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Growth and yield of *Solanum khasianum* in *Pinus roxburghii* forest based silvi-medicinal system in mid hills of Indian Himalaya

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Abstract

Background: In mid hills of Western Himalayas, Himachal Pradesh India, growth, yield and economics of *Solanum khasianum* as a potential medicinal herb under *Pinus roxburghii* (Chir pine) plantation has been studied for two consecutive years to assess the performance of *Solanum khasianum* in undercanopy of *Pinus roxburghii* for developing *Solanum khasianum* and *Pinus roxburghii* based innovative silvi-medicinal system.

Methods: Growth parameters such as plant height, number of branches per plant and leaf area index followed by yield were estimated after Solanum khasianum was grown on three topographical aspects as; Northern, North - western and Western at a spacing of 45 cm × 45 cm, followed by three tillage depths as; minimum (0 cm), medium (up to 10 cm) and deep tillage (up to 15 cm), in open and below canopy conditions treatment. The study was conducted to explore the possibility of using Solanum khasianum based silvi-medicinal system to utilize the below canopy of Chir pine forest for enhancing the productivity of forests besides the conservation of the medicinal herb.

Results: The growth parameters such as plant height, number of branches per plant and leaf area index were non-significantly affected by topographical aspects and tillage practices, both below canopy and open conditions except fresh weight and dry weight of berries during harvesting stage. The maximum yield (0.61 $t \cdot ha^{-1}$) was observed on Western aspect in open conditions as compared to below canopy of Chir pine. The highest gross returns were observed for the crop cultivated on Western aspect under deep tillage in open conditions than other aspect and tillage combinations. However the positive net returns from the crops raised in below canopy of Chir pine indicates its possible economic viability under agroforestry system as the gross returns was higher than the cost of cultivation.

Conclusion: *Solanum khasianum* when grown in below canopy of *Pinus roxburghii*, its growth and yield indicated positive net returns. *Solanum khasianum* and *Pinus roxburghii* based silvi-medicinal system has the potential to enhance the overall productivity of Chir pine forest. This silvi-medicinal system gives scope for utilizing floor Chir pine forests for growth and production of *Solanum khasianum* beside conservation of the medicinal herb.

Keywords: Bio-economic evaluation, Silvi-medicinal system, Inter-specific competition, Topographical aspect, Tillage depth, Leaf area index (LAI)

Introduction

Almost all the medicinal plants collected either legally or illegally all over the Himalayas or even other parts of Asia for various purposes are collected from the natural plant communities and only a few species are cultivated (Uniyal et al. 2002). The loss or degradation of forest and grasslands worldwide has led to the shrinking habitat of medicinal plants in almost every country. As a result of which number of medicinal herbs are depleting rapidly from natural plant communities and are threatened with extinction. There are numbers of studies and survey reports those have indicated that over exploitation of several of these medicinal plants for economic gain has rendered them as endangered or vulnerable species (Behrens 2001). The regeneration, protection and preservation of the medicinal plants are a serious challenge for restoring our biological heritage (Hamilton 2004). The future of hundreds of plants species used for medicinal purposes which once

