

Commercial viability of cultivation of an endangered medicinal herb *Nardostachys jatamansi* at three different agroclimatic zones

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Cultivation trial of an important medicinal herb, Nardostachys jatamansi was carried out at three altitudes (low – 1800 m, middle – 2200 m and natural habitat – 3600 m) using vegetative propagules and seedling transplantation methods under different treatments. Economic yield varied with treatment, age of plant at the time of transplantation and altitude of nursery. Economic yield increased with the addition of manure (FYM) in all the treatments and altitudes compared to control. Yield significantly increased under horizontal ridge conditions at 3600 m. Cultivation was found commercially viable at 2200 and 3600 m in most treatments. Due to total mortality, cultivation was not found commercially viable at 1800 m in any of the treatments. Highest profit was shown by both vegetatively grown as well as seedling-transplanted crop at 3600 m in polyhouse condition. Profit was almost similar in both vegetatively as well as seedling-raised crop at 2200 m.

Keywords: Agroclimatic zone, cultivation, *Nardostachys jatamansi*, profit, yield.

NARDOSTACHYS jatamansi DC., commonly known as Jatamansi, Indian Nard, Balchar or Spikenard, is a small herbaceous species of family Valerianaceae. It is a perennial, dwarf, hairy, rhizomatous herb forming a group of thick roots covered with fibres. The plant mostly grows randomly in steep areas, moist, rocky, undisturbed grassy slopes or on stones with coarse sandy loam soil, with 40–70° slope between 3000 and 5000 masl (Figure 1 a).

Jatamansi has a long history of use as ethnomedicine, perfume, incense and in modern medicine industry. The plant valued for its antispasmodic and stimulant properties, is useful in the treatment of heart palpitations, constipation, urination, menstruation and digestion¹. The dried rhizomes are steam-distilled to yield up to 1.9% of a pale yellow essential oil (Spikenard oil) with a pleasant odour.

Rhizomes and roots are used as cardiac tonic, tranquilizer, antiseptic, laxative, stomachic, for curing wound, insomnia, hysteria, neuralgia, convulsion, vertigo, chronic skin disease, kidney stone, nervous headache, seminal disability, low and high blood pressure, snake and scorpion sting, epilepsy, leprosy, bronchitis, jaundice, carminative, gastric, respiratory troubles and promoting mental awareness. It is also used as an insect repellent², promotes blackness and growth of hairs and is used in a native drug 'Sataushadhi'³. The species is used as a substitute for Valerian

and the extract used in more than 26 Ayurvedic formulations. Under the name of 'Asaroon', the plant is used in nine herbal preparations according to *Hamdard Pharmacopoeia*, for treatment of hemiplegia, Bell's palsy, Parkinson's syndrome, tumours, indigestion and deafness due to age.

Reports suggest that the species has become endangered due to over-exploitation of rhizomes for its medicinal value, habitat degradation and other biotic interferences in its distribution ranges. In Northwest Himalaya, *N. jatamansi* has been reported as endangered⁴⁻⁶. Realizing the high level of threat, CITES has notified *N. jatamansi* in its schedule for ensuring conservation. In view of this, urgent need was felt to propagate and multiply the species via planned and protected cultivation⁶⁻¹⁰. In India, there is a need for 300 metric tons of *N. jatamansi* every year^{11,12}, to meet this requirement, 1000 tons of *N. jatamansi* is imported every year from Nepal¹³. Market survey reveals that demand of high-altitude species, including *N. jatamansi*, is increasing while supply is decreasing regularly¹⁴. Such increased demand can only be met through cultivation. Cultivation will not only meet the demand of market and help in improving the socio-economic status of the local people, but also help in conservation of species in natural habitats. No report of cultivation is available for this species, although considerable information is available on taxonomy, general distribution, uses and phytochemical properties^{5,15-22}. Keeping in view this gap and endangered status of the species, a domestication study was conducted at three agroclimatic zones.

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Material and methods

Studies were conducted at Tungnath-TN (3600 m asl, between 30°14'N lat. and 79°13'E long.), Pothiwas-PW (2200 m asl, between 30°28'N lat. and 79°16'E long.) and Tala (1800 m asl, between 30°31'N lat. and 79°07'E long.) in Rudraprayag district, Garhwal Himalaya, Uttarakhand, India.

