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EFFECTS OF SOIL WORKING TECHNIQUES AND STOCK TYPE ON THE REGENERATION PERFORMANCE OF *CELTIS AUSTRALIS* IN NORTHWESTERN HIMALAYA

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BHARDWAJ, D. R., GUPTA, N. K. & BHARDWAJ, S. D. 2000. Effects of soil working techniques and stock type on the regeneration performance of *Celtis australis* in northwestern Himalaya. *Celtis australis*, an important indigenous agroforestry tree species of northwestern Himalaya, was evaluated for survival response and quantitative performance in relation to various soil working techniques and planting methods on dry hill slopes. Different soil working and planting techniques significantly influenced survival, height, collar diameter, above-ground biomass, root biomass, tap and total root lengths. Planting in trenches, ditches and inward sloping contour terraces (gradonies) was observed to be superior to the conventional pit planting technique. Planting of bare-root seedlings outperformed that of direct seeded stocks, with winter-planted bare-root seedlings and stumps (root-shoot cuttings) performing equally well. Establishment costs per plant at one year were lower for bare-root seedlings than for direct seeded stock. Costs of establishing stumps (root- shoot cuttings) were lower than those of bare-root seedlings when raised in small ridge ditches. The cost efficiency (yield index + planting cost) of bare-root seedlings irrespective of soil working techniques was markedly higher than that of direct seeded stock, whereas bare-root seedlings and stumps performed equally well in respect of cost efficiency. The cost efficiency irrespective of soil working technique and planting stock was markedly higher after five years than after the first year.

Key words: Soil working techniques - planting methods - bare-root seedlings - stumps - direct seeded stock - performance - trenches - ditches - gradonies

BHARDWAJ, D. R., GUPTA, N. K. & BHARDWAJ, S. D. 2000. Kesan teknik kerja tanah dan jenis stok terhadap prestasi pemulihan *Celtis australis* di barat laut Himalaya. *Celtis australis*, spesies pokok agro perhutanan asli yang penting dari barat laut Himalaya, dinilai bagi tindak balas kemandirian dan prestasi kuantitatif dalam kaitannya dengan pelbagai teknik kerja tanah dan kaedah penanaman di cerum bukit yang kering. Teknik kerja tanah dan teknik penanaman yang berbeza mempengaruhi dengan bererti kemandirian, ketinggian, garis pusat kolar, biojisim atas tanah, biojisim akar, torehan dan jumlah panjang akar. Penanaman di dalam parit, longkang dan teres kontur curam ke dalam didapati lebih baik daripada penanaman lubang secara konvensional. Penanaman anak benih akar terdedah menandingi stok biji benih terus, dengan anak benih akar terdedah dan tunggul (keratan akar-pucuk) yang ditanam pada musim sejuk menunjukkan prestasi yang sama baik. Kos untuk penubuhan setiap pokok pada satu tahun adalah lebih rendah bagi anak benih akar terdedah berbanding dengan stok biji benih terus. Kos penubuhan tunggul (keratan akar-pucuk) adalah lebih rendah berbanding dengan stok anak benih terus apabila ditanam di parit batas kecil. Keberkesanan kos (indeks hasil + kos penanaman) bagi anak benih akar terdedah tanpa mengambil kira teknik kerja tanah adalah jelas lebih tinggi daripada stok biji benih terus, manakala anak benih akar terdedah dan tunggul menunjukkan prestasi yang sama baik dari segi keberkesanan kos. Keberkesanan kos tidak mengambil kira teknik kerja tanah dalam stok penanaman adalah jelas lebih tinggi selepas lima tahun berbanding dengan selepas satu tahun.

Introduction

With the ever-increasing demand on forests to supply domestic and industrial goods and services in northwestern Himalaya, the amelioration and afforestation of drier hill slopes have assumed regional and national significance. The biomass-based economy of northwestern India's rural population necessitates restoration of forest cover on hill slopes not used for intensive agriculture in order to provide fodder, fuelwood and small timber needs. However, on these sites, the establishment and growth of forest trees are limited by poor soil depth and lack of moisture due to high rainfall runoff. Large scale afforestation, which was earlier carried out on these sites with conventional plantation technology, suffered from heavy mortality. Intensive soil working, coupled with moisture conservation techniques, provides an answer to these constraints towards successful establishment and subsequent performance of useful broad-leaved tree species. Outplanting of bare-root seedlings tends to be more successful than direct seeding for establishing forest trees, though it tends to be expensive, time consuming and demanding of skilled labour. Nonetheless, direct seeding may still have a role in dryland afforestation because of its time, cost and simplicity advantages, and importantly because disturbance of seedling roots during outplanting is avoided (Westveld & Peck 1951, Suri & Seth 1959).