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grew abundantly in our forest and elsewhere are at a risk, as they often are exploited indiscriminately from the wild, leaving little scope for their regeneration. Another reason for the disappearance of many species is ignorance on our part with regard to the knowledge on identification and use of such species. One of them is *Solanum khasianum* Clarke, a stout, much branched, under shrub with almost straight prickles which is found in the wastelands, ravines and in the North-Eastern hills of India and the upper Gangetic plains up to an altitude of 1600 m. This species is an important medicinal plant that contains solasodine as a secondary metabolite (Maiti et al. 1979). Glycoalkaloid, solasodine, is found in mature berries of the plant which has great pharmacological importance in the synthesis of steroids (Trivedi and Pundarikakshudu 2007) and used for the treatments of asthma, inflammatory disorders, sex hormones imbalance and as oral contraceptives (Maiti et al. 1979). Consumption of this herbal medicine is increasing worldwide day by day and harvesting from the wild as a raw material causing loss of genetic diversity and habit destructions (Canter et al. 2005; Julsing et al. 2007). Therefore need was felt to regenerate and conserve it in the wild (Sanwal et al. 2011). Hence considering the socio-economic importance of *Solanum khasianum* for human health and well beings, a field trial was conducted for two consecutive years (2006–07, 2007–08) to assess its regeneration and conservation potential under the Chir pine plantations in its local habitat. Chir pine (*Pinus roxburghii*), which is closely related to Canary Island pine, Turkish pine and Maritime pine, is one of the most important timber species in the mountain subtropical region of India. It is typically gregarious, indigenous to India, forming extensive natural pure stands, though occur mixed with some broad leaf species at its upper and lower limits (Troup 1921), covering an area of 3853 km^2 in Himachal Pradesh (IFS, 2002). The species has a wide adaptability, less demanding of nutrient rich soil than other conifer. Chir pine, like other pine also subject to influence of biotic and abiotic factors, and changing climatic conditions (Kumar et al. 2013; Khaki et al. 2015; Kumar et al. 2016a; Kumar et al. 2016b). But the Chir pine forests have very less or no undercanopy vegetation and hence the productivity of these forests is very low. So keeping in view the vast area under *Pinus roxburghii* in India and also the greater demand for this medicinal herb, the present study were undertaken to assess the possibility of regenerating *Solanum khasianum* in undercanopy of *Pinus roxburghii* for developing innovative *Solanum khasianum* and *Pinus roxburghii* based silvi-medicinal system in mid hills of western Himalayas. Thus the experiment was conducted to sustainably utilize the unutilized floor of Chir pine forest while assessing the growth, yield and economics of *Solanum khasinaum* as a potential medicinal herb in below canopy of Chir pine for its commercial exploitation and conservation.

Methods

Study area

The investigations were carried out at different aspects in Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni Solan, Himachal Pradesh (Fig. 1) at an elevation of 1250 m above mean sea level (30°51' N latitude and 76°11' E longitude). The climate of the area is transitional between subtropical to sub-temperate with maximum temperatures was recorded 37.8 °C during summer.

