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Rehabilitation of old river bed lands by an intensively managed silvi-pastoral system in the north-west Himalayas

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ABSTRACT

Coarse sediments deposited as gravel bars along seasonal rivers, which often overflow, deposit them on arable lands rendering them unproductive. Rehabilitation of such areas was attempted by a silvi-pastoral system with *Grewia optiva* (J.R. Drummond ex Burret), *Chrysopogon fulvus* (Spreng.) and *Panicum maximum* (Jacq.), which belong to this region. Three tree canopy management practices-coppicing, lopping and pollarding were imposed on *G. optiva* trees at the age of 5 years, and tree leaf fodder and woody biomass production were estimated, with and without grasses as understorey components. Results of the study indicate that among the systems evaluated, pollarding system was the most productive method for obtaining higher leaf and woody biomass on a regular basis. Averaged over 9 years, leaf biomass (kg ha^{-1}) from tree only plots recorded was 803.4, 920.0 and 355.4 in the coppiced, pollarded and lopped treatments, respectively. Woody biomass in the same sequence was 3.24 Mg ha^{-1}, 2.81 Mg ha^{-1} and, 1.08 Mg ha^{-1}, respectively. There was an average decline of 37 and 35% in leaf and woody biomass production, respectively, over 9 years as a result of incorporation of the two fodder grasses under different canopy management practices. This long term study indicates that old river bed lands can be rehabilitated by raising *G. optiva* trees alongwith fodder grasses *viz., C. fulvus* and *P. maximum* and managing the tree canopy by pollarding for obtaining fodder and woody biomass on a regular basis.

1. INTRODUCTION

Land degradation due to natural and anthropogenic reasons has increased significantly over the last two decades (Cerdà *et al*., 2009; de la Paix *et al.,* 2013; Salvati *et al.,* 2015). This is more evident in the developing countries which directly affects the livelihood security of millions alongwith an equal number of livestock (Wang *et al.,* 2013; Izzo *et al*., 2013; Yan and Cai, 2015; Jafari and Bakhshand-ehmehr, 2013. It has been estimated that nearly 5-7 M ha of arable land is lost annually by land degradation (Lal and Stewart, 1990). Soil erosion undermines the long term viability of agriculture in many parts of the world (Kraaijvanger and Veldkamp, 2014) which directly affects global food security. An analysis by Crosson (1994) indicates that globally there has been a loss of 17% cumulative productivity over 45 years (1945-90) due to soil erosion. Tesfaye *et al.* (2014) investigated the use of tree species for meeting energy needs and also for soil management in Ethiopia.

Improper land use, forest degradation, large livestock population and poor productivity of 'common property resources' in rural India are major causative factors of land degradation. With 2% of the earth's surface area, India supports 15% of the global livestock population and 18% of the human population. The per capita land availability has declined from 0.89 ha in 1951 to 0.37 ha in 1991, and is expected to be 0.20 ha by 2035 (Singh, 2005). The deficit in supply of green and dry fodder would be 64% and 24%, respectively, of the demand by 2020 (Sharda *et al.,* 2010). Studies on soil erosion, soil degradation have been investigated for many years in India, and recent studies include the estimation of production losses due to water erosion in India (Sharda, 2010) which was estimated to be worth US $ 2.51 billion yr^{-1}. An assessment of erosion rates in eastern India was reported by Mandal and Sharda (2013) and Warjri (2019), while Choudhury *et al.* (2014) reported the impact of land use and slopes on soil organic matter concentration in Eastern India. From the north-west alluvial plains in India, Kukal *et al.* (2014) reported upon the carbon fractions under maize-wheat rotation, while from the Shiwalik regions (India), Saha and Kukal (2013) reported the soil structural characteristics under different land use systems. An estimate of erosion prone areas from the Shivalik foot hills was reported by Sushanth *et al.* (2019).

