2.21 ± 0.01	0.23 ± 0.01	0.98 ± 0.05	0.19 ± 0.003	0.02 ± 0.003	0.50 ± 0.09
T2	6	0.88 ± 0.02	0.20 ± 0.01	1.40 ± 0.07	2.29 ± 0.04	0.44 ± 0.18	2.29 ± 0.70	0.13 ± 0.03	0.03 ± 0.01	0.23 ± 0.03
	12	2.21 ± 0.08	0.63 ± 0.01	2.57 ± 0.23	7.08 ± 0.04	0.48 ± 0.02	2.41 ± 0.48	0.16 ± 0.01	0.04 ± 0.01	1.11 ± 0.21
T3	6	0.79 ± 0.07	0.12 ± 0.01	1.32 ± 0.03	1.80 ± 0.05	0.39 ± 0.003	2.78 ± 0.44	0.17 ± 0.07	0.07 ± 0.01	0.16 ± 0.04
	12	2.53 ± 0.01	1.10 ± 0.001	4.26 ± 0.07	7.61 ± 0.03	0.66 ± 0.13	3.23 ± 0.38	0.21 ± 0.01	0.07 ± 0.05	1.65 ± 0.06
T4	6	0.80 ± 0.03	0.16 ± 0.002	1.61 ± 0.12	1.53 ± 0.05	0.23 ± 0.05	2.13 ± 0.03	0.08 ± 0.03	0.01 ± 0.004	0.34 ± 0.003
	12	2.73 ± 0.10	0.75 ± 0.04	6.26 ± 0.07	7.12 ± 0.10	1.14 ± 0.28	2.54 ± 0.29	0.24 ± 0.01	0.04 ± 0.02	2.26 ± 0.51
LSD (p = 0.05)	6	0.15	0.05	0.29	0.25	1.04	1.71	0.16	0.02	1.73
	12	0.25	0.08	0.51	0.21	0.60	1.36	0.02	0.30	1.25

T1 = control, T2 = pure rhizosphere soil, T3 = rhizosphere soil (1 part) placed over 9 parts of non-forest soil as top layer, T4 = rhizosphere soil uniformly mixed with forest soil (1:9)
All values are averages of three replicates ± SE.

Table 3 Nutrient contents of soil used to grow *C.deodara* and *Q. semecarpifolia* at day 0, and after 6 and 12 months of seed sowing

Soil treatment	% N			% P			% K			% C		
	0 day	6 months	12 months	0 day	6 months	12 months	0 day	6 months	12 months	0 day	6 months	12 months
C. deodara												
T1	0.19 ± 0.02	0.15 ± 0.01	0.11 ± 0.01	0.17 ± 0.01	0.13 ± 0.01	0.07 ± 0.01	0.37 ± 0.01	0.36 ± 0.01	0.33 ± 0.01	0.98 ± 0.01	0.91 ± 0.01	0.86 ± 0.01
T2	0.22 ± 0.01	0.19 ± 0.01	0.15 ± 0.003	0.13 ± 0.01	0.12 ± 0.01	0.10 ± 0.01	1.13 ± 0.003	1.09 ± 0.04	0.98 ± 0.01	1.68 ± 0.01	1.63 ± 0.01	1.54 ± 0.01
T3	–	0.14 ± 0.003	0.13 ± 0.01	–	0.12 ± 0.01	0.08 ± 0.01	–	0.54 ± 0.01	0.46 ± 0.01	–	1.28 ± 0.01	1.12 ± 0.01
T4	0.20 ± 0.01	0.18 ± 0.01	0.15 ± 0.01	0.15 ± 0.01	0.13 ± 0.01	0.10 ± 0.01	0.69 ± 0.01	0.62 ± 0.01	0.59± 0.01	1.36 ± 0.01	1.31 ± 0.01	1.23 ± 0.02
LSD (p = 0.05)	0.05	0.03	0.03	0.04	0.04	0.03	0.03	0.08	0.04	0.04	0.04	0.06
Q. semecarpifolia												
T1	0.18 ± 0.01	0.16 ± 0.01	0.08 ± 0.03	0.14 ± 0.004	0.10 ± 0.004	0.07 ± 0.01	0.36 ± 0.02	0.39 ± 0.02	0.21 ± 0.02	0.94 ± 0.04	0.80 ± 0.01	0.51 ± 0.03
T2	0.48 ± 0.01	0.42 ± 0.01	0.38 ± 0.01	0.09 ± 0.02	0.08 ± 0.02	0.06 ± 0.01	1.62 ± 0.05	1.41 ± 0.10	1.00 ± 0.03	3.82 ± 0.02	4.10 ± 0.05	3.36 ± 0.05
T3	–	0.30 ± 0.01	0.24 ± 0.02	–	0.09 ± 0.01	0.07 ± 0.01	–	0.71 ± 0.05	0.61 ± 0.05	–	2.15 ± 0.03	1.95 ± 0.02
T4	0.42 ± 0.01	0.40 ± 0.003	0.29 ± 0.04	0.10 ± 0.01	0.09 ± 0.004	0.06 ± 0.004	1.04 ± 0.03	0.92 ± 0.04	0.85 ± 0.06	2.92 ± 0.04	2.98 ± 0.01	2.47 ± 0.20
LSD (p = 0.05)	0.04	0.03	0.12	0.05	0.04	0.02	0.26	0.23	0.18	0.16	0.12	0.41