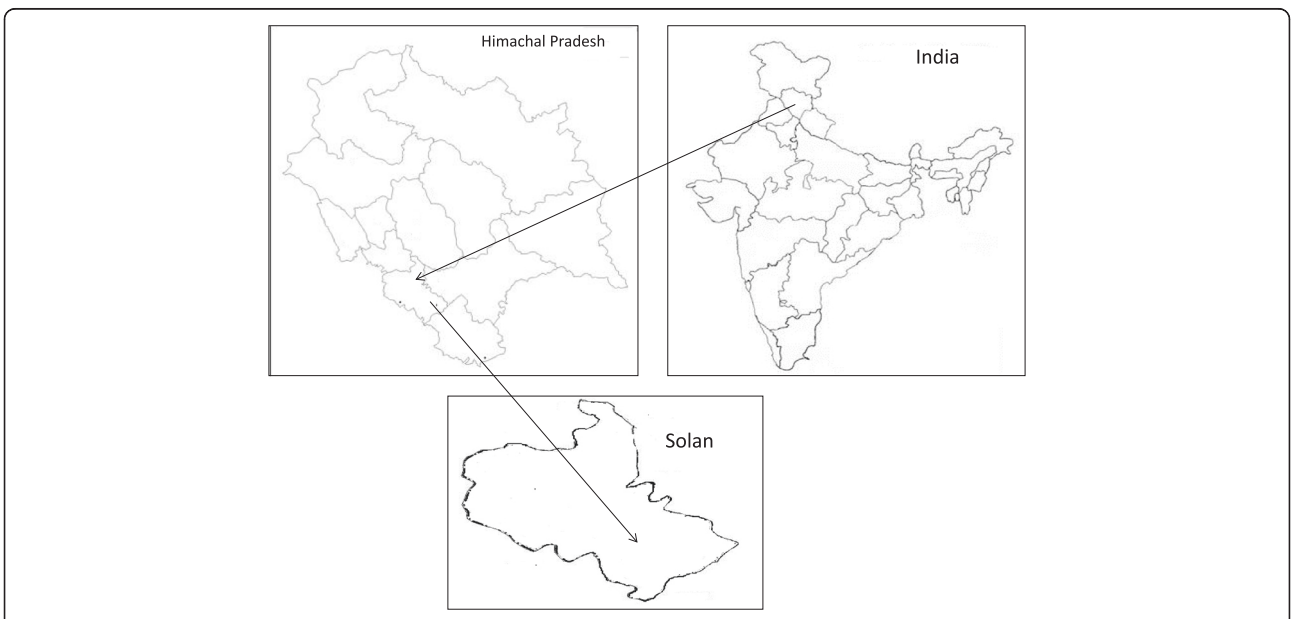

Fig. 1 Location map of the study area

June was the hottest month, whereas December was the coldest month with mean annual temperature was recorded 19.8 °C. The annual rainfall ranges between 800–1300 mm of which 75 per cent is received during mid June to mid September. The soil type is incept sols and typic entrochrepts with gravely sandy loam texture. The parent material consists of sand stone, conglomerate, boulders, dolomite and calcareous.

Experiment technique and statistical analysis

Seedlings of *Solanum khasianum* procured from nursery, were used for the transplantation in the planting site at the spacing of 45 cm × 45 cm. Generally it does not require any fertilizer and irrigation practices as the herb is well adapted to the waste lands. Weeding as one of the cultural operations carried out for better growth and yield of the *Solanum khasianum*. The seedlings were transplanted during monsoons (June–July) and berries harvested at the end of winter season. *Solanum khasianum* grown under Chir pine canopy and in open conditions on different aspects and under different tillage practices were studied separately to assess former's growth and yield. Hence, studies involved three factors i.e. Aspects, tillage practices and systems. *Solanum khasianum* was grown on three aspects such as; Northern, North-Western and Western at a spacing of 45 cm × 45 cm adopting recommended cultural practices, followed by three tillage depths such as; minimum (T_1: 0 cm), medium (T_2: up to 10 cm) and deep tillage (T_3: up to 15 cm) in open conditions and under canopy of Chir pine plantations. The 18 treatments combinations, including all possible combination of three aspects, three tillage depths and two systems were evaluated for growth, yield and economics of *Solanum khasianum* using three replicates in factorial randomized block design. The entire data generated from the present investigation were analyzed statistically using the technique of analysis of variance for factorial randomized block design in accordance with the procedure outlined by Gomez and Gomez (1984).

Field preparation and transplanting

The forest floor was cleared from needle by manual laborers who collected the needles heaped on the forest floor and removed before transplanting the seedlings at the site. After removing the pine needles, tillage practices were adopted just before the onset of monsoon. The whole experiment was conducted under rainfed conditions entirely depending on the monsoon rains. Keeping in view the forest site conditions, no irrigation and fertilizer was applied because crop has minimum input requirement. For transplanting of seedlings, nursery was prepared, and at the commencement of monsoon, healthy seedlings of *Solanum khasianum* were lifted from nursery and transplanted in the experimental field after recording sufficient moisture in the soil during first fortnight of July. Planting was done using a wooden stick with good penetration in the experimental area including in minimum tillage plots area. The crop was harvested in the month of December.

Characteristics of Chir pine stand

The characteristics of Chir pine stand in all aspects in which *Solanum khasianum* was introduced has been presented in the Table 1. The experiment was conducted under 20 years old plantations of *Pinus roxburghii* and all plots on different aspects were selected having similar density of tree crop (952 trees·ha^{-1}). Average volume of tree (Chir pine) was calculated using local volume table based on diameter. Annual increment in volume thus calculated, was then used to estimate returns from tree at the prevailing market price. The same procedure was used for calculating net returns from trees on all the three aspects.