Celtis australis Linn. is an important indigenous agroforestry tree species of mid-hill eco-system of the northwestern Himalayas. It can withstand a moderate amount of shade and is not very exacting of soil, growing both on mesic and on dry rocky ground, but in the latter case it becomes stunted. It is frequently cultivated around villages and lopped for fodder. Its foliage is highly palatable and nutritious to stock (Singh 1982) and its fuelwood and small timber qualities are good. The principal concern of the present study was to work out an appropriate soil working technique and to compare the survival and growth performance and economic efficacy of using bare-root seedlings versus direct seeded stock/seedling stumps.

Material and methods

Geographic location, climate and soil of the experimental sites

The study was carried out at the experimental farm of the Department of Silviculture and Agroforestry, Dr Yashwant Singh Parmar University of Horticulture and Forestry, Solan, India (30° 50 'N, 76° 11' E; 1200 m above mean sea-level).

The climate is transitional between subtropical and subtemperate, with mean annual rainfall of 1150 mm, most of which is concentrated during the monsoons (July and August). Summers are moderately hot during April to June, and winters severe during December and January. Frost occurrence is almost a daily feature during winter.

The study was conducted in two separate experiments and the sites for these experiments were located within the same locality. The average slope of experiment 1 site is 55% and that of experiment 2 is 30%. The sites of both the experiments are natural grasslands inhabited by isolated trees and shrubs. The tree species were *Acacia catechu, Albizia stipulata, Bombax ceiba, Celtis australis, Pitasia integrimma,* etc. The shrub species prevailing in the area were *Berberis lycium, Carissa opaca, Prunus padus, Rubus elipticus, Zizyphus jujuba,* etc. Prior to laying out of experiments, the shrub species were clear cut and removed from the sites, whereas in the case of tree species only the lower branches were removed in order to minimise the shading effect. In general, both sites had a poor soil depth (10–20 cm) underlain with loose rocky material. Further details of the edaphic environment are summarised in Table 1a.

Table 1a. Soil properties of the sites in experiments 1 and 2

Soil characteristic	Experiment 1	Experiment 2	Assessment technique
Texture	Clay loam	Clay loam	International pipette method (Piper 1966)
pH	7.4	7.2	1:2.5 soil water suspension glass electrode method (Jackson 1967)
Organic carbon (%)	2.3	2.1	Walkley and Black's rapid titration method (Piper 1966)
Available nitrogen (kg ha^{-1})	256	221	Alkaline potassium permanganate method (Subbiah & Asija 1956)
Available phosphorus (kg ha^{-1})	13	10	Olsen's method (Olsen *et al.* 1954)
Available potassium (kg ha^{-1})	232	379	Ammonium acetate method using a flame photometer (Jackson 1967)

Experimental design and plot adjustment

Experiment 1 was conducted to compare survival, growth performance and economic efficacy of planting *C. australis* direct seeded stock and bare-root seedlings under eight soil working techniques. Experiment 2 was conducted to compare survival, growth performance and economic efficacy of planting seedling stumps and bare-root seedlings under three soil working techniques. This experiment was in slight variation to experiment 1 as in this we tested the seedling stumps with bare-root seedlings instead of direct seeded stock.

Experiment 1

Experiment 1 had 16 treatment combinations—8 soil working techniques (Table 1b, Figure 1) (main plots) and 2 planting stocks (sub-plots). Treatments were replicated three times in a split plot design. The plot size was 48 m^2 with 16 plants planted at a spacing of 1.5 × 2.0 m. Plots were laid out at a distance of 3 m each.

Table 1b. Experiment 1 treatment combinations for main plots

Treatment Soil working technique	Dimensions	Soil working intensity plant^{-1} (m^3)
WM1 - Fully filled pits	45 × 45 × 45 cm	0.091
WM2 - 3/4 filled pits	45 × 45 × 45 cm	0.068
WM3 - 1/2 filled pits	45 × 45 × 45 cm	0.045
WM4 - Small ridge ditches	1.95 m × 45 cm × 30 cm	0.132
WM5 - Half slanting trenches	1.95 m × 45 cm × 30 cm	0.133
WM6 - Slanting ridge ditches	1.95 m × 45 cm × 30 cm	0.137
WM7 - Deep filled shelfed trenches	1.95 m × 45 cm × 30 cm	0.117
WM8 - Inward sloping contour terraces (gradonies)	12 m × 60 cm × 30 cm	0.112

Each replication was laid across the slope along contour lines and treatments were staggered so as to trap runoff. Soil working was started from the top and progressively extended down the slope. Boulders and gravels from excavation work were stacked on the lower side of the ditches, trenches and inward sloping contour terraces (gradonies) to serve as the toe to the spoil-bank. Fully filled pits (WM1) measuring 45 × 45 × 45 cm in size were treated as the standard control, as these types of pits are routinely used for plantation.

