Productivity of Wheat (*Triticum Aestivum*) as Intercrop in *Grewia Optiva* Based Traditional Agroforestry System along Altitudinal Gradient and Aspect in Mid Hills of Garhwal Himalaya, India

Arvind Bijalwan¹,², Manmohan J. R. Dobriyal²

¹Indian Institute of Forest management (IIFM) Nehru Nagar, Bhopal-462 003, M.P., India
²Department of Silviculture and Agroforestry ASPEE College of Horticulture and Forestry Navsari Agricultural University, Navsari - 396 450, Gujarat, India

*Corresponding author: arvindbijalwan276@gmail.com

Received October 08, 2014; Revised October 21, 2014; Accepted October 23, 2014

Abstract Grewia optiva, wonder tree of western Himalaya locally known as Bhimal is the most common multipurpose tree is a boon for the inhabitants of Garhwal Himalayan region. About 2/3rd of the cultivated area of Garhwal is rainfed and Wheat (*Triticum aestivum*) is the predominant food grain crop cultivated on the sloppy terraces in combination of G. optiva trees on terrace bunds. In Present study the productivity of wheat (*Triticum aestivum*) as intercrop in Grewia optiva based traditional agroforestry system along altitudinal gradient and aspect in mid hills of Garhwal Himalaya, India reveals that G. optiva occupied average highest frequency (85%), stem density (145 trees/ha), TBC (7.68 m²/ha), IVI (86.51), tree height (7.38 m), Crown spread (5.34 m) in the elevation 1000-1500 m of Northern aspect (E1/N site). In the elevation 1000-1500 m, it was observed that there is a reduction in grain, straw and biological yield of wheat as 17.59%, 17.77% and 17.71% respectively on the southern aspect compared to northern aspect. Further elevation 1500-2000 m, the reduction in the average grain yield was recorded 37.31% under G. optiva based traditional agroforestry system in E2/S site. The phenophases of the wheat crop is sown in the month of December which emerges to crown root initiation (CRI) in January followed by tillering, milking, maturity and final harvest during May while G. optiva remain dormant from December to February, leafless in March and new flush of shoots in May. This reversal phenopases of two components are complimentary in tree crop interaction to enhance productivity.

Keywords: Agroforestry, Garhwal, Himalayas, Grewia optiva, wheat, yield

Cite This Article: Arvind Bijalwan, and Manmohan J. R. Dobriyal, “Productivity of Wheat (*Triticum Aestivum*) as Intercrop in *Grewia Optiva* Based Traditional Agroforestry System along Altitudinal Gradient and Aspect in Mid Hills of Garhwal Himalaya, India.” *American Journal of Environmental Protection*, vol. 2, no. 5 (2014): 89-94. doi: 10.12691/env-2-5-3.

1. Introduction

Agroforestry is a new name for the old practice, exceptionally common in the Garhwal Himalayan regions of India. More than 70% population of this region depends upon agriculture for livelihood while the land suitable for agriculture is limited to few pockets only. The multifarious trees deliberately retained by the farmers on the farm bund forms the agroforestry combinations, which supplement the fodder, fuel, fiber, fruits and flosses as their life support system. The unusually wide altitudinal range, rapid change in altitudinal gradient even at small distances and high endemism make it interesting for studies (Singh and Singh, 1992). The increasing population is subsequently creating higher demands for the forest products and the alarming fact is that, even today the production from forestry sector is not enough to meet out the existing demands. The vegetation of the varying topography of the Garhwal Himalaya changes its species diversity, composition and structure along altitudinal gradient. Moreover the direction of the sun (aspect) in the hilly topography also plays an important role in the vegetation and land use pattern. The season is also an important factor which decides the availability of fodder to the livestock of this region, hence some trees which are boon for the region provides the green fodder in the lean period. Though there are many trees species in practice in the traditional Agroforestry systems in Garhwal Himalaya but some tree species are prioritized by the farmers for daily need and livelihood support.