Observations recorded

Once the needles were removed from the experimental site, the availability of major nutrient viz., organic carbon, available N, available P and available K were analyzed after harvesting *Solanum khasianum* (Tables 2 and 3). Effect of tree canopy of Chir pine, topographical aspect and tillage depths on growth parameters of *Solanum khasianum* (height, number of branches per plant and leaf area index) were recorded after transplanting at vegetative (60 d), pre-bloom (120 d) and harvesting stage (180 d). Leaf area index (LAI) of medicinal herb was measured with the help of pre-calibrated, pre programmed LAI-2000 plant canopy analyzer (LICOR-USA) using 45° view cap. Whereas, the data for growth and yield attributes were measured at the time of harvesting. To make the economic appraisal for developing this silvi-medicinal system, the yield of *Solanum khasianum* was subjected to economic analysis by calculating cost of cultivation, gross and net returns per hectare including the net returns from trees. The cost of cultivation was worked out by adding variable and fixed cost as mentioned in Additional file 1: Table S1. The cost incurred on clearing of forest floor varied with respect to treatments. Generally it was 10–20 % of the total cost of cultivation.

Table 1 Height, diameter, crown area and crown density of chir pine stands on different aspects

Aspect	Height (m)	Diameter (cm)	Crown area (m^2)	Crown density
Northern aspect	11.23	19.94	2.99	0.85
North-western aspect	10.22	18.15	2.87	0.75
Western aspect	11.09	19.39	2.98	0.64

Table 2 Effect of topographical aspect on available nutrient in below canopy and open conditions

Aspect	Organic carbon (%)		N (kgha^{-1})		P (kgha^{-1})		K (kgha^{-1})	
	Below canopy	Open conditions	Below canopy	Open conditions	Below canopy	Open conditions	Below canopy	Open conditions
A_1: Northern	1.32	1.10	323	310	18.3	17.7	298	276
A_2: North-western	1.44	1.24	336	323	19.9	19.0	313	292
A_3: Western	1.58	1.37	350	340	22.2	20.9	325	314
Mean (S)	1.44	1.24	337	325	20.0	19.0	312	249
$CD_{0.05\ (A)}$	0.01		NS		0.07		NS	
SEm± (A)	0.01		2.54		0.03		4.70	
$CD_{0.05}$ (S)	0.01		2.98		0.04		5.50	
SEm ± (S)	0.01		1.46		0.02		2.71	

Results

Effect of tree canopy

Plant height (cm) was significantly affected at vegetative stage, pre- bloom stage and harvest stage, but it was recorded more outside tree canopy (open) than below tree canopy (Fig. 2). Number of branches per plant and leaf area index revealed no significant affect below and outside tree canopy. Similarly, yield (Dry weight of berries) (tha^{-1}) significantly decreased (35.72 %) below tree canopy than outside tree canopy (Fig. 2).

Effect of topographical aspect

Plant height (cm) significantly differed with changing aspect at vegetative, pre-bloom and harvest stage (Fig. 3). Values of leaf area and leaf area index were also significantly affected on different aspects at vegetative, pre-bloom and harvest stage. Similarly, yield (Dry weight of berries) (tha^{-1}) significantly varied with different aspect and higher yield of these was recorded on Western aspect than on North-Western and Northern aspect, respectively (Fig. 3).

Effect of tillage

Tillage significantly affected plant height (cm) at vegetative, pre-bloom and harvesting stage and higher plant height (cm) was observed in deep tillage than medium and minimum tillage at all the growth stages (Table 4). Leaf area and leaf area index also varied significantly with different tillage practices. The yield was significantly affected by deep tillage (Dry weight of berries) (tha^{-1}) and highest yield was obtained in deep tillage than other tillage practices (Table 5).

Economics of silvi-medicinal systems

The bio-economic appraisal of *Solanum khasianum* was undertaken to ascertain its economic viability. The total cost of cultivation of *Solanum khasianum* was found to vary with different treatment combinations. The maximum net returns were observed for crop growing on western aspect under deep tillage in open conditions followed by the crops cultivated on western aspect under deep tillage in undercanopy (Table 6). The minimum net returns were obtained for crop growing on western aspect

Table 3 Effect of tillage practices on available nutrients in below canopy and open conditions