The two planting stock treatments were 6-month-old bare-root seedlings, (22–25 cm height and 0.3 cm mean collar diameter) and viable seeds (soaked in water for 48 h after depulping). These were hand planted/sown in the first week of August 1989. Four seeds were sown at each seed spot and germination was complete within one month. At each seed spot a single seedling with good growth potential was retained after two months of germination.

Experiment 2

Experiment 2 had 6 treatment combinations—3 soil working techniques (main plots) (Table 1c, Figure 1) and 2 planting stocks (sub-plots). Treatments were replicated three times in a split plot design. The plot size was 64 m^2 and had 16 plants at a spacing of 2.0 × 2.0 m. Plots were laid out at a distance of 3 m.

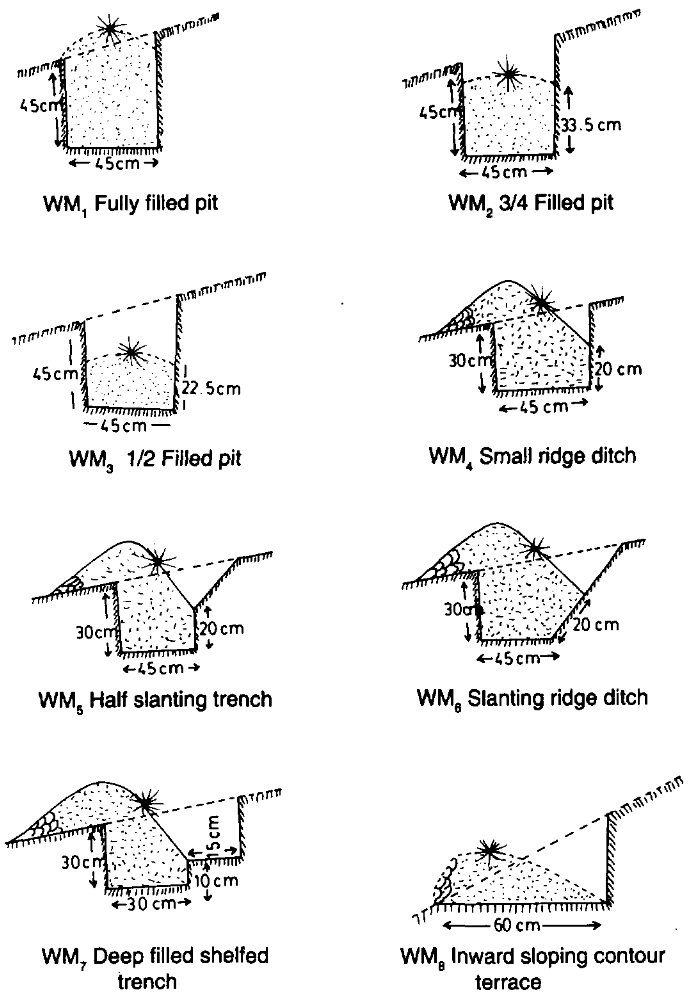

Figure 1. Soil working techniques (diagrammatic)
* The point where the seed/seedling was planted.

Table 1c. Experiment 2 treatment combinations for main plots

Treatment Soil working technique	Dimensions	Soil working intensity plant^{-1} (m^3)
WM1 - Fully filled pits	45 x 45 x 45 cm	0.091
WM2 - Small ridge ditches	3 m x 45 cm x 30 cm	0.202
WM3 - Inward sloping contour terraces (gradonies)	28 m x 60 cm x 30 cm	0.180

Ten-month-old bare-root seedlings of uniform height, and stumps (root-shoot cuttings) having 20 cm root and 2.5 cm shoot were hand-planted in the last week of January 1990.