T1 = control, T2 = pure rhizosphere soil, T3 = rhizosphere soil (1 part) placed over 9 parts of non-forest soil as top layer, T4 = rhizosphere soil uniformly mixed with forest soil (1:9)
All values are averages of three replicates ± SE.

deodara, the bacterial population in T2 was almost 4.5 times higher than T1, and approximately 2.0 and 4.0 times higher than T3 and T4 respectively. Fungi and actinomycete populations were also stimulated. In *C. deodara,* the fungal population became slightly more than double over T1 in T3 and T4. However, stimulation of this group was somewhat lower in T2, though higher in comparison with T1. Increase in the actinomycete population was two to three folds greater than T1. The best proliferation was in T4. Overall differences were statistically significant.

In *Q. semecarpifolia,* proliferation of bacteria, fungi and actinomycete population was two to three folds higher in comparison with T1. While differences were also observed in fungi and actinomycete populations, the data were statistically not significant.

DISCUSSION

The benefits of using rhizosphere soil in improving seed germination and subsequent plant growth were distinctly observed in these two species. The benefits were apparent right from the seed germination stage. The beneficial effects of rhizosphere soil on germination and subsequent survival of seedlings in *C. deodara* and *Pinus wallichiana* were reported recently. Soil combination (1:9) was found to be superior

Table 4 Effects of soil treatment on nutrient concentration in various plant parts of 12-month-old *C. deodara* and *Q. semecarpifolia* seedlings

	C. deodara					*Q. semecarpifolia*				
Seedling component	T1	T2	T3	T4	LSD (p = 0.05)	T1	T2	T3	T4	LSD (p = 0.05)
Nitrogen (%)										
Root	0.78 ± 0.01	0.93 ± 0.01	1.35 ± 0.01	1.43 ± 0.03	0.08	0.86 ± 0.02	1.05 ± 0.02	1.45 ± 0.01	1.60 ± 0.01	0.06
Shoot	0.56 ± 0.01	0.67 ± 0.03	0.84 ± 0.02	0.91 ± 0.02	0.08	0.67 ± 0.01	0.83 ± 0.01	1.02 ± 0.02	1.02 ± 0.01	0.05
Needle/Leaf	1.23 ± 0.01	1.46 ± 0.02	1.61 ± 0.02	1.68 ± 0.01	0.06	1.44 ± 0.02	1.65 ± 0.02	1.80 ± 0.02	1.90 ± 0.05	0.12
Phosphorus (%)										
Root	0.07 ± 0.01	0.14 ± 0.02	0.17 ± 0.02	0.20 ± 0.02	0.07	0.10 ± 0.01	0.15 ± 0.01	0.18 ± 0.01	0.20 ± 0.02	0.04
Shoot	0.04 ± 0.01	0.09 ± 0.01	0.11 ± 0.01	0.09 ± 0.01	0.03	0.06 ± 0.01	0.11 ± 0.01	0.15 ± 0.01	0.12 ± 0.02	0.05
Needle/Leaf	0.10 ± 0.01	0.15 ± 0.01	0.16 ± 0.01	0.22 ± 0.01	0.04	0.11 ± 0.01	0.16 ± 0.01	0.18 ± 0.003	0.25 ± 0.03	0.06
Potassium (%)										
Root	0.28 ± 0.01	0.39 ± 0.01	0.40 ± 0.02	0.43 ± 0.01	0.05	0.49 ± 0.02	0.79 ± 0.01	1.08 ± 0.03	1.26 ± 0.02	0.10
Shoot	0.34 ± 0.01	0.36 ± 0.02	0.29 ± 0.01	0.44 ± 0.02	0.07	0.45 ± 0.02	0.64 ± 0.01	0.75 ± 0.02	0.98 ± 0.01	0.07
Needle/Leaf	0.41 ± 0.01	0.71 ± 0.01	0.70 ± 0.02	0.77 ± 0.01	0.05	0.55 ± 0.01	0.96 ± 0.02	1.43 ± 0.10	1.39 ± 0.03	0.22

T1 = control, T2 = pure rhizosphere soil, T3 = rhizosphere soil (1 part) placed over 9 parts of non-forest soil as top layer, T4 = rhizosphere soil uniformly mixed with forest soil (1:9)
All values are averages of three replicates ± SE.