Tillage	Organic carbon (%)		N (kgha^{-1})		P (kgha^{-1})		K (kgha^{-1})	
	Below canopy	Open conditions	Below canopy	Open conditions	Below canopy	Open conditions	Below canopy	Open conditions
T_1: Minimum	1.42	1.22	330	320	19.5	18.7	307	292
T_2: Medium	1.45	1.24	337	326	20.3	19.2	313	295
T_3: Deep	1.46	1.25	342	329	20.6	19.4	316	296
Mean(S)	1.46	1.24	337	325	20.1	19.1	312	249
$CD_{0.05\ (T)}$	0.01		NS		0.06		NS	
SEm± (T)	0.01		2.54		0.03		4.68	
$CD_{0.05}$ (S)	0.01		2.98		0.04		5.50	
SEm ± (S)	0.01		1.46		0.02		2.71	

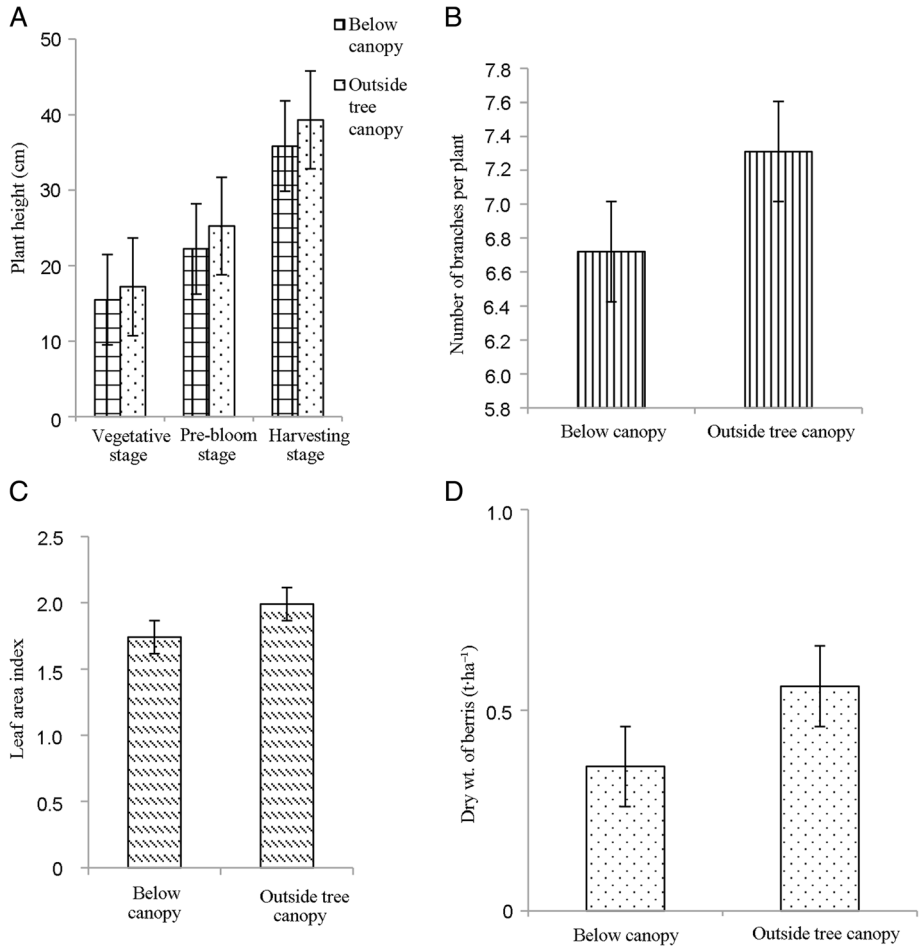

Fig. 2 Plant height (**a**), no. of branches per plant (**b**), leaf area index (**c**) and dry wt. of berries (**d**) below and outside tree canopy (Error bar indicates standard error of the mean)

under minimum tillage in below canopy conditions. In all different treatment combinations, higher net returns were observed in open than below canopy conditions.

Discussion

The production potential of *Solanum khasianum* can be judged by the effect of different aspect, tillage and systems on growth parameters and final yield.