Experimental beds of 1 × 1 m area were prepared by digging or ploughing the land three times. All the treatments consisted of three replicates. Beds were raised (10 cm from land surface) to prevent waterlogging during rainy season. Ridges/bunds were made vertically (ridges along the slope) and horizontally (ridges across the slope), prior to plantation, to observe impact of land condition on economic yield of plants, they were termed as vertical (VR) and horizontal ridge (HR) respectively. The beds prepared inside the polyhouse to protect plants from adverse environmental conditions were termed as polyhouse beds (PB). Soil characters of all the three nurseries are presented in Table 1. Manure (FYM) was prepared with a mixture of decomposed cow dung, sheep dung and decomposed leaves (leaf litter) in equal volume, i.e. 1 : 1 : 1 proportion. FYM was spread in experimental beds at the start of each growing season. No manure was added in control beds (control). Two kg manure/bed/yr in manure bed-1 (MB-1) treatments, VR, HR and PB, and four kg manure/bed/yr in manure bed-2 (MB-2) treatments were added. Plants were transplanted during the month of May 2000 with appropriate spacing distance of 20 cm in the above-mentioned beds¹⁴. Thus 250,000 plants are needed for plantation in 1 ha land.

Planting in experimental beds was carried out by two different means, i.e. vegetative and seedling transplantation. For vegetative propagation, rhizomes of *N. jatamansi* were collected from alpine garden, Tungnath and separated in such a way that each rhizome got at least an apical bud. Seedlings were raised by sowing seeds in a mixture of soil : sand and FYM in equal proportion inside polyhouse for experimental purpose. Planting material was culled and equal size planting material was taken and transplanted in experimental beds. All the treatments consisted three replicates of 25 plants each.

Plants for vegetative propagation were transplanted in all the altitudes in control, MB-1, VR, HR and PB treatments. Seedlings were transplanted in the nursery beds (at 60, 90 and 180 days) at three altitudes in control, MB-1 and MB-2, whereas 90-day-old seedlings were transplanted in some other treatments also at PW and TN, i.e. in VR, HR, MB-2 and PB treatments. Cultural practices, i.e. weed removing, irrigation, etc. were performed whenever necessary. Each treatment was examined for economic yield at the end of each growing season.

To observe yield, rhizomes and roots of five plants in each treatment were uprooted at the end of each growing season. These were taken to the laboratory, washed with

running water and dried at 40°C temperature until constant weight, to measure average yield in milligram per plant. Analysis of Variance (ANOVA) was done for variation in yield data among different treatments. ANOVA was followed by the estimation of Fisher's Least Significant (LSD), $P < 0.05$ among mean economic yields²³.

To calculate commercial viability of cultivation total investment on infrastructure development, land preparation, fencing, manure cost, irrigation facilities, harvesting, post-harvesting cost, etc. was calculated during the three-year period and total cost of cultivation was calculated for 1 ha land. Total cost for land preparation and infrastructure development was estimated as Rs 30,000, manure cost as Rs 12,000 (@ Rs 20 per quintal, Rs 4000/yr), harvesting and post-harvesting cost as Rs 4000, labour charge (@ Rs 80/day/labour on the basis of 6, 5 and 3 days per month during first, second and third year respectively) as Rs 13,440 and low cost polyhouse (temporary) as Rs 5000. This value was Rs 64,440 in case of 200 quintal manure/ha/yr and Rs 76,440 for 400 quintal manure/ha/yr calculated for 1 ha land. However, cost of planting material (rhizomes, seed or seedling) is not calculated because no agency is selling such material.

For estimation of projected yield, plant density (250,000) in a hectare land was multiplied with average yield by the end of the third year for each treatment. Yield estimated on the basis of plant survival in different treatments was termed as actual yield. Projected and actual profit was calculated on the basis of yield, multiplied with the present market rate (@ Rs 250/kg) and cost of cultivation during three years was subtracted. All treatments which were found economically viable were presented in tabular form and the rest (where net profit reached negative values) discarded.

Results

The yield varied in each year depending on treatment, age of plants at the time of transplantation and altitude of nursery during different growth seasons. Economic yield increased with the addition of manure in all the treatments compared to control.

Yield of vegetatively propagated plants

In TN (Table 2) yield was minimum (654 mg/plant) under control and maximum (1778 mg/plant) in PB during the first year. During the second year, increase in yield over the first year was recorded 43, 68, 65, 59 and 67% in different treatments. By the end of the third year, yield was minimum (1169.66 mg/plant) in plants of control and maximum (5180 mg/plant) in PB. Variation in yield was noted significant during three years ($F = 6.64$, $P = 0.01$) as well as among different treatments ($F = 8.45$, $P = 0.01$). LSD value (682.40, $P = 0.05$) suggested significant increment

Table 1. Soil pH and nutrient level (on % dry weight basis) in different nurseries

Nursery site	Soil depth (cm)	pH	Organic carbon	Nitrogen	Phosphorus	Potassium
TN	0–10	4.49	3.83	0.16	0.016	0.005
	20–30	4.01	3.91	0.023	0.019	0.0049
	20–30	3.29	4.08	0.03	0.022	0.0053
PW	0–10	4.69	1.042	0.08	0.0203	0.0024
	20–30	5.01	1.002	0.231	0.0680	0.0033
	20–30	4.67	1.238	0.041	0.0073	0.0024
Tala	0–10	5.76	0.319	0.033	0.0176	0.0027
	20–30	6.33	0.691	0.086	0.0178	0.0035
	20–30	6.33	0.622	0.0173	0.0223	0.0036