Plant studies

Data on plant survival and growth characters were recorded at the end of the 1st and 5th years of growth. Four plants of each treatment were randomly selected for above- and below-ground biomass assessment at the end of the 1st year. Roots were exposed using the method of Bohm (1979). The biomass samples were first air and then oven dried at 60 °C until they attained constant weight. The length of tap roots was measured by tape, while the lengths of the tertiary roots and root hairs were measured using a Comair root lengths scanner (Bohm 1979). Shoot-root length ratio was calculated by dividing the main shoot length by the tap root length of the same plant. Increments in relevant growth characters were calculated by substracting the initial value, and used for statistical analysis.

Economic studies

For this study an average cost of a 'Farmer Nursery' was adopted for various types of planting stock. A twenty per cent margin in planting stock was added to allow for casualties before planting. For other items actual costs incurred were used. The planting cost under various treatments was based on planting density of 3333 and 2500 plants ha^{-1} in experiments 1 and 2 respectively. The cost per plant at the end of the 1st year of growth was calculated on the basis of survival percentage in the relevant treatment. While calculating the cost per plant, the costs of land, maintenance, watch and ward, etc. were ignored.

For a given treatment, compounded planting cost (*Ct.* in Indian rupees) was calculated for 1st and 5th years of study as :

$$Ct = Cx\ (1 + i)^t$$

where, C is the per hectare planting cost of a given treatment and i is a hypothetical interest rate (13%) and t stands for number of years.

Seedling ground-line diameter (nearest cm) and height (nearest cm) were measured at the end of the 1st and 5th years of growing seasons. For a given treatment, an index of wood yield (Yt, $cm^3\ ha^{-1}$ of stem volume) was calculated for the 1st and 5th years of the study by multiplying a expansion factor (number of seedlings/ha + 16 seedlings/ replicate) by the sum of stem volumes (based on the formula for parabolic cone) of surviving seedlings per replicate:

$$Yt = \frac{\text{No. of seedlings ha}^{-1}}{16} \times \sum_{i=1}^{16} \Pi(1/2 \times ct/10)^2\ (ht/10 \times 1/2)$$

where ct and ht are the ground-line diameter (cm) and height (cm) respectively of an individual seedling in year t. Yield index integrates the separate responses to treatment of seedling survival, diameter and height.

For a given treatment, cost efficiency (*Et*, cm^3/Rs, Barnett & Baker 1991) was calculated for the 1st and 5th years of study using yield index and compounded planting cost as

$$Et = \frac{Yt}{Ct}$$

The treatment having the highest value of *Et* would be considered the most cost efficient.

Results and discussion

Effect of soil working techniques

Celtis australis survival at age one was improved by using trenches, ditches and gradonies compared to conventional pit planting techniques (Table 2a). The experimental results support the findings of Arora (1986) and Yadav *et al.* (1987), who reported that trenches and gradonies, which conserve moisture *in situ*, improve survival in comparison to conventional pit planting methods.

Irrespective of planting stock, different types of trench, ditch and gradoni in experiment 1 and of ditch and gradoni in experiment 2 produced significantly ($p \leq 0.05$) higher plant height, collar diameter and above-ground biomass compared to fully filled pits (Tables 2a and 3a). This was due to more root rejuvenation, measured in terms of root dry weight, and tap and total root lengths (Tables 2b and 3b). Better root development in these devices was presumably due to either one or a combination of high soil working and improved water conservation (Bhardwaj 1991). Both would increase the soil volume colonised by roots thereby increasing the potential for plant water and nutrient uptake (Gardner 1960, Pradhan & Dayal 1973). Other factors that may underpin the improved performance in ditches and trenches include the potential for sheltering resulting in reduced evapo-transpiration and radiation incidence and the potential for increased entrapment of litter resulting in soil chemical and physical improvements.

The survival and increment in growth characters in the three different types of pit in experiment 1 were not significantly different at the end of the 1st year of growth. However, in the different types of trench and ditch used in experiment 1, half slanting trenches (WM5) and slanting ridge ditches (WM6) supported better plant growth than either small ridge ditches (WM4) or deep filled shelfed trenches (WM7), due to their higher soil working intensity. *Celtis australis*, being a mesophytic species (Singh 1982), responded favourably to higher soil working intensity and moisture availability (Bhardwaj 1991). In experiment 2, plants in the small ridge ditches recorded 12, 50, 152, 99, 85 and 79 per cent higher values of plant survival, height, total above-ground biomass, root weight, tap root and total root lengths over fully filled pits respectively. The growth performance of the species in small ridge ditches was also superior to that in gradonies.