Effect of tree canopy

Plant growth and yield parameter of *Solanum khasianum* was generally higher outside tree canopy than below tree canopy (Fig. 2). However the higher values for all growth parameters and yield attributes of *Solanum khasianum* outside tree canopy suggests that the plants grown outside tree canopy as sole crop has better opportunities to reap more solar energy for photosynthetic activity, less intra-specific competition for critical resources like water, nutrients, and photo synthetically active radiation. These favorable factors seem to result in higher values of growth and yield parameters of *Solanum khasianum* outside tree canopy conditions. Chauhan (2000), Karikalan et al. (2002), Lott et al. (2000), Okorio (2000) and Singh et al. (2012a) have earlier made similar observations for different agricultural crop and grasses under agroforestry systems. Apart from above the lower values of growth parameters and yield attributes of *Solanum khasianum* in below canopy of Chir pine might be because of allelopathic effect of tree on crops. Some of the previous study had shown allelopathic effect of Chir pine on different plants (Singh and Verma 1988; Gupta et al. 2007; Aliloo et al. 2012; Sharma 2013a; Sharma 2013b). The findings of this investigation are also in agreement with the earlier findings of many researchers (William and Gordon 1995; Jose et al. 2000; Singh et al. 2012b) who have reported higher production of dry matter in the outside tree canopy than in the inter-cropped field.

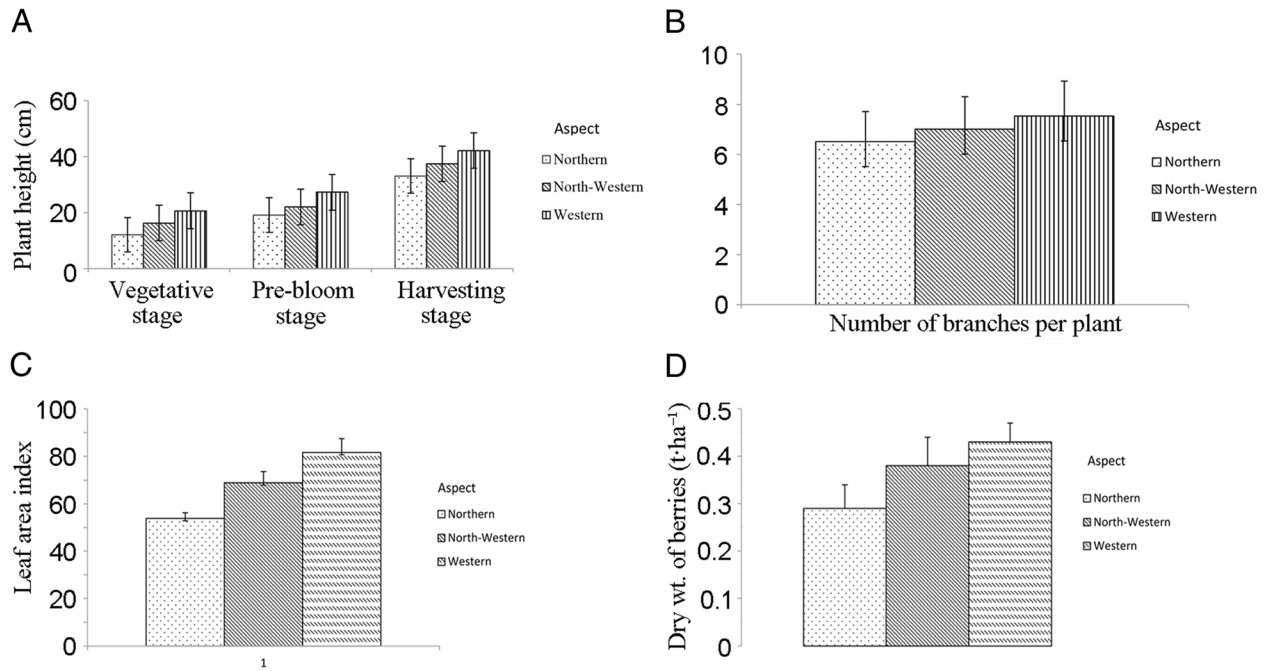

Fig. 3 Plant height (**a**), no. of branches per plant (**b**), leaf area index (**c**) and dry wt. of berries (**d**) in Northern, North-west and Western aspect (Error bar indicates standard error of mean)