*Grewia optiva*, wonder tree of western Himalaya locally known as *Bhimal* is the most common multipurpose tree is the boon for the inhabitants of Garhwal Himalayan region. This tree abundantly grown on the farmers filed under traditional agroforestry along
with most of the agricultural crops. The *G. optiva*-wheat based combination is a common practice by the local people to supplement the additional benefits from the tree. The *G. optiva* is rated as good fodder tree having fairly high protein and nutrients without tannin content, moreover, supplies green fodder during lean period (winter) when generally no other alternative for green fodder are available in this region. *G. optiva* also support the farm community through its fiber, used for making ropes and the branches of this tree also used for making baskets. The tree is also used for fuelwood purpose in the areas where no other choice of good fuel is available. The Land-use systems in the Himalayan region comprised of forestry, agriculture, horticulture and animal husbandry (Sundriyal et al., 1994) however, the importance of agroforestry with *G. optiva* based combinations are highly supportive. Beside, *G. optiva* the other fodder tree species like *Melia azedarach, Ficus roxburghii, F. palmata, F. glomerarata, Boehmeria rugulosa, Celtis australis* etc are also found in the traditional agroforestry systems but their preference is always secondary by the farmers. About 2/3rd of the cultivated area of Garhwal Himalaya is rained and Wheat (*Triticum aestivum*) is the predominant food grain crop cultivated on the sloppy terraces in combination of *G. optiva* on terrace bunds. The productivity of wheat is usually reduced under tree cover but the additional benefits of *G. optiva* trees supplements the fodder, fuel and fiber that bound farmers to retain these trees on their farm bunds. The selection of intercrops depends mainly on edapho-climatic conditions of the area, farmer’s need/traditions and resource availability (Saroj and Dadhwal, 1997).

The agroforestry interventions seem to be more worthwhile due to the share of tremendous pressure on forest for the fuel and fodder by these farm trees. Although a number of studies on the Himalayan agroforestry systems (Toky et al., 1989; Ralhan et al., 1991; Sundriyal et al. 1994; Semwal and Maikhuri, 1996; Singh et al., 1997) are available, but the productivity of agricultural crops under agroforestry systems have not worked out properly. This study aimed to analyse the wheat productivity as intercrop under *G. optiva* based traditional agroforestry system along altitudinal gradient and aspect in mid hills of Garhwal Himalaya.

2. Materials and Methods

The study was carried out in the traditional agroforestry systems of mid hill situation of Chamba block of Garhwal Himalaya in district Tehri Garhwal (Uttarakhand), India located between 77°51’ 30” to 80°30” E longitudes and 29°40’ to 31°28” N latitudes. Geographically the area falls in transition zone of sub-tropical and temperate zone, with majority of agricultural fields fall in high degree of terraced slopes, resulted soil and water losses. The traditional agricultural fields are dominated with luxuriant and green lush natural vegetation. The soil of this region is acidic in nature varying in texture as per the availability of organic matter. Agricultural is the mainstay of livelihood of this region and the villagers are engaged in agricultural interventions all through the year which is usually low productive. Majority of the farmers of this region are small with fragmented land holding around 0.04 hectare. The 85% of the agricultural area is rained while some of the valley areas have limited irrigation through natural tributaries of rivers (locally known Gadhera). The study area covers three main seasons: rainy (Last week of June-August), winter (September-February) and summer (March-third week-June). The area receives an average annual rainfall of 1240 mm with most of the rain occurs during July to September (monsoon period). The mean annual temperature of the area varies from 9° to 33°C with occurrence of snowfall during November to February.

*G. optiva* (Blimal) is an extremely common multipurpose tree of this region, grown on the farmers’ field under traditional agroforestry design on terrace bunds along with all crop combinations. The *G. optiva*-wheat based agroforestry combination (agrisilviculture) is a common practice by the local people to supplement the additional benefits from the tree. The elevation and aspect (direction of sun light faced by slope) play a significant role in growth, development and composition of vegetation in the hilly areas. It has generally observed that the tree and agricultural crops change their productivity in varying slopes and aspect with morphological changes in the plant characters. The present study is planned in such a way that the feasibility of *G. optiva* based agroforestry combination could be assessed in accordance to different elevation and aspects. The effect on the productivity of wheat under *G. optiva* tree was the sole objective of the study in varying elevation and aspect.