Table 2. Yield (mg/plant) of plants through vegetative propagation

Treatment	Economic yield (mg/plant) during different years		
	I year	II year	III year
TN			
Control	654 ± 128	941 ± 103	1169.66 ± 111
Manure bed-1	1111 ± 191	1868 ± 317	2105 ± 115
Vertical ridge	1207 ± 98	2001 ± 112	2524 ± 198
Horizontal ridge	1327 ± 77	2114 ± 248	2643 ± 102
Polyhouse bed	1778 ± 300	2976 ± 138	5180 ± 1042
PW			
Control	522 ± 106	946 ± 227	1233 ± 90.70
Manure bed-1	780 ± 203	1530 ± 349	1499 ± 190
Vertical ridge	804 ± 207	1606 ± 212	1905 ± 175
Horizontal ridge	799 ± 173	1681 ± 117	1941.6 ± 219
Polyhouse bed	635 ± 188	725 ± 157	670 ± 101
Tala			
Control	510 ± 07	550 ± 140	–
Manure bed-1	763 ± 162	819 ± 176	–
Vertical ridge	760 ± 106	819 ± 176	–
Horizontal ridge	743 ± 184	800 ± 141	–
Polyhouse bed	395 ± 115	–	–

in yield. In PW (Table 2), yield in control was minimum (522 mg/plant) and maximum (804 mg/plant) in VR treatment by the end of the first year. During the second year minimum increase of 14% under polyhouse and 81–103% under other nursery bed treatments was recorded over the first year. By the end of the third year, yield was minimum (670 mg/plant) in PB and maximum (1941.6 mg/plant) in HR treatment. Variation was found significant for years ($F = 6.50$, $P = 0.01$) as well as for treatments ($F = 13.62$, $P = 0.003$). LSD value (279.20, $P = 0.05$) was significant. In Tala (Table 2), yield was minimum (510 mg/plant) in control and maximum (763 mg/plant) in MB-1 during the first year. During the second year, increase of approximately 7% was recorded in yields in all the treatments over the first year. Plants transplanted in polyhouse died subsequently, whereas plants in other treatments also died by

the end of the second year. All the transplanted plants died by the end of the second year.

Yield of seedling-raised plants

Yield of plants transplanted at seedling stage (Table 3) showed an increase with increase in age. Maximum yield was observed at the end of the third year in all treatments in PW and TN, whereas all the plants died by the end of second year at Tala nursery. In plants transplanted at 60-day-old seedling stage, yield was maximum in PW and minimum in Tala by the end of the first year in control, MB-1 and MB-2 treatments. However, yield had more than twofold increase during the second year over the first year in all treatments. By the end of the third year yield was

Table 3. Yield (mg/plant) of plants raised through seedlings of different age groups

Treatment	I year	II year	III year
Sixty-day-old seedlings in plain beds at different altitudes			
Tala control	18.33 ± 3.21	22.63 ± 2.82	–
Tala manure bed-1	28.33 ± 2.08	49.96 ± 3.69	–
Tala manure bed-2	48.48 ± 3.32	103.0 ± 17.33	–
PW control	28.0 ± 4.35	74.12 ± 12.48	303.0 ± 121.5
PW manure bed-1	46.0 ± 5.56	103.33 ± 18.11	449.0 ± 132.0
PW manure bed-2	63.33 ± 3.33	169.66 ± 33.33	510.66 ± 80.0
TN control	24.12 ± 2.60	48.6 ± 8.12	258.0 ± 58.0
TN manure bed-1	37.66 ± 6.02	78.02 ± 25.2	413.33 ± 72.5
TN manure bed-2	58.0 ± 10.0	120.0 ± 25.0	506.0 ± 185.0
Ninety-day-old seedlings in TN			
Control	39.7 ± 7.64	121.93 ± 13.89	517.0 ± 145.3
Manure bed-1	57.66 ± 8.66	462.66 ± 54.37	1747.0 ± 154.45
Manure bed-2	72.22 ± 12.44	580.4 ± 84.2	2655.66 ± 416.5
Vertical ridge	60.80 ± 8.40	492.88 ± 118.6	1748.33 ± 167.8
Horizontal ridge	64.4 ± 10.06	503.33 ± 133.33	1919.0 ± 130.18
Polyhouse bed	192.56 ± 7.77	1804 ± 79.37	3780.0 ± 150.93
Ninety-day-old seedlings in PW			
Control	58.66 ± 8.65	281.66 ± 28.63	2075.0 ± 277.5
Manure bed-1	109.0 ± 7.81	618.10 ± 80.66	2460.0 ± 235.7
Manure bed-2	124.33 ± 16.44	1973.3 ± 132.3	3306.0 ± 223.3
Vertical ridge	105.33 ± 13.61	589.0 ± 89.3	1734.0 ± 84.67
Horizontal ridge	93.33 ± 23.07	531.11 ± 84.6	1668.33 ± 152.5
Polyhouse bed	53.0 ± 2.64	223.66 ± 12.55	488.0 ± 41.67
Ninety-day-old seedlings in Tala			
Control	57.0 ± 9.84	86.38 ± 18.44	–
Manure bed-1	78.0 ± 5.65	141.66 ± 28.18	–
Manure bed-2	139.3 ± 33.33	592.20 ± 52.2	–
Polyhouse bed	43.5 ± 9.19	50.8 ± 11.8	–
One hundred and eighty-day-old seedlings in plain bed at different altitudes			
Tala control	104.0 ± 20.5	136.44 ± 32.4	–
Tala manure bed-1	153.0 ± 26.88	289.3 ± 43.33	–
Tala manure bed-2	160.3 ± 38.4	600.92 ± 67.33	–
PW control	112.23 ± 20.89	392.0 ± 62.8	1661.33 ± 153.5
PW manure bed-1	145.33 ± 25.18	735.5 ± 92.6	2440.0 ± 165.22
PW manure bed-2	160.8 ± 22.0	740.92 ± 80.6	3304.62 ± 152.0
TN control	60.8 ± 5.04	148.12 ± 22.22	462.0 ± 86.13
TN manure bed-1	126.24 ± 32.6	602.66 ± 54.37	1485.33 ± 257.79
TN manure bed-2	146.24 ± 40.6	736.80 ± 93.33	2697.75 ± 185.0