Table 5 Effects of soil treatment on rhizosphere microbial communities in 12-month-old *C. deodara* and *Q. semecarpifolia* seedlings

	Colony forming units (× 10^4 cells/g soil)					
Soil treatment	*C. deodara*			*Q. semecarpifolia*		
	Bacteria	Fungi	Actinomycete	Bacteria	Fungi	Actinomycete
T1	7.51 ± 3.24	1.64 ± 0.89	11.18 ± 0.82	6.13 ± 1.53	2.47 ± 0.61	2.26 ± 0.78
T2	31.87 ± 6.01	2.75 ± 0.34	23.02 ± 5.23	22.94 ± 3.19	3.15 ± 0.45	2.46 ± 0.60
T3	15.27 ± 1.47	3.95 ± 0.29	26.98 ± 2.41	5.68 ± 0.58	5.16 ± 0.70	5.15 ± 1.10
T4	27.29 ± 4.86	3.99 ± 0.32	32.07 ± 2.35	11.08 ± 1.52	6.19 ± 0.31	5.41 ± 1.12
LSD (p=0.05)	17.00	2.08	12.52	7.77	2.15	3.69

T1 = control, T2 = pure rhizosphere soil, T3 = rhizosphere soil (1 part) placed over 9 parts of non-forest soil as top layer, T4 = rhizosphere soil uniformly mixed with forest soil (1:9)
All values are averages of three replicates ± SE.

to pure rhizosphere soil (Pandey *et al.* 1998, Durgapal *et al.* 2002). This is likely the result of colonization of non-forest soil by the native microflora contained in the rhizosphere soil used as inoculum (Trofymow & van den Driessche 1991, Bakshi 1995).

Another important parameter influenced by soil treatments was enhancement in the uptake of nutrients from the soil by plants. This further indicated colonization of the non-forest soil by rhizoflora, well known for their importance in nutrient uptake. Dilfuza (2007) also observed positive effect of bacterial inoculation on plant growth and nutrient uptake. The rhizosphere soil, in general, is characterized by the much greater colonization by microbial communities than the corresponding non-forest soils or soils from degraded sites. Such plant–microbe relationship is likely to be more intense as well as specific in long-lived forest tree species. The improvement in plant growth in a stimulated mycorrhizosphere (due to the presence of other microbial communities) may result from (a) improvement in the nutrient status due to higher solubilization and nutrient uptake (Trofymow & van den Driessche 1991, Illmer & Schinner 1992, Rousseau *et al.* 1992, Barr & Oude Elferink 1996), (b) higher concentration (accumulation) of nutrients in various plant components (Trofymow & van den Driessche 1991, Barr & Oude Elferink 1996) and (c) an increase in the volume of soil being used by the mycorrhizal fungi for absorption of nutrients and their translocation beyond the root and root hair zones (Haselwandter & Bowen 1996, Ananthakrishnan *et al.* 2004, Caravaca *et al.* 2006)

This study introduced a simple and inexpensive method for afforestation programmes. A small volume of rhizosphere soil may act as a consortium of complete rhizoflora, required for seed germination and subsequent plant growth. The rhizosphere acts as the centre of greater microbial activity as it harbours micro-organisms beneficial for plant growth. At degraded sites, where afforestation is needed most, soils are usually poor in terms of both the microbial activity and nutritional status. For such sites, inoculation of 'degraded soil' with a small quantity of rhizospheric soil obtained from the same taxa can result in improved seedling establishment. The use of this simple technology, nevertheless, needs certain precautions before its implementation on a larger scale. While the rhizosphere soil is known to possess beneficial rhizoflora, it may also have some pathogens. Another possible difficulty may occur if the rhizosphere soil contains certain anti-germination factors. Presence of such factors, probably of microbial origin, has recently been reported in the case of *Taxus baccata* sub sp. w*allichiana* (Pandey *et al.* 2002). In the study, seed germination was significantly higher in degraded soil compared with rhizosphere soil. In view of such possibilities, the advantage of this simple technology may be exploited by taking two major precautions: (1) soil testing for possible presence of pathogen and (2) limited nursery trial using rhizosphere soil of the corresponding taxa and non-forest soil obtained from potential plantation sites in appropriate combinations.

ACKNOWLEDGEMENTS

We gratefully acknowledge financial assistance provided by the Union Ministry of Environment & Forests and the Department of Biotechnology, Government of India, New Delhi. A. Mishra helped in the chemical analyses.

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