Recent reports indicate that the total area under degraded and wasted lands in India is 114.01 M ha (Maji *et al.,* 2010) with the area affected by water erosion being 23.62 M ha and 8.89 M ha affected by wind erosion. Inappropriate land use in the middle Himalayas (<2800 msl), road construction and consequent deforestation has led to high rates of soil erosion (Samra *et al.,* 1999[a]), that may range from 5 Mg $ha^{-1}yr^{-1}$ in dense forests to 80 $tha^{-1}yr^{-1}$ in the Shiwalik belt alongwith land slips and movement of slope forming material which is carried down the slopes into river valleys and gets deposited as gravel bars along rivers that carry seasonal flows (July-September) often with high sediment load which ranges from 6.0 $M^3ha^{-1}yr^{-1}$ to 98.4 $M^3ha^{-1}yr^{-1}$. The area occupied by these gravel bars in the valley portions of the north-west Himalayas alone is estimated to be 2.73 M ha (Arora and Vishwanatham, 1995). The Doon valley covers an area of 0.21 M ha out of which 0.074 M ha is degraded (Kumar, 2004) with similar problems.

The major constraints in areas covered with gravel bars are shallow soil depth (<20 cm) with high percentage of gravels, pebbles and stones (70-75%), sand (20-25%), silt (3-5%) and clay (2-4%), poor soil organic carbon, poor fertility and high infiltration rates (2.13 cm hr^{-1} to 3.0 cm hr^{-1}). The substratum remains dry for nearly six months (February-July) in a year making the sites unsuitable for drought sensitive plants. Due to the nature of the substratum, no current productive use is possible and the area is occupied by seasonal weeds, grasses and early colonizers like *Acacia catechu*, *Dalbergia sissoo*, *Bombax ceiba* etc. Studies indicated that these areas can be used, with various interventions, for fruit based agri-horticultural systems (Saroj *et al.,* 2004; Rathore *et al.,* 2013) or for the production of firewood (Raizada *et al*., 2014).

Livestock and livestock rearing provide a valuable source of food and income for rural societies worldwide and the sustainability of livestock production system is being increasingly addressed by developing land use practices that can meet fodder requirements of the future. The use of degraded land not fit for cultivation of deep rooted plant species like fruit plants, provides an opportunity to use such lands for the production of fodder and small timber or firewood. Critical evaluation of the use of degraded areas by establishing silvi-pastoral system suggests that they are a viable land use practice to meet small farmer needs for fodder, firewood and small timber (Singh *et al.,* 2008; Mathew *et al*., 1992; Okorio *et al.,* 1994). Silvi-pastoral systems offer several environmental advantages-reduce erosion on sloping lands, allow organic matter build-up and improve soil physico-chemical properties. Trees and grasses simulate the multi-storied physiognomy of natural forests and help in the recovery of degraded habitats through nutrient cycling and enrichment (Nair, 1983).

However, the successful establishment of trees and grasses growing together depends on access to sunlight, water and nutrients. Establishment of understorey vegetation is affected by tree density (Walker *et al.,* 1986), light interception (Wilson, 1996), shade tolerance (Walters *et al.,*1982) and moisture and nutrient availability (Raison *et al.,* 1992). Complete overhead canopy may affect herbage yield (Mathew *et al*., 1992) or may compete for water and nutrients in stressed sites (Balocchi and Philips, 1997). Artificial shading of N deficient pastures can increase growth of grasses by increasing availability of immobilized soil N (Wilson, 1996). High tree density may give excessive shade and lead to detrimental competition (Robinson, 1991).

It is therefore necessary to manage tree canopies in a silvi-pastoral system by lopping, pollarding or coppicing. Canopy management by lopping or pollarding has been reported to improve below tree productivity by enhanced light penetration (Deb-Roy, 1994). Crown pruning is known to modify rooting patterns of trees and below ground processes (Jones *et al.,* 1998). Impact of tree canopy management on fodder grass productivity has been reported earlier by Vishwanatham *et al.* (1999), Samra *et al.* (1999[b]) and Singh *et al*. (2008) from the north-west Himalayas, from semi-arid Central India by Mishra *et al.* (2010), from the semi-arid Deccan by Narendra *et al.* (2011) and from the deserts of Rajasthan by Gupta (1992).

This paper reports on the performance of a silvi-pastoral system using *G. optiva* alongwith two fodder grasses-*P. maximum* (Guinea) and *C. fulvus* (Gorda), which have been raised on gravel bars along the Asan river in the Doon valley situated in the foothills of the north-west Himalayas. The trees were managed in three different ways to determine the most productive method for obtaining fodder and firewood in combination with the selected fodder grasses.