maximum at PW and minimum at TN in all treatments. Variation was found significant among treatments ($F = 6.77$, $P = 0.01$). LSD value (119.97, $P = 0.05$) suggested significant increment only during the third year in manured beds of PW and TN.

In plants transplanted at 90-day-old seedling stage in PW, yield was minimum in PB and maximum in MB-2 treatment by the end of all years. During the second year, more than fourfold increase was recorded in yield over the first year in all treatments. During the third year, yield increased fourfold in MB-1 and threefold in VR and HR beds over the second year (Figure 1 b). Variation was found significant among treatments ($F = 29.86$, $P = 0.000$). LSD value (457.55, $P = 0.05$) showed significant increase

only in MB-2 treatment during the second year among all the years and treatments. In plants transplanted at 90-day-old seedling stage in TN, yield was minimum in control and maximum in PB treatment by the end of all years, while it was almost similar in all other treatments. However, increase in yield over the previous year was more than three times in control and more than eight times in all other treatments during the second year. Variation was found significant in both for years ($F = 3.31$, $P = 0.03$) as well as treatments ($F = 28.49$, $P = 0.001$). LSD value (469.66, $P = 0.05$) indicated significant increment only in PB during the second year and in all other treatments during the third growth season. In plants transplanted at 90-day-old seedling stage in Tala, yield was minimum in PB and maximum

Table 4. Commercial viability of cultivation using vegetative propagation in different nurseries

Treatment	Projected yield (kg/ha)	Projected value (Rs)	Projected profit (Rs)	Plant density/ha	Actual yield (kg/ha)	Actual value (Rs)	Actual profit (Rs)
TN (3600 m)							
Control	292.42	73,103	8663	224997	263.17	65,793	1,353
Manure bed-1	526.25	1,31,562	67,122	233325	491.15	1,22,787	58,347
Vertical ridge	631.00	1,57,750	93,310	239576	604.69	1,51,171	86,731
Horizontal ridge	660.75	1,65,187	1,00,747	242399	640.66	1,60,165	95,725
Polyhouse bed	1295.0	3,23,750	2,59,310	242400	1255.63	3,13,908	2,49,468
PW (2200 m)							
Manure bed-1	374.75	93,687	29,247	224476	336.64	84,159	19,719
Vertical ridge	476.25	1,19,062	54,622	174152	331.36	82,938	18,498
Horizontal ridge	485.40	1,21,350	56,910	200000	388.32	97,080	32,640

Table 5. Commercial viability of cultivation through seedlings of different age group