2.1. Experimental Design

The experiment was conducted in four experimental sites during Rabi (November-March) season in the wheat fields dominated by *G. optiva* trees (agrisilviculture model) between 1000 to 2000 m of elevation. The four different study sites were based on elevation and aspects are as given below: E1/N -Northern aspect between 1000-1500 m msl; E1/S - Southern aspect between 1000-1500 m msl, E2/N- Northern aspect between 1500-2000 m msl, E2/S- Southern aspect between 1500-2000 m msl. The stratified random sampling was carried out in the area (sample intensity 0.1) with 40 samples laid in each site having quadrat size of 10x10 m, following Mishra, 1968. In each quadrat, the trees of different species were enumerated. The elevation and aspect of the area was measured with the help of GPS (Model No. Rino-130, Garmin). The composition of different agroforestry components were enumerated on the basis of population dynamics and functional diversity (James, 1988). The frequency, stem density (SD), Total Basal Cover (TBC) and Importance Value Index (IVI) analysis of *G. optiva* (in particular) and other associate trees (in general) in the existing agrisilviculture system in each study site was done. The elevation and aspect wise analysis was done to quantify the influence of physiographic variation on growth and yield of wheat under *G. optiva* based agroforestry system.

In each study site, the *G. optiva* trees per hectare was categorized in 0-10, 10-20, 20-30 and 30-40 cm diameter classes in four replications. In each sample plot, the diameter at breast height (DBH) of *G. optiva* was measured at 1.37 m using tree caliper while heights of trees were measured by Abney’s level in meters. The diameter class was considered to be the major factor, influenced the growth and yield of wheat. The Crown
spread (CS) of *G. optiva* was also measured for the assessment of effect of diameter and canopy on wheat productivity under different distance from the tree trunk.

In case of wheat crop, the 1x1 m quadrant was laid for the same agroforestry field at different distances under the average canopy of *G. optiva*. The Crown spread of *G. optiva* was measured with the five radial transsects from the tree trunk randomly under each diameter class. The wheat crop growth was studied along transects at 1 m (D1), 1-2 m (D2), 2-4 m (D3) and 4-5 m (D4) distances from the *G. optiva* tree trunk. The open field with the distance >5 m from the tree trunk was considered as control. The different growth and yield attributes of wheat viz: number of plants, number of tiller per plant, plant height (cm), thousand grain weights (gm), grain yield, straw yield and biological yield was estimated under *G. optiva* tree and open condition. Finally the harvest index (HI) was calculated to determine the fraction of economically useful products of a plant in relation to its total productivity (grain to straw ratio) and calculated using following formula:

\[ HI = \frac{EY}{BY} \times 100 \]

Where: HI = Harvest Index, EY = Economic Yield (grain yield), BY = Biological Yield (grain + straw).

The same experiment was conducted in four different sites (E1/N, E1/S, E2/N and E2/S) to quantify the impact on wheat yield on different distances from tree trunk along varying elevation and aspect. Statistically the study was tested in Factorial Analysis of Variance (F-ANOVA) to find out the effect of two or more than two factors in different study sites and level of significance was tested at probability levels 5 per cent as per the procedure outlined by Snedecor and Cochran (1967). The main factors considered elevation, aspect, and distance from tree trunk for wheat productivity estimation. The productivity of sole wheat crop was performed in Randomize Block Design (RBD) and estimation was done in agronomical method. The statistical analysis was performed using MSTAT C and SPSS statistical software under PC atmosphere.

## 3. Results

The results of the present study (Table 1) showed that the *G. optiva* occupied average highest frequency (85%), stem density (145 trees/ha), TBC (7.68 m²/ha), IVI (86.51), tree height (7.38 m), Crown spread (5.34 m) in the elevation 1000-1500 m of Northern aspect (E1/N site). The tree occupied average lower frequency (55%), density (70 trees/ha), TBC (4.58 m²/ha), tree height (6.08 m) in the elevation 1500-2000m of Southern aspect (E2/S site).

In the present study the proportionate Stem Density (SD %) distribution of *G. optiva* varied form 2.86% in 30-40 cm diameter class of E2/S site to 61.60% in 10-20 diameter class of E1/S site. The highest percentage of Stem Density (*G. optiva*) was recorded in 10-20 cm diameter class in all the sites as 57.24% (E1/N), 61.60% (E1/S), 52.63% (E2/N) and 57.14% (E2/S). The minimum percentage of Stem Density was observed in 30-40 cm diameter class as 3.45% (E1/N), 3.20% (E1/S), 4.21% (E2/N) and 2.86% (E2/S).