2. MATERIALS AND METHODS

The study was initiated in July, 1996 and continued till December, 2009 at Research Farm, ICAR-IISWC, Dehradun (30°19'N latitudes and 78°02'E longitudes) situated at an elevation of 517 m above mean sea level. Annual rainfall (averaged from 1956 to 1998) is 1646 mm received in about 82 rainy days. Summers are hot and dry while winters are quite cold with occasional frost. The rainfall received during the study period averaged 1485.33 mm, received in

72 rainy days. Nearly 80% of this was received during the monsoon period (July to September) and the rest during December-January. Vegetative growth of almost all plant forms takes place during the summer and rainy seasons (March to September), with drought like conditions experienced frequently during the hot summers (April to June), and plants remain dormant during the winter season.

The experimental site is an old riverbed wasteland where soils have been classified as sandy skeletal typic Ustifluvent soils (Bharadwaj and Singh, 1981). Infiltration rates at these sites are high (2.13 cm hr^{-1} to 3.0 cm hr^{-1}) which is due to sandy soil texture and a permeable stony layer at lower depths of the profile. Gravels of sizes ranging from 0.2 cm to 10 cm constituted 60% of the total weight of the contents excavated from a one cubic meter pit. A detailed description of the soil conditions have been described in Vishwanatham *et al.* (1999).

One year old *G. optiva* (Drumm.) (Vern.-*Bhimal*) seedlings were obtained from the State Forest Nursery and planted during July in pits of size 45 cm^3 at a spacing of 4 m × 4 m giving a density of 625 trees ha^{-1}. Because *G. Optiva* trees provide the only green winter fodder, they are heavily lopped throughout the Himalayan region. Crude protein content of leaves ranges from 15-20% on dry matter basis during different months of the year. Rooted slips of two fodder grasses *viz., C. fulvus* (Spreng.) Chiov. (Red false beard grass) and *P. maximum* Jacq. (Guinea grass) were planted at a spacing of 0.75 m × 0.75 m in each plot during July 1998 (2 years after planting of *G. optiva* seedlings). *C. fulvus* is a native species of the region and grows abundantly in forest openings and dry sites. The fodder is nutritious when green and quality reduces with ripening. *P. maximum* is ideal for the 'cut and carry' system and is shade tolerant, prefers to grow in well drained moist soils and cannot tolerate water logging.

The gross plot size was 256 m^2 (16 m × 16 m) with a net plot of 144 sq m (12 m × 12 m); each net plot had four *G. optiva* trees and 256 clumps of grass. There were 11 plots each replicated thrice in a RBD making a total of 33 plots, covering 0.84 ha. There were 11 treatments-coppiced trees only (T_1), pollarded trees only (T_2), lopped trees only (T_3), *C. fulvus* only (T_4), *P. maximum* only (T_5), coppiced trees with *C. fulvus* (T_6), pollarded trees with *C. fulvus* (T_7), lopped trees with *C. fulvus* (T_8), coppiced trees with *P. maximum* (T_9), pollarded trees with *P. maximum* (T_{10}), and, lopped trees with *P. maximum* (T_{11}).

The trees and grasses were maintained completely under rainfed conditions, and routine weeding and cleaning were carried out. Observations were recorded on tree survival, collar diameter (cm), dbh (cm), tree height (m) and yield of green leaf and woody biomass from loppings. Prunings and coppiced stumps were also estimated once the treatments were imposed on the *G. optiva* trees. Data was also collected on grass survival percent, number of tillers, tiller height (m), and clump diameter (cm). Grass was harvested manually during October each year, biomass obtained was air dried till constant weight, and dry weight was recorded.

After five years of establishment of tree seedlings (in 2001), treatments were imposed on the trees-coppicing was carried out at a height of 10 cm from the ground, pollarding at a height of 1.5 m from the ground, and lopping with 75% canopy removal. Consequent to the treatment imposed on the trees, data collection on fodder yields from grasses from all treatments and biomass from trees obtained annually from trees was continued for the next eight years. Woody biomass obtained from trees was recorded immediately in the field. Leaves were separated manually from the twigs, and green weight recorded. Representative samples of woody biomass were oven dried at 70°C till constant weight, and dry weight was recorded.