Treatment	Projected yield (kg/ha)	Projected value (Rs)	Projected profit (Rs)	Plant density/ha	Actual yield (kg/ha)	Actual value (Rs)	Actual profit (Rs)
Ninety-day-old age group at PW							
Control	518.75	1,29,687	65,247	1,80,000	373.50	93,375	28,935
Manure bed-1	615.00	1,53,750	89,310	1,93,325	475.58	1,18,894	54,454
Manure bed-2	826.50	2,06,625	1,30,185	1,93,324	639.13	1,59,783	83,343
Vertical ridge	433.50	1,08,375	43,935	1,50,000	260.10	65,025	585
Horizontal ridge	417.08	1,04,270	39,830	1,75,001	291.96	32,374	8,549
Ninety-day-old age group at TN							
Manure bed-1	436.75	1,09,187.5	44,747	2,06,651	361.02	90,254	25,814
Manure bed-2	663.92	1,65,978.7	89,538	2,23,327	593.08	1,48,268	71,828
Vertical ridge	437.08	1,09,270.6	44,830	1,80,000	314.70	78,674	14,234
Horizontal ridge	479.75	1,19,937.5	55,497	1,86,649	358.18	89,545	25,105
Polyhouse bed	945.00	2,36,250	1,71,810	2,33,325	881.97	2,20,492	1,56,052
One hundred and eighty-day-old age group at different altitude							
PW control	415.33	1,03,833	39,393	1,86,652	310.09	77,521	13,081
PW manure bed-1	610.00	1,52,500	88,060	1,96,652	479.83	1,19,956	55,516
PW manure bed-2	826.15	2,06,537	1,30,097	1,93,323	638.86	85,406	83,275
TN manure bed-1	371.33	92,833	28,393	2,30,003	341.63	85,406	20,966
TN manure bed-2	674.73	1,68,682	92,242	2,33,324	629.45	1,57,362	80,922

in MB-2 treatment by the end of the first year. During the second year significant increase was shown in MB-1 and MB-2, whereas slow increase was shown in control and PB.

In plants transplanted at 180-day-old seedling stage, yield was maximum in PW and minimum in TN by the end of the first growth season and maximum in PW and minimum at Tala by the end of the second year in all treatments. At the end of the third year, plants grown in PW nursery accumulated more yield compared to TN in all the treatments. Variation was noted significant only among treatments ($F = 12.64$, $P = 0.007$). LSD value (552.07, $P = 0.05$) suggested significant increment only during the third year in manured beds of PW and TN.

Commercial viability of cultivation using vegetative propagation

In TN (Figure 1 c), projected profit was calculated minimum Rs 8663 in control and maximum Rs 100,747 in HR.

However, actual profit was Rs 1353 in control, Rs 58,347 in MB-1, Rs 86,731 in VR and Rs 95,725 in HR. Under polyhouse treatment, projected profit was Rs 259,310 and actual profit Rs 249,468. In PW, projected profit was minimum Rs 12,622 in control and maximum Rs 56,910 in HR. However, actual profit was Rs 19,719 in MB-1, Rs 18,498 in VR and Rs 32,640 in HB. Cultivation in control and PB was not found profitable at PW (Table 4).

Commercial viability of cultivation through seedling transplantation

Commercial viability of plants transplanted (Table 5) with different age groups and treatments showed that seedlings transplanted at 60 days age are not viable at any of the three altitudes, whereas cultivation at Tala is not viable in any of the treatments. In plants transplanted at seedling stage (90-day-old) in TN, projected profit was minimum Rs 44,747 in MB-1 and maximum Rs 89,538 in MB-2.