Table 2a. Survival and growth characters of *Celtis australis* as affected by soil working techniques, planting stock and their interactions after the 1st year in experiment 1

Treatment	Survival (%)			Plant height (cm)			Plant collar diameter (cm)			Total above-ground DM[c] (g/plant)		
	PS^b_1	PS_2	Mean	PS_1	PS_2	mean	PS_1	PS_2	mean	PS_1	PS_2	mean
WM[a]1	66 (83)	31 (27)	49 (55)	54	30	42	0.54	0.38	0.46	10.4	4.1	7.2
WM2	61 (77)	33 (29)	47 (53)	55	32	44	0.65	0.38	0.51	10.5	3.9	7.3
WM3	60 (75)	34 (31)	47 (53)	55	33	44	0.48	0.32	0.40	12.8	6.0	9.4
WM4	65 (82)	33 (29)	49 (56)	63	41	52	0.72	0.42	0.57	25.8	7.0	16.4
WM5	71 (90)	27 (21)	49 (55)	87	40	64	0.69	0.40	0.54	30.5	9.2	19.9
WM6	67 (85)	33 (29)	50 (57)	72	44	58	0.67	0.40	0.53	27.8	7.6	17.7
WM7	63 (79)	35 (33)	49 (56)	65	45	55	0.62	0.40	0.51	23.9	7.4	15.7
WM8	68 (85)	34 (31)	51 (50)	59	36	47	0.63	0.32	0.47	15.4	6.2	10.8
Mean	65 (82)	36 (27)		64	38		0.63	0.38		19.7	6.4	
SE[d]± WM			2.4			4.0			0.036			1.34
CD[e] at 5%			ns			8.5			0.077			2.85
SE ± PS			2.4			2.0			0.013			0.57
CD at 5%			5.0			4.2			0.027			1.22
SE ± WM x PS			4.2			6.3			0.044			1.36
CD at 5%			ns			ns			0.093			2.90

Arc-sine or angular transformation is used for analysing survival percentage. Figures in parentheses are original values. a = soil working method, b = planting method, c = dry matter, d = standard error difference, e = critical difference, PS_1 = bare-root seedlings, PS_2 = direct seeded stock, ns = not significant.

The above-ground biomass production per unit of root biomass for different types of ditch and trench was significantly higher than for conventional fully-filled pits–confirming the finding of Carlowitz and Wolf (1991). Shoot–root ratio was significantly lower in the plants grown in the trenches and ditches compared to those grown in the conventional pits. A lower shoot–root ratio imbues the plant with an inherent capability to survive on moisture stressed sites (Goor & Barney 1976).

The survival percentage as well as plant height and collar diameter growth was significantly influenced by soil working techniques in both experiments at the end of the 5th year of growth (Tables 4 & 5). In experiment 1, the plant height and collar diameter increments were markedly superior in half slanting trenches (WM5) and slanting ridge ditches (WM6) compared to other soil working techniques (Table 4), whereas in experiment 2 ridge ditches (WM2) and inward sloping contour terraces (WM3) outperformed the conventional pits (WM1) in respect of the recorded parameters (Table 5).

Table 2b. Root associated characters of *C. australis* as affected by soil working techniques, planting stock and their interactions after the 1st year in experiment 1

	Root DM (g/plant)			Tap root length (cm)			Total root length (cm)			Shoot–root ratio			Above- and below-ground DM ratio		
Treatment	PS_1	PS_2	mean	PS_1	PS_2	mean	PS_1	PS_2	mean	PS_1	PS_2	mean	PS_1	PS_2	mean
WM1	11.6	2.9	7.3	39	33	36	2205	1036	1620	1.40	0.92	1.16	0.89	1.39	1.14
WM2	14.4	3.4	8.9	43	33	38	2057	848	1452	1.29	0.96	1.13	0.73	1.14	0.94
WM3	14.0	3.2	8.6	43	35	39	1913	926	1419	1.28	0.95	1.12	1.91	1.85	1.38
WM4	22.6	5.3	14.0	56	40	48	3684	1751	2717	1.13	1.03	1.08	1.14	1.31	1.23
WM5	23.2	5.5	12.8	68	46	57	4017	1931	2974	1.27	0.86	1.06	1.31	1.68	1.49
WM6	21.9	3.8	12.8	57	47	52	4757	1498	3122	1.26	0.93	1.09	1.27	2.03	1.65
WM7	22.4	4.6	13.5	56	44	50	3498	1474	2486	1.15	1.01	1.08	1.06	1.61	1.33
WM8	13.4	3.8	8.8	53	43	48	2363	1390	1876	1.20	0.83	0.98	1.13	1.59	1.36
Mean	18.0	4.1		52	40		3061	1355		1.23	0.93		1.06	1.57	
SE ± WM			1.93			4.3			302			0.056			0.018
CD at 5%			4.10			9.2			436			0.120			0.038
SE ± PS			0.83			2.0			97			0.009			0.042
CD at 5%			1.76			4.3			062			0.020			0.090
SE ± WM x PS			2.54			5.6			583			0.056			0.018
CD at 5%			5.41			ns			637			0.120			0.038

Abbreviations as in Table 2a.