Effect of topographical aspect

Our result showed the growth and yield parameters observed on Western aspect was greater than North-west and Northern aspect (Fig. 3). On the other hand, Nevo et al. (1999) found that plant cover may reach 150 % on the Northern aspect. Nevo et al. (2000) also confirmed that species inhabit on different aspect display genetic, morphologic, physiological and behavioral adaptive complexes in relation to each of the aspect. The maximum growth and yield of *Solanum khasianum* on Western aspect was attributed to higher intensity of light during forenoon when the temperature is more favourable and leaves remain turgid which limit rate of photosynthesis. On the other hand Northern aspect receiving lower intensity of light in afternoon when the temperature is less favourable and leaves remain less turgid thereby reducing photosynthetic efficiency of the crop on this aspect. Similar findings were observed when *Mucuna pruriens* and *Andrographis paniculata* showed highest yield when cultivated on Western aspect (Sanwal et al. 2013, 2015 and Chandra et al. 2016). Nevo (1997) also proved that microclimatic conditions on the aspects vary dramatically, affecting the biology of plants at all levels.

Table 4 Effect of tillage practices on plant height and number of branches per plant of *Solanum khasianum*

Tillage	Plant height (cm)			Number of branches per plant
	Vegetative stage	Pre-bloom stage	Harvesting stage	
Minimum	$13.02^{c} \pm 2.54$	$19.15^{a} \pm 6.87$	$30.61^{a} \pm 6.49$	$5.83^{a} \pm 0.85$
Medium	$16.67^{b} \pm 3.65$	$23.16^{a} \pm 5.98$	$38.53^{a} \pm 7.59$	$6.87^{a} \pm 1.15$
Deep	$19.34^{a} \pm 3.42$	$26.36^{a} \pm 6.59$	$43.54^{a} \pm 8.67$	$8.37^{a} \pm 1.35$

Value (±) followed by mean indicates standard deviation of mean; Different letters indicate significant differences at $p < 0.05$.

Effect of tillage

In our study, plant growth and yield parameter in deep tillage was recorded more than medium and minimum tillage (Table 5). Higher values of growth and yield in deep tillage were due to better soil permeability, soil aeration, root penetration and weed control. Similar findings were observed by Sanwal et al. (2013, 2015), when medicinal plants like *Mucuna pruriens* and *Andrographis paniculata* showed highest yield when cultivated on deep tillage. These results are in agreement with those of Khan et al. (1999), Iqbal et al. (2005), Keshavarzpour and Rashidi (2008), Rashidi and Keshavarzpour (2008) and Rashidi et al. (2008). Khurshid et al. (2006) also reported that development of roots was better in less

Table 5 Effect of tillage practices on leaf area index and yield of *Solanum khasianum*

Tillage	Leaf area index (LAI)	Yield (Dry weight of berries) (qha^{-1})
Minimum	$1.63^{a} \pm 0.45$	$0.38^{c} \pm 0.08$
Medium	$1.77^{a} \pm 0.56$	$0.43^{b} \pm 0.06$
Deep	$2.19^{a} \pm 0.61$	$0.57^{a} \pm 0.12$

Value (±) followed by mean indicates standard deviation of mean; Different letters indicate significant differences at $p < 0.05$.

Table 6 Bio-economic appraisal of *Solanum khasianum* (ha^{-1})

Treatment combination	Gross return ($)	Cost of cultivation ($)	Net return ($)
$A_1T_1S_1$	171.33	123.33	47.98
$A_1T_2S_1$	188.83	141.67	47.17
$A_1T_3S_1$	213.83	151.63	62.20
$A_1T_1S_0$	222.50	142.37	80.13
$A_1T_2S_0$	232.50	157.55	74.95
$A_1T_3S_0$	312.50	173.43	139.07
$A_2T_1S_1$	174.35	130.22	44.13
$A_2T_2S_1$	216.85	147.05	69.80
$A_2T_3S_1$	294.35	162.05	132.30
$A_2T_1S_0$	242.50	153.42	89.08
$A_2T_2S_0$	255.00	168.93	86.07
$A_2T_3S_0$	335.00	185.03	149.97
$A_3T_1S_1$	192.55	149.05	43.50
$A_3T_2S_1$	242.55	161.98	80.55
$A_3T_3S_1$	335.05	179.70	155.35
$A_3T_1S_0$	265.00	170.03	94.97
$A_3T_2S_0$	285.00	188.35	96.65
$A_3T_3S_0$	365.00	207.05	157.95