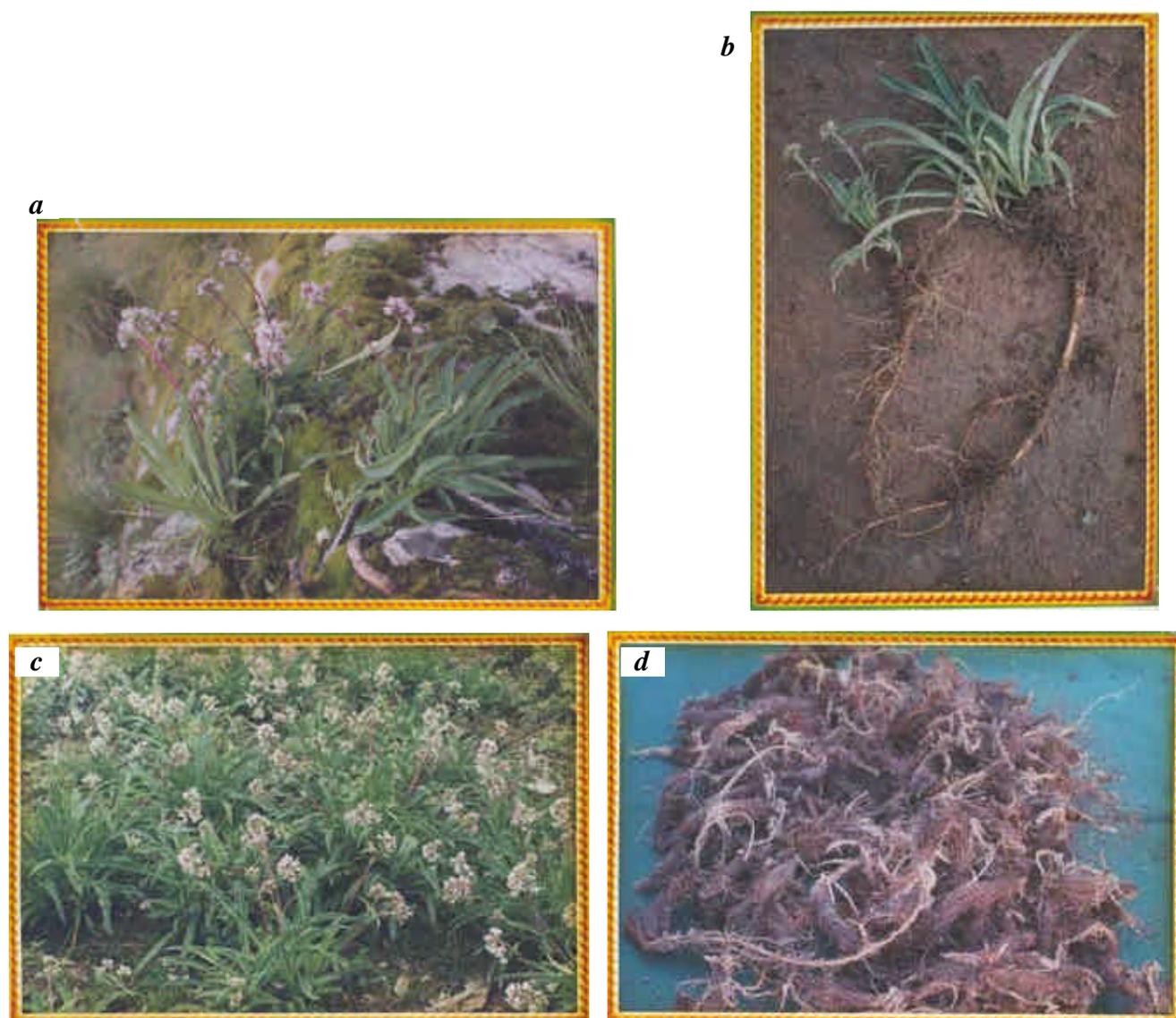


Figure 1. *a*, *Nardostachys jatamansi* flowering in its natural habitat. *b*, Three-year-old uprooted plants of *N. jatamansi* grown through seedlings. *c*, Cultivation of *N. jatamansi* in alpine garden, Tungnath (3600 m asl). *d*, Harvested rhizomes of *N. jatamansi*.

However, actual profit was minimum Rs 14,234 in VR and maximum Rs 71,828 in MB-2. In PB, Rs 171,810 was projected profit and Rs 156,052 was actual profit. In plants transplanted at seedling stage (90-day-old) in PW, projected profit was minimum Rs 39,830 in HR and maximum Rs 130,185 in MB-2 treatment. However, actual profit was minimum Rs 585 in VR and maximum Rs 83,343 in MB-2 treatments. In 180-day-old seedlings transplanted at TN, projected profit was Rs 28,393 in MB-1 and Rs 92,242 in MB-2 treatment, whereas actual profit was Rs 20,966 in MB-1 and Rs 80,922 in MB-2 treatment. In 180-day-old seedlings transplanted at PW nursery, projected profit was Rs 39,393 in control, Rs 88,060 in MB-1 and Rs 130,097 in MB-2 treatment. However, actual profit was Rs 13,081 in control, Rs 55,516 in MB-1 and Rs 83,275 in MB-2 treatment.

Discussion

Increase in yield with addition of manure was due to low mineral nutrients in soil, needed for proper growth and development of plants. Addition of 5–10 tons/ha of FYM has also suggested rectifying nutritional problems of various hill crops and deteriorating physical condition of soil^{24,25}. Addition of FYM increased moisture content of soil, improved its physical, chemical and microbial properties and thereby its productivity. Increased soil fertility increased growth of plants and additional food got stored in underground rhizomes. Several workers^{26–29} have also supported addition of biofertilizer for improvement of soil quality. Under polyhouse, yield was much higher at TN, whereas it decreased at Tala and PW. Such increase in TN could become possible due to increased temperature

and long growth period (early emergence and late senescence). Plants under polyhouse condition sprouted 15 days earlier and senescence was delayed by 15 days compared to nursery-grown plants. Similar results for polyhouse grown plants in *Aconitum* sp. were also recorded earlier³⁰. Temperature is the most important factor in different phenological phases³¹.