Table 3a. Survival and growth characters of *C. australis* as affected by soil working techniques, planting stock and their interactions after the 1st year in experiment 2

	Survival (%)			Plant height (cm)			Plant collar diameter (cm)			Total above-ground DM[c] (g/plant)		
Treatment	PS^b_1	PS_2	Mean	PS_1	PS_2	mean	PS_1	PS_2	mean	PS_1	PS_2	mean
WM[a]1	89	78	84	58	48	53	1.41	1.59	1.50	19.8	21.0	20.4
WM2	91	100	94	84	75	80	1.47	1.38	1.43	58.2	44.5	51.3
WM3	96	89	93	63	53	58	1.41	1.35	1.38	21.0	27.0	24.0
Mean	92	89		68	59		1.43	1.44		33.0	30.8	
SE[d]± WM			2.3			3.0			0.01			2.3
CD[e] at 5%			6.3			8.2			0.03			6.2
SE ± PS			4.5			4.9			0.01			1.8
CD at 5%			ns			ns			ns			ns
SE ± WM x PS			3.2			3.1			0.01			1.9
CD at 5%			7.8			7.7			0.02			4.6

PS_1 - bare-root seedlings, PS_2 - stumps. Other abbreviations as in Table 2a.

Effect of planting stock

In experiment 1, rainy season outplanting of bare-root seedlings resulted in superior survival and growth at both one and five years of age than direct seeding (Tables 2a & b). These findings are consistent with those of Singh (1972) who observed that germinating tree seeds were particularly vulnerable to periodic droughting that frequently occurs on drier slopes in northwestern Himalaya.

In experiment 2, both bare-root seedlings and stumps performed equally well in terms of survival and growth (Tables 3a & b). The reason for their good performance can be attributed to the seedling dormancy for nearly two months after planting out, which enables root systems to establish firm contact with the soil before commencement of growth in spring. Other broad-leaved species in which stump planting has resulted in good survival under semi-arid conditions include *Acacia nilotica, Albizia lebbeck, Gmelina arborea, Azadirachta indica, Dalbergia sissoo* and *Prosopis chinensis* (Jha & Choudhary 1990).

Table 3b. Root associated characters of *C. australis* as affected by soil working techniques, planting stock and their interactions after the 1st year in experiment 2

	Root DM (g/plant)			Tap root length (cm)			Total root length (cm)			Shoot–root ratio			Above- and below-ground DM ratio		
Treatment	PS_1	PS_2	mean	PS_1	PS_2	mean	PS_1	PS_2	mean	PS_1	PS_2	mean	PS_1	PS_2	mean
WM1	22.8	26.0	24.4	42.3	55.0	48.9	7100	6800	6950	1.36	0.86	1.11	0.86	0.80	0.83
WM2	52.9	49.1	48.5	115.6	102.5	109.0	12825	12020	12422	0.72	0.73	0.72	1.09	1.01	1.04
WM3	29.2	27.2	98.2	65.0	77.5	71.3	8470	7860	8165	0.97	0.68	0.82	0.72	0.98	0.85
Mean	35.0	32.2		74.3	78.5		9465	8893		1.01	0.75		0.89	0.93	
SE ± WM			1.5			5.3			57			0.02			0.035
CD at 5%			4.2			14.6			159			0.06			0.070
SE ± PS			1.7			3.4			74			0.04			0.022
CD at 5%			ns			ns			180			ns			ns
SE ± WM x PS			1.7			4.1			78			0.31			0.027
CD at 5%			4.2			10.1			191			0.76			0.066

Abbreviations as in Table 3a.