The mean effect of treatment (lopping at 75% intensity, pollarding and coppicing) on grass yields and their interactions were analyzed, and data were subjected to standard analysis of variance tests. Statistical analysis for individual year data as well as for the pooled data over the years was carried out using standard methods of analysis. The data were analyzed for significant differences at $P \leq 0.05$ by Duncan's multiple range test (DMRT), using SAS (*ver.* 9.3) statistical software.

3. RESULTS AND DISCUSSION

Performance of Trees

Average seedling height (m) in all plots at the time of planting was 1.43 m, which increased progressively every year reaching 5.43 m in the 5th year when treatment was imposed. Similarly, collar diameter (cm) at the time of planting was 1.76 cm, and diameter at breast height (DBH) at the time of treatment imposition was 6.33 cm with an average canopy spread of 5.44 sq m. By the 5th year, the average survival ranged from 96% in T_2 and T_7 to 100% in T_1, T_6, T_9, T_{10} and T_{11}. The average height of trees was 5.5 m in the plots where the trees were to be coppiced, and 5.76 m in the plots where the trees were to be lopped and pollarded. Average DBH (cm) was 6.46, 6.40 and 6.10 in the trees where coppicing, lopping and pollarding was carried out, respectively.

Performance of Grasses

The number of tillers in *C. fulvus* clumps was much more than *P. maximum* at the time of planting, and the numbers increased rapidly during the monsoons. The number of tillers increased from 48 (on an average) in the first year to 100 per clump by the time of imposition of treatments. Similarly, the number of tillers in *P. maximum* one year after planting averaged about 11 which increased to 24 per clump at the time of imposition of treatment. Tiller height (m) increased rapidly in both the fodder grasses from the 2nd year till the 5th year, when the treatments were imposed. In *C. fulvus,* average tiller height was 1.72 m when treatments were imposed on *G. optiva* trees. As is evident from Fig.1a, tiller height in this grass began to decline after imposition of treatment and reached the lowest value by the 7th and 8th year, below coppiced and lopped trees, respectively. Subsequently, increases were observed in plots with lopped trees, while in all other treatments the tiller height remained at par and reached 1.49 m by the 12th year.

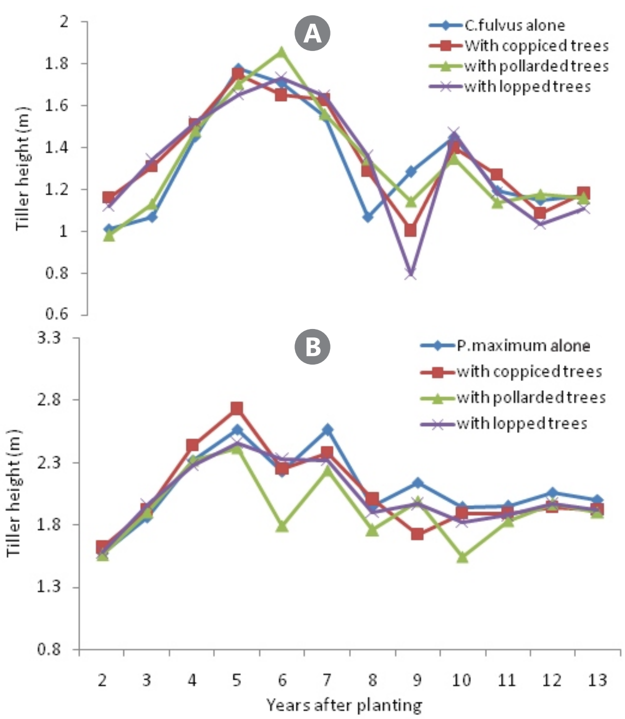

Fig. 1. Variations in tiller height (m) in (A) *C. fulvus* and (B) *P. Maximum* in different treatments with managed *G. optiva* as the over storey tree species

In *P. maximum*, the average height during the 5th year was 2.54 m, but a decline was observed in all the plots after imposition of treatments on the trees (Fig. 1b). However, from the 7th year, marginal increases in tiller height were observed, although differences amongst treatments were not significant. In general, tiller height in plots with pollarded trees was lower than other treatments although by the 12th year, tiller height was 1.91 m on an average across all the plots.