Yield increased with age of transplanted seedlings (60–180 days), but yield was almost similar in 90- and 180-day-old seedlings, which clearly indicates that seedlings of < 90 days should not be transplanted to take maximum benefit. The study revealed that yield from seedlings was maximum at middle altitude (PW), which could become possible due to favourable environment, microclimatic condition, long growth period (April to November), increased temperature, etc. Highest economic yield also recorded at middle altitude (2200 m) in *Glycine max* and *Selinum vaginatum*³². Decrease in growth and dry matter accumulation with increasing altitude has earlier been reported in several plant species, e.g. *Artemisia vulgaris*³³ and *Anaphalis* species³⁴.

Yield increased with increase in altitude in vegetatively transplanted plants. Much higher yield at TN might be due to larger root system of plants that could utilize nutritional requirement efficiently (Figure 1 d). However, in control, higher yield at middle altitude was probably due to higher mineral nutrient level in the soil of PW compared to TN. Minimum increase in yield at Tala during the second year over the previous year showed that environmental conditions do not favour growth of *N. jatamansi* at this altitude. This may be due to higher temperature, which increased metabolic activities during dormant phase after the first year compared to higher altitudes. There is no active growth of plants on exposed and frozen Tundra during winter, but even frozen plants must have some metabolic activity³⁵. Yield increased under ridge/bund conditions significantly at TN under HR. This increase may be due to soil condition, water-holding capacity, etc. Ridges prevent waterlogging at higher altitudes which resulted in higher plant survival. However, at lower altitudes, soil moisture become low and the ridges dry earlier compared to plain beds during summer season and decreased plant survival, growth and yield. Higher yield was also recorded in horizontal bunds/ridges³. But at lower altitude, plain beds are useful compared to ridge formation or polyhouse. Levelled ground with litter treatment was also found suitable for cultivation of *P. kurroa* at lower altitude³⁶.

Commercial cultivation was found viable in most of the treatments at TN and PW. In Tala, cultivation was not viable in any of the treatments, which clearly indicates that cultivation below 2200 m asl in Garhwal is not successful for *N. jatamansi*. Variation in projected and actual yield at PW and TN may be reduced up to some limit by filling up practice after seedling mortality. Commercial viability data clearly indicate that vegetative propagation is superior over seedling transplantation at TN, whereas seedling

transplantation is superior at PW in *N. jatamansi* cultivation.

- Jain, S. K., In *Medicinal Plants*, National Book Trust, New Delhi, 1968.
- Subedi, B. and Shretha, R., Plant profile. *Himalayan Bioresour.*, 1999, **3**, 14–15.
- Nautiyal, M. C., Cultivation of medicinal plants and biosphere reserve management in alpine zone. In *Conservation and Management of Biological Resources in Himalaya* (eds Ramakrishna, P. S. et al.), GBPIHED and Oxford & IBH, New Delhi, 1994, pp. 570–582.
- Nayar, M. P. and Sastry, A. R. K., In *Red Data Book of Indian Plants. Vol. II*, Botanical Survey of India, Kolkata, 1998.
- Airi, S., Rawal, R. S., Dhar, U. and Purohit, A. N., Assessment of availability and habitat preference of *Jatamansi* – A critically endangered medicinal plant of west Himalaya. *Curr. Sci.*, 2000, **79**, 1467–1470.
- Nautiyal, B. P., Chauhan, R. S., Vinay Prakash, Purohit, H. and Nautiyal, M. C., Population studies for the evaluation of germ-plasm and threat status of the alpine medicinal herb *Nardostachys jatamansi*. *Plant Genet. Resour. Newsl.*, 2003, **136**, 34–39.
- Nautiyal, M. C., Medicinal plants: A resource for Uttarkhand. In *Uttarakhand Statehood: Dimensions of Development* (eds Sati, M. C. and Sati, S. P.), Indus Pub Co, New Delhi, 2000, pp. 302–312.
- Nautiyal, M. C., Vinay Prakash and Nautiyal, B. P., Cultivation technique of some high altitude medicinal herbs. *Ann. For.*, 2002, **10**, 62–67.
- Dhar, U., Conservation implication of plant endemism in high altitude Himalaya. *Curr. Sci.*, 2002, **82**, 141–148.
- Nautiyal, M. C. and Nautiyal, B. P., In *Agrotechniques for High Altitude Medicinal and Aromatic Plants*, Bishan Singh Mahendra Pal Singh, Dehradun, 2004.
- Ahuja, P. S., In *Medicinal Plants in India: Report and Directory*, Institute of Economic and Market Research, New Delhi, 2003.
- Uniyal, M. R. and Uniyal, R. C., Utilization of medicinal plants by pharmaceutical industries in India. In a paper presented in workshop on ‘Vanaspati van’ VII, Dehradun, 24–25 June 2002.
- Olsen, C. S., CITES appendix II revisited: Is the listing of *N. grandiflora* and *P. kurroa* appropriate? *Med. Plants Conserv.*, 1999, **5**, 8–10.
- Chauhan, R. S., Ecophysiology, agro-technology and trade of an endangered medicinal herb *Nardostachys jatamansi* DC, D Phil thesis, HNB Garhwal University, Srinagar Garhwal, 2004.
- Indrayan, A. K., Shukla, R. K. and Shukla, A., Medicinal plant trade in Dehradun, Saharanpur and Haridwar – A study. *J. MAPs*, 22/4A and 23/1A, 2000.
- Anon., In *The Wealth of India – Raw Material*, Publication and Information, Directorate, CSIR, New Delhi, 1966, vol. 7, pp. 3–4.
- Kirtikar, K. R. and Basu, B. D., In *Indian Medicinal Plants*, Lalit Mohan Basu, Allahabad, 1989, vol. 2, pp. 1307–1309.
- Mathur, J., Somatic embryogenesis from callus cultures of *Nardostachys Jatamansi*. *Plant Cell Tiss. Org. Cult.*, 1993, **33**, 163–169.
- Gargya, G. R., Sharma, A. K. and Vasistha, H. B., Phytosociological analysis of some subalpine and alpine regions of Garhwal Himalaya in relation to *Nardostachys jatamansi*. *Ann. For.*, 1998, **6**, 213–220.
- Samant, S. S. and Pal, M., Diversity and conservation status of medicinal plants in Uttaranchal state. *Indian For.*, 2003, **129**, 1090–1108.
- Prakash, V., In *Indian Valerianaceae*, Scientific Publishers, Jodhpur, 1999.
- Yamaji, S., Komatsu, Y. and Tani, T., Pharmaceutical study on the Tibetan crude drug ‘SPang-spos’ Chinese ‘Gansongxiang’ and