Table 4. Survival, plant height and plant collar diameter of *C. australis* as affected by soil working techniques, planting stock and their interactions after 5 years of growth in experiment 1

Treatment	Survival (%)			Plant height (cm)			Plant collar diameter (cm)		
	PS^b_1	PS_2	Mean	PS_1	PS_2	mean	PS_1	PS_2	mean
WM[a]1	66 (79)	31 (19)	49 (49)	224	108	167	3.39	2.43	2.91
WM2	61 (77)	29 (24)	45 (50)	210	113	161	3.80	2.64	3.22
WM3	60 (75)	32 (29)	46 (52)	226	120	173	3.16	2.00	2.58
WM4	65 (82)	25 (18)	45 (50)	248	131	190	4.10	2.28	3.19
WM5	67 (85)	30 (25)	48 (55)	322	148	235	4.08	2.50	3.29
WM6	67 (85)	34 (32)	50 (59)	275	150	213	3.91	2.76	3.33
WM7	63 (79)	38 (38)	50 (59)	255	147	201	3.70	2.28	2.99
WM8	83 (79)	38 (38)	50 (59)	241	127	184	3.18	2.13	2.65
Mean	64 (80)	32 (28)		250	130		3.74	2.32	
SE[d] ± WM			1.6			18.8			0.23
CD[e] at 5%			3.5			40.0			0.50
SE ± PS			12.8			4.3			1.24
CD at 5%			27.3			9.3			2.65
SE ± WM x PS			5.2			15.8			0.82
CD at 5%			ns			33.5			1.73

Abbreviations as in Table 2a.

Interaction effects

The ANOVA revealed that significant interactions ($p \leq 0.05$) existed between soil working methods and stock types for collar diameter growth, total above-ground and root dry matter, total root length and shoot:root ratios. In general, there were more significant differences between treatments for seedlings than for direct seeded plants, indicating that seedlings were more responsive to the soil working conditions. In experiment 2, after the 1st year all variables measured showed a significant interaction at $p \leq 0.05$. For example, with survival the interaction is a result of the low survival of the stump plants in WM1. In contrast, for collar diameter the stump growth was greatest in WM1, but for the seedlings WM2 was the best treatment (Table 3a). At the end of five years of growth, maximum height increment (322 cm) in experiment 1 (Table 4) was recorded in the plants of nursery origin growing under the soil working method of half slanting trenches (WM5), which differed significantly from all other treatment combinations. In experiment 2 (Table 5) maximum survival (88%) and height (389 cm) values were recorded in the stumps planted in small ridge ditches (WM2). However, the maximum plant collar diameter was recorded in the treatment combination for bare-root seedlings in WM2.

Table 5. Survival, plant height and root collar diameter of *C. australis* as affected by soil soil working techniques, planting stock and their interactions after 5 years of growth in experiment 2

	Survival (%)			Plant height (cm)			Plant collar diameter (cm)		
Treatment	PS^b_1	PS_2	Mean	PS_1	PS_2	mean	PS_1	PS_2	mean
WM^a1	62	60	61	132	128	136	2.34	2.26	2.30
WM2	84	88	86	385	389	387	2.63	2.51	2.57
WM3	82	86	84	360	371	366	2.58	2.49	2.53
Mean	76	78		292	296		2.51	2.42	
SE^d± WM			3.3			5.5			0.16
CD^e at 5%			9.2			15.2			0.28
SE ± PS			4.1			3.2			0.01
CD at 5%			ns			ns			ns
SE ± WM x PS			3.2			3.1			0.01
CD at 5%			7.8			7.6			0.02

Abbreviations as in Table 3a.

Planting cost

Initial planting cost per plant of bare-root seedlings was much higher than that of direct seeded stock (Table 6) due to additional expenditure involved in raising and transporting the seedlings to the planting sites. Initial planting cost per plant in different types of trenches, ditches and gradonies in general was higher than in various types of pits. This is due to higher soil working intensity involved in their preparation. Plants originating through seeds sown *in situ* registered low survival per cent, thereby inflating the cost at the end of the 1st year. In contrast, bare-root seedlings had only marginal increase in cost over their initial costs per plant because of high survival rates.

Initial planting cost per plant of bare-root seedlings of *C. australis* in experiment 2 was higher than that of stumps due to additional transportation costs incurred. At the end of the 1st year of planting, it was noticed that the cost per plant of both bare-root seedlings as well as of stumps was found to be lowest and highest in fully filled pits (WM1) and small ridge ditches (WM2) respectively (Table 7). Establishment cost per plant of bare-root seedlings and stumps raised under small ridge ditches (WM2) was 70 and 40% higher over that for fully filled pits (WM1) respectively. This means that the establishment of stumps is cheaper than that of bare-root seedlings raised under small ridge ditches.