### Table 1. Ecobiometrics of *Grewia optiva* in traditional agroforestry practices

| Parameters          | E1/N | E1/S | E2/N | E2/S |
|---------------------|------|------|------|------|
| SD (Trees ha⁻¹)     | 85   | 75   | 60   | 55   |
| DBH (cm)            | 15.19| 15.19| 14.13| 14.13|
| TBC (m² ha⁻¹)       | 7.68 | 6.08 | 5.03 | 4.58 |
| IVI                 | 86.51| 65.74| 58.52| 53.71|
| DBH (cm)            | 145  | 125  | 95   | 70   |
| Tree ht (m)         | 7.38 | 6.76 | 6.29 | 6.08 |
| CS (m)              | 5.54 | 5.08 | 4.95 | 4.41 |
| CI                  | 1.63 | 1.78 | 1.65 | 1.72 |
| % (F), Frequency    | 55%  | 70%  | 61.60%| 57.24%
| SD (Trees ha⁻¹)     | 85   | 75   | 60   | 55   |
| DBH (cm)            | 15.19| 15.19| 14.13| 14.13|
| TBC (m² ha⁻¹)       | 7.68 | 6.08 | 5.03 | 4.58 |
| IVI                 | 86.51| 65.74| 58.52| 53.71|
| DBH (cm)            | 145  | 125  | 95   | 70   |
| Tree ht (m)         | 7.38 | 6.76 | 6.29 | 6.08 |
| CS (m)              | 5.54 | 5.08 | 4.95 | 4.41 |
| CI                  | 1.63 | 1.78 | 1.65 | 1.72 |

All the growth and yield attributes of wheat reduced under *G. optiva* tree in different study sites. The growth parameters as number of plants m⁻², plant height and Number of tiller per plant decreased significantly at 1 m distance (D1) from the tree trunk compared to other distances. Similarly the yield attributed (thousand grain weight, grain yield, straw yield and biological yield) reduced maximum under 1 m distance (D1) and gradually increased from 1 m to 4-5 m (D5). The minimum reduction of growth and yield attributes beneath the trees were noticed in 4-5 m (D5) distance from tree trunk as compared to other distances. The growth and yield attributes of wheat were significantly reduced in all the distances of wheat compared to control (wheat grown open areas without tree).

### Table 2. Productivity of Wheat under traditional agroforestry systems in 1000-1500m elevation on northern aspect (E1/N)

| Distance       | No. of plants/m² | Plant ht (cm | No. of effective tiller/plant | 1000 Grain wt (gm) | Grain (t ha⁻¹) | Straw (t ha⁻¹) | B.Y. (t ha⁻¹) | H.I. (%) |
|----------------|------------------|--------------|-------------------------------|--------------------|----------------|---------------|---------------|----------|
| D1 (up to 1m)  | 31.43            | 61.64        | 2.38                          | 29.53              | 0.625          | 1.354         | 1.979         | 31.58    |
| D2 (1-2m)      | 33.85            | 60.47        | 2.69                          | 30.54              | 0.698          | 1.418         | 2.116         | 32.99    |
| D3 (2-3m)      | 35.86            | 62.63        | 2.82                          | 31.88              | 0.835          | 1.613         | 2.448         | 34.11    |
| D4 (3-4m)      | 32.66            | 66.74        | 2.96                          | 32.65              | 1.164          | 2.722         | 3.286         | 35.42    |
| D5 (4-5m)      | 76.45            | 72.36        | 3.21                          | 33.75              | 1.311          | 2.282         | 3.593         | 36.49    |
| Mean           | 44.05            | 64.77        | 2.81                          | 31.67              | 0.927          | 1.758         | 2.684         | 34.12    |
| Control        | 81.54            | 86.65        | 3.78                          | 38.38              | 1.417          | 2.186         | 3.603         | 39.33    |
| CD 5%          | 14.78            | 24.80        | 0.89                          | 2.07               | 0.15           | 0.16          | 0.30          | 7.06     |