- Ayurvedic 'Jatamansi' derived from the plant of genus *Nardostachys*. *Nat. Med.*, 1999, **53**, 61–71.
23. Snedecor, G. W. and Cochran, W. G., In *Statistical Methods*, Oxford and IBH Publishing Co, New Delhi, 1968, VI edn.
 24. Chauhan, V. S. and Bhatt, J. C., Agriculture in Uttarakhand: From subsistence towards self-sufficiency. In *Uttarakhand Statehood: Dimensions of Development* (eds Sati, M. C. and Sati, S. P.), Indus Pub. Co, New Delhi, 2000, pp. 168–180.
 25. Chapin, F. S., The mineral nutrition of wild plants: A review. *Ecol. Syst.*, 1980, **11**, 233–260.
 26. Kostov, O., Tzvetkov, Y., Kalonianova, N. and Cleemput, V., Production of tomato seedlings on compost of vine branches, grape pruning, husk and seeds. *Compost Sci. Util.*, 1996, **4**, 55–61.
 27. Ramamurthy, V., Sharma, R. K. and Kothari, R. M., Microbial conservation of ligno-cellulosic waste into soil conditioner. In *Advances in Biotechnology* (ed. Pandey, A.), Educational Pub, New Delhi, 1998, pp. 433–438.
 28. Vyas, S. C., Vyas, S. and Modi, H. A., In *Introduction to Bio-fertilizers and Organic Farming*, Ekta Prakashan, Nadiad, 1998, pp. 1–17.
 29. Kasera, P. K. and Sharan, P., Economics of *Evolvus alsinoides* (Sankhpusphi) from Indian Thar desert. *Ann. For.*, 2002, **10**, 167–171.
 30. Nautiyal, M. C. and Purohit, A. N., Cultivation of Himalayan *Aconites* under polyhouse conditions. *Curr. Sci.*, 2000, **78**, 1062–1063.
 31. Holway, J. G. and Ward, R. T., Phenology of alpine plants in northern Colorado. *Ecology*, 1965, **46**, 73.
 32. Rajasekaran, C., Changes in the activities of enzymes of ammonium assimilation in plants along an altitudinal gradient. D Phil thesis, Garhwal University, Srinagar, 2000.
 33. Todaria, N. P. and Purohit, A. N., Functional dynamics of plant species from different altitudes: Growth pattern of *Artemisia vulgaris*. *Indian J. Plant Physiol.*, 1979, **22**, 231–241.
 34. Bhatt, R. M. and Purohit, A. N., Morpho-physiological behaviour of two *Anaphalis* species from contrasting environments along an altitudinal gradient. *Indian J. Plant Physiol.*, 1984, **27**, 130–137.
 35. Spomer, G. G. and Salisbury, R., Carbohydrate cycles in the bulbs of some spring ephemerals. *Bull. Torrey Bot. Club.*, 1968, **95**, 359–369.
 36. Nautiyal, B. P., Prakash, V., Chauhan, R. S., Purohit, H. and Nautiyal, M. C., Assessment of germinability, productivity and cost-benefit analysis of *Picrorhiza kurrooa* cultivated at lower altitude. *Curr. Sci.*, 2001, **81**, 579–585.

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