1 dollar is equivalent to 60 INR

A_1 = Northern aspect, A_2 = North-Western aspect, A_3 = Western aspect, T_1 = Minimum tillage, T_2 = Medium tillage, T_3 = Deep tillage, S_1 = Below canopy, S_0 = Open

compacted soil whereas dense soil markedly reduced root growth. This was attributed to the favorable effect on plant height, number of branches per plant and shoot and biomass yield. Thus the greater value of growth parameter and yield in deep tillage is attributed to the higher infiltration and increased soil depth for moisture storage (Moreno et al. 1997). While the lower yield under minimum tillage is attributed to less favorable condition for shoot and root growth, and less moisture storage and poor soil aeration. Lampurlanes et al. (2002) also reported the reduced shoot growth in compact soil because of the poor root development. The other reason for lower value of growth parameters and yield attributes might be because of poor control on weed growth and less nutrient availability under minimum tillage. Unger and Baumhardt (1999) also reported reduction in yield under no tillage as compared to conventional tillage occurred due to lack of control over the weed population.

Economic analysis

Higher gross returns for *Solanum khasianum*, in open conditions were due to the fact that in open conditions the gross returns were already higher for the crops to the extent that additional returns from trees in below canopy could not surpass the average returns than open conditions (Table 5). The positive net returns in case of *Solanum khasianum* may be due to their suitability in the environment given in open conditions and in association with the Chir pine. This finding can be supported by the Harrington et al. (2003) who initiated a research to determine the separate effects of above and below ground competition and needlefall from overstorey pines on below canopy plant performance and found that depending on species the effects of needle fall were positive, negative, or negligible. Besides, the positive net returns in *Solanum khasianum* were attributed to lower cost of cultivation than gross returns (Table 4). The lower cost of cultivation in the given condition can be attributed to the three times lower rental value of land in below canopy of Chir pine than open conditions as; no fertilizers and irrigation practices and lower cost of planting material as the nursery was prepared for *Solanum khasianum* (Fig. 4). Thus this feasible sustainable cultivation and conservation of *Solanum khasianum* can be economically viable only in the waste land like land in association with Chir pine where the opportunity cost is zero (i.e. no alternative use of below canopy land is feasible). This finding can be supported by Chatterjiee et al. (2004) who reported that targeted species like *Andrographis paniculata* etc. could better flourish on natural ecosystem under in-situ conditions and the conservation and cultivation of these species under controlled cultural practices did not prove to be economically feasible under ex-situ.

Conclusions

The positive net returns received from *Solanum khasianum* when recorded in below canopy of Chir pine which indicates the great possibility of economic viability of *Solanum khasianum* and Chir pine based innovative silvi-medicinal system. *Solanum khasianum* and *Pinus roxburghii* based innovative silvi-medicinal system also endeavour to use the unutilized floor of Chir pine forest by associating naturally growing *Solanum khasianum* to

Fig. 4 Growth of *Solanum Khasianum* in Chir pine forest

improve the productivity of these forests along with conserving medicinal plants. This study can have potential implications in the Chir pine growing belt of the continent if this innovative silvi-medicinal system is implemented by the local farming community or the state forest department. The combination of *Solanum khasianum* with *Pinus roxburghii* will not only ensure regular supplies of medicinal herbs but also their conservation. The findings of the present investigation indicate that raising with Chir pine is a viable option for enhancing the diversification and rise in income from Chir pine forest.

Additional file

Additional file 1: Table S1. Cost of cultivation of Solanum Khasianum ($/ha.) (XLS 18 kb)

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Authors' contributions
CSS and SDB conducted research work, while RK and RA, VK and SK were involved in Data analysis and writing manuscript, respectively. All authors read and approved the final manuscript.

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Competing interests
The author(s) declare that they have no competing interests.

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