On the northern aspect of elevation 1000-1500 m (E1/N), the number of wheat plant varied 31.43 (D1) to 76.45 (D5) per m², number of tiller/plant 2.38 (D1) to 3.21 (D5) and the grain yield from 0.625 t ha⁻¹ (D1) to 1.311 t ha⁻¹ (D5). The reduction of grain yield was observed to be highest 55.89% under D1, 50.74% (D2), 41.07% (D3), 17.85% (D4) and 7.48% (D5) compared to control (Table 2). The average reduction in this site was recorded to be 34.61% against the control. The biological yield (grain + wheat) in the site varied from 1.979 t ha⁻¹ (D1) to 3.593 t ha⁻¹ (D5). The southern aspect in the same elevation (E1/S) showed the overall reduction in both growth and yield parameters of wheat. In this site the number of wheat plant varied 31.25 (D1) to 66.23 (D5) per m², number of
The higher elevation (1500-2000 m) was observed in a reduction of growth and yield attributes of wheat compared to middle elevation (1000-1500 m). The northern aspect (E2/N) showed number of wheat plant 30.47 (D1) to 68.53 (D5) per m², number of tiller/plant 2.73 (D1) to 3.43 (D5) and the grain yield from 0.524 t ha⁻¹ (D1) to 0.657 t ha⁻¹ (D5) (Table 4). The reduction in grain yield was observed to be maximum 37.19% of this site when compared with control. It was observed that there is a reduction in grain, straw and biological yield of wheat as 17.59%, 17.77% and 17.71% respectively on the southern aspect compared to northern aspect within the same elevation level under traditional agroforestry systems.

The higher elevation (1500-2000 m) was observed in a reduction of growth and yield attributes of wheat compared to middle elevation (1000-1500 m). The northern aspect (E2/N) showed number of wheat plant 30.47 (D1) to 68.53 (D5) per m², number of tiller/plant 2.73 (D1) to 3.43 (D5) and the grain yield from 0.524 t ha⁻¹ (D1) to 3.062 t ha⁻¹ (D5) (Table 5). The grain yield was noticed 37.19% of this site when compared with control. It was observed that there is a reduction in grain, straw and biological yield of wheat as 17.59%, 17.77% and 17.71% respectively on the southern aspect compared to northern aspect within the same elevation level under traditional agroforestry systems.
to Sahgal et al. (2003), the *G. optiva* is one of the most important fodder trees of north-western and central Himalaya and is found distributed throughout the Sub-Himalayan tracts. The species is considered as a boon for the Himalayan regions by several workers (Chandra and Sharma, 1977; Singh, 1982; Sehgal and Chauhan, 1989; Khybri et al., 1992; Nautiyal et al., 1998; Bhatt and Pathak, 2003). In the hilly areas of Garhwal Himalaya, farmers commonly use FYM in their fields after the harvest of Rabi and Kharif crops. The terraces have generally an outward slope therefore, after rains; the nutrients of FYM are washed away towards the bunds, where the farmers are deliberately retaining the fodder trees. These trees get sufficient nutrients from FYM, hence, have good growth and development. The practice of agroforestry justified that in agrihorticulture systems, the interaction of annual crops with fruit trees in different ecological regions of the country have shown quite encouraging response in terms of multiple outputs, with assured income generation (Bhuva et al., 1989; Randhawa, 1990; Chundawat, 1993; Saroj et al., 2000; Osman, 2003). Khybri et al. (1988) recorded the adverse effect of trees near the tree base, which subsequently increased with the age of trees.

In a similar type of agroforestry systems, Singh (1986) in Himachal Pradesh between 1000 to 2000 m asl, found that *G. optiva*, Celtis australis, Robinia pseudoacacia, Sapindus mukorossii, Melia azedarach, Eucalyptus spp., Bauhinia spp., Juglans regia, Toona ciliata, Quercus leucotrichophora, Populus spp., Prunus spp., Cedrus deodara, Quercus floribunda, Morus serrata etc. were the prominent tree species raised by farmers on bunds of their fields. On the other hand Tejwani (1987) also enlisted the tree species used in agroforestry systems in Uttar Pradesh and Himanchal Pradesh between 500 to 2300 m elevation and revealed the same tree species i.e., *Grewia optiva*, *Celtis australis*, *Quercus spp.* as reported in this study, except few tree species i.e., *Bauhinia variegata* and *Ficus roxburghii*, which were reported from Himachal Pradesh (Toky et al., 1989).