Table 6. Planting costs (Indian rupees) of *C. australis* in experiment 1 (planting density 3333 plants ha^{-1})

	Soil working technique							
	WM1	WM2	WM3	WM4	WM5	WM6	WM7	WM8
A) Bare-root seedlings								
Total cost	9982	9755	9589	14591	15757	16391	14174	11589
Cost/plant	2.98	2.92	2.87	4.38	4.72	4.91	4.25	3.47
Survival (%)	83.33	77.08	75.00	83.50	89.50	85.33	79.16	85.41
Cost/plant after 1 year	3.57	3.79	3.83	5.29	5.28	5.76	5.38	4.07
Et after 1st year	1.51	2.12	1.15	2.15	2.74	1.94	1.61	1.99
Et after 5 years	144.73	170.04	125.39	166.43	205.41	154.88	138.22	118.02
B) Direct seeded stocks								
Total cost	5039	4872	4706	9708	16874	11508	9291	6706
Cost/plant	1.51	1.46	1.41	2.91	3.26	3.95	2.78	2.01
Survival (%)	27.08	29.08	31.25	29.16	20.83	29.16	33.33	31.25
Cost/plant after 1 year	5.58	5.39	4.51	9.98	15.66	11.84	8.36	6.43
Et after 1st year	0.26	0.31	0.25	0.25	0.92	0.20	0.29	0.19
Et after 5 years	17.08	27.56	21.01	8.97	9.73	22.57	22.20	23.19

Et = cost efficiency.

Table 7. Planting costs (Indian rupees) of *C. australis* in experiment 2 (planting density of 2500 plants ha^{-1})

	Soil working method		
	WM1	WM2	WM3
A) Bare-root seedlings			
Total cost	7790	13540	10915
Cost /plant	3.11	5.41	4.36
Survival (%)	89.28	91.23	96.41
Cost/plant after 1 year	3.49	5.93	4.52
Et after 1st year	15.25	14.13	12.76
Et after 5 years	40.86	117.36	127.89
B) Stumps			
Total cost	7430	13180	10555
Cost/plant	2.97	5.27	4.22
Survival (%)	78.57	100.00	89.28
Cost/plant after 1 year	3.78	5.27	4.72
Et after 1st year	14.75	12.55	9.43
Et after 5 years	37.50	116.24	133.14

Et = cost efficiency.

The first and fifth year cost efficiency (yield index + planting cost) in experiment 1 of bare-root seedlings was over five times higher than the values for direct seeded stocks (Table 6). The cost efficiency of bare-root seedlings at the end of the 1st year in all soil working techniques except in half filled pits

(WM3) was markedly higher than in conventional pit planting technique (WM1). But at the end of the 5th year of growth only small ridge ditches (WM4), half slanting trenches (WM5), slanting ridge ditches (WM6) and 3/4 filled pits (WM2) were found to be more cost efficient than fully filled pits (WM1). Amongst the three different types of pit, 3/4 filled pits (WM2) were found to be more cost efficient than WM1 and WM3 both after the first and 5th years of growth.

In experiment 2 cost efficiency of bare-root seedlings as well as of stumps at the end of the 1st year was higher in fully filled pits (WM1) as compared to small ridge ditches (WM2) and gradonies (WM3). But at the end of 5 y, plants under small ridge ditches (WM2) and inward sloping contour terraces (WM3) were found to be over three times more cost efficient than in fully filled pits (WM1). The cost efficiency of bare-root seedlings as well as of stumps was markedly higher after the 5th year in comparison to the 1st year growth under all soil working techniques.

Conclusion

These two trials on *C. australis* showed that small ridge ditches, half slanting trenches, slanting ridge ditches and deep filled shelfed trenches techniques are superior to conventional pit planting methods for the drier hill slope soils of northwestern Himalaya. They are particularly appropriate in dry sites that experience marked long dry periods. Both bare-root seedlings as well as stumps (root-shoot cuttings) planting proved superior to direct seeded stock for survival and growth, as well as being economically advantageous.

The establishment cost of bare-root seedlings was comparable to that of stumps. The establishment cost per plant in soil working methods involving higher disturbance was greater than for conventional pit planting techniques. This expense, however, is justifiable due to the enhanced establishment performance.

The results presented here cover only one species; however, the fact that the species is more or less mesic in nature suggests that trial results are also applicable to a wide range of species. Field trials with other broad-leaved tree species are in progress to verify the findings of the study described in this paper.

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