All the growth and yield attributes of wheat were decreased highest in closer vicinity of tree trunk at 1 m and lowest at 5 m from the tree trunk. The maximum yield was recorded in open condition. Similarly the number of wheat plant/m² was minimum at 1 m and maximum at 5 m away from tree trunk in all the sites. The minimum number of wheat plant near the tree trunk is primarily due to low amount of sunlight received by the plant and human interference while climbing the tree for consecutive collection of fodder. There could be a leachats form the branches and leaves are maximum at the basement of the tree. Sharma et al., (2000) was observed the similar results of reduction in plant population of wheat crop (34.2%) due to poplar tree at 0-3 m distance from tree base when compared with control. Though there was no proper trend was observed in the crop height under different distances from tree trunk, it is generally decreased in different sites as the distance from the tree trunk increased except in the distance of 5 m. The control (open) field had higher crop height compared to plants under shade. The reason behind more height of crop under shade for tendency to approach sunlight for photosynthesis, moreover plants have got the photophyllic nature and they incline in the direction of sunlight. The
reduction in the grain yield was reported to be significantly (p<0.01, Table 2, Table 3, Table 4, Table 5) higher up to 1 m compared at 5 m distance in different sites. The diameter and crown spread were directly correlated with the grain yield and with increase of diameter and crown spread the yield was significantly reduced, thus light becomes the limiting factor. The crown spread plays a significant role in grain yield and the yield decreased with increase of crown spread. The crown index (ratio of crown length and crown width) gives the exact status of shade under tree. Some time the crown spread is more but the thickness/length of crown is lower, therefore both crown length and crown width have role to block the sun light. The G. optiva is extensive lopped during the winter period that also sometimes plays positive role in penetration of sun light to the grown level. The gradual and continuous collection of fodder from the tree also lead trampling of the wheat crop and that also create a reasonable part to reduce the yield of the wheat.

**Acknowledgement**

The authors are grateful to the Director, IIFM, Bhopal, India; Vice Chancellor and Principle, College of Horticulture and Forestry, Navsari Agricultural University, India and the anonymous reviewers for support and guidance. The farmers of the study sites are deeply acknowledged.

**References**

[1] Bhatt, R.K. and Pathak, P.S. 2003. Upscaling quality fodder production in semi-arid tropics by Grewia optiva. ICAR News. 9 (1) January to March 2003.

[2] Bhava, H.P., Ktordia, J.S., Patel, G.L. and Chundawat, B.S. 1989. Response of intercropping on economics and effect on main crop of mango under South Gujrat conditions. Acta. Hort. 231: 316-320.

[3] Chandra, J.P. and Sharma, R. 1977. Note on nursery techniques of buel (Grewia optiva). Indian Forester 103: 684-685.

[4] Chundawat, B.S. 1993. Intercropping in orchards. Advances Hort. 2: 763-775.

[5] James, D.N. 1988. Deep ecology meets the developing world. In: E.O.Wilson (ed.), Biodiversity, Pub. National Academy of Sciences, U.S. pp 79-82.

[6] Khybri, M.L., Gupta, R.K. and Sewa Ram. 1988. Effect of Grewia optiva, Morus alba and Eucalyptus hybrid on the yield of crops under rainfall conditions. Annual Report, CSWCTR, Dehradun.

[7] Khybri, M.L., Gupta, R.K., Ram, S. and Tomar, H.P.S. 1992. Crop yields of rice and wheat grown in rotation as intercrops with 3 tree species in the outer hills of Western Himalaya. Agroforestry Systems 17 (3): 193-204.

[8] Khybri, M.L., Gupta, R.K., Ram, S. and Tomar, H.P.S. 1992. Crop yields of rice and wheat grown in rotation as intercrops with 3 tree species in the outer hills of Western Himalaya. Agroforestry Systems 17 (3): 193-204.

[9] Mishra, R. 1968. Ecology Work Book Oxford and IBH Publishing Co., Calcutta, pp 244.

[10] Nautiyal, S., Maikhuri, R.K., Semwal, R.L., Rao, K.S. and Saxena, K.G. 1998. Agroforestry Systems in the rural landscape-a case study in Garhwal Himalaya, India. Agroforestry Systems 41 (2): 151-165.

[11] Osman, M. 2003. Alternate land use systems for sustainable production in rainfall areas. In: F. S. Pathak and Ram Newaj (eds.) Agroforestry-potential and opportunities. pp 171-181.

[12] Ralhan, P.K., Negi, G.C.S. and Singh, S.P. 1991. Structure and function of the agroforestry system in Pithoragarh district of central Himalaya: an ecological viewpoint. Agric Ecosyst Environ. 55: 283-296.

[13] Randhava, K.S. 1990. Pulses based cropping systems in juvenile orchards, International symposium on Natural Resource Management for Sustainable Agriculture, New Delhi.

[14] Saroj, P.L., Samra, J.S., Sharma, N.K., Dadhwal, K.S., Shrimali, S.S. and Arora, Y.K. 2000. Mango based agroforestry systems in degraded foothills of north-western Himalayan region. Indian Journal of Agroforestry 1: 121-128.

[15] Saroj, P.L. and Dadhwal, K.S. 1997. Present status and future scope of mango based agroforestry systems in India. Indian Journal of Soil Conservation 25 (2): 118-127.

[16] Sehgal, R.N. and Chauhan, V. 1989. Grewia optiva an ideal agroforestry tree of Western Himalaya. Farm Forestry News. Winrock International USA.

[17] Sehgal, R.N., Rathore, A. and Chauhan, S.K. 2003. Divergence studies in selected genotypes of Grewia optiva. Indian Journal of Agroforestry 5 (1&2): 99-102.

[18] Semwal, R.L. and Maikhuri, R.K. 1996. Structure and functioning of traditional hill agroecosystems of Garhwal Himalaya. Biological Agriculture and Horticulture 13: 267-289.

[19] Singh, G., Singh, N.T., Dagar, J.C., Singh, H. and Sharma, V.P. 1997. An evaluation of agriculture, forestry and agroforestry practices in a moderately alkalai soil in northwestern India. Agroforestry Systems 37: 279-295.

[20] Singh, R.V. 1982. Fodder trees of India. Oxford and IBH Publ. Co., New Delhi, pp 663.

[21] Singh, R.V. 1986. People’s participation in social forestry programme in Himachal Pradesh. F.R.I., Dehradun, pp 28.

[22] Singh, S.P. and Singh, J.S. 1992. Forest of the Himalaya: Structure, Functioning and Impact of Man. Gyanodaya Prakashan, Nainital, India, pp 294.

[23] Snedecor, G.W. and Cochran, W.G. 1967. Statistical Methods. Oxford and IBH Publishing Co., New Delhi.

[24] Sundriyal, R.C., Rai, S.C., Sharma, E. and Rai, Y.K. 1994. Hill agroforestry Systems in south Sikkim, India. Indian Journal of Agroforestry 7 (2): 127-130.

[25] Toky, O.P., Kumar, P. and Khosla, P.K. 1989. Structure and functioning of Man. Gyanodaya Prakashan, Nainital, India; Vice Chancellor and Principle, College of Horticulture and Forestry, Navsari Agricultural University, India and the anonymous reviewers for support and guidance. The farmers of the study sites are deeply acknowledged.

**References**

[1] Bhatt, R.K. and Pathak, P.S. 2003. Upscaling quality fodder production in semi-arid tropics by Grewia optiva. ICAR News. 9 (1) January to March 2003.

[2] Bhava, H.P., Ktordia, J.S., Patel, G.L. and Chundawat, B.S. 1989. Response of intercropping on economics and effect on main crop of mango under South Gujrat conditions. Acta. Hort. 231: 316-320.

[3] Chandra, J.P. and Sharma, R. 1977. Note on nursery techniques of buel (Grewia optiva). Indian Forester 103: 684-685.

[4] Chundawat, B.S. 1993. Intercropping in orchards. Advances Hort. 2: 763-775.

[5] James, D.N. 1988. Deep ecology meets the developing world. In: E.O.Wilson (ed.), Biodiversity, Pub. National Academy of Sciences, U.S. pp 79-82.

[6] Khybri, M.L., Gupta, R.K. and Sewa Ram. 1988. Effect of Grewia optiva, Morus alba and Eucalyptus hybrid on the yield of crops under rainfall conditions. Annual Report, CSWCTR, Dehradun.

[7] Khybri, M.L., Gupta, R.K., Ram, S. and Tomar, H.P.S. 1992. Crop yields of rice and wheat grown in rotation as intercrops with 3 tree species in the outer hills of Western Himalaya. Agroforestry Systems 17 (3): 193-204.

[8] Khybri, M.L., Gupta, R.K., Ram, S. and Tomar, H.P.S. 1992. Crop yields of rice and wheat grown in rotation as intercrops with 3 tree