Imposition of treatments in the 5th year yielded different quantities of tree components. The highest biomass was obtained in the plots where the trees had been coppiced with leaf quantity of 635 kg ha^{-1} being obtained from trees with *P. maximum* as the under storey grass (Table 1), while from trees alone plots, leaf biomass of 625 kg ha^{-1} was obtained. Stem biomass of 3275 kg ha^{-1} at the age of 5 years was obtained from coppiced trees alone and coppiced trees with *C. fulvus*, while the quantity of leaf biomass obtained with *P. maximum* was only 690.50 kg ha^{-1}. In the pollarded trees the amount of leaf biomass from trees alone and trees with *C. fulvus* was nearly similar, but was lower by 35.4% in trees with *P. maximum* as the understorey. Stem biomass from the pollarded trees alone was 61.4% and 53.80% more over trees growing in combination with *C. fulvus* and *P. maximum*, respectively. In the lopped trees, maximum leaf biomass was obtained from the tree only plot (293.75 kg ha^{-1}) followed by that with understorey of *P. maximum* and *C. fulvus* plots (Table 1).Woody biomass obtained by lopping of the canopy was highest from trees with *P. maximum,* and least in plots with *C. fulvus*.

Green Biomass Production from Grasses

Green biomass from *C. fulvus* was harvested one year after planting (October, 1997), and yields were 3 Mg ha^{-1} and 2 Mg ha^{-1} in plots with *C. fulvus* alone and plots with three year old *G. optiva* trees (average of three plots), respectively. Within these *G. optiva* plots, grass yields varied from 1.65 Mg ha^{-1} to 2.47 Mg ha^{-1}, indicating significant heterogeneity in the area due to the nature of the

Table: 1

Biomass (kg ha^{-1}) available from various tree-grass combinations at the time of imposition of treatment (after five years of tree establishment) in the silvi-pastoral systems

Treatment	Green leaf Biomass	Oven dry weight of twigs	Over dried branch biomass	Oven dried stem biomass	Total
Coppiced trees only	625	88.05	2827.50	3275.00	8195
Coppiced trees with *P. maximum* as understorey	635	607.20	2402.00	2070.25	6119.25
Coppiced trees with *C. fulvus* as understorey	419.37	372	1441.25	3275.00	5755.62
Pollarded trees only	328.12	366.75	1293.75	1115	3348.12
Pollarded trees with *P. maximum* as understorey	212.50	268.50	1079.00	725.00	2464.00
Pollarded trees with *C. fulvus* as understorey	329.37	267.15	1077.00	690.50	2542.12
Lopped trees only	293.75	292.05	1259.25	-	2039.75
Lopped trees with *P. maximum* as understorey	262.50	327.45	1754.00	-	2562.25
Lopped trees with *C. fulvus* as understorey	116.87	132.15	635.50	-	970.62

Coppiced trees were harvested at 10 cm from ground level; pollarded trees were harvested at a height of 1.5 m from ground level; in lopped trees, 75% of canopy was removed by selective cutting using secateurs.

underlying soils and substratum. Green biomass production progressively increased every year till the 5th year when the treatments were imposed on the *G. optiva* trees. Biomass production in the control (*C. fulvus* alone) plot continued to increase till the 6th year when a yield of 1.83 Mg ha^{-1}was recorded (Fig. 2a). Biomass yields in the plots with coppiced trees continued to increase after imposition of treatments and reached a value of 12.74 Mg ha^{-1} by the 7th year after which there was a decline. Yields again improved and reached 9.6 Mg ha^{-1} by the 12th year. In plots with pollarded *G. optiva* trees, *C. fulvus* yields indicated a similar trend producing 12.8 Mg ha^{-1} in the 7th year (Fig. 2a), and similar trends were observed in the plots with lopped *G. optiva* trees where yields began to decline after the 6th year and reached the lowest by the 11th year (0.94 Mg ha^{-1})

In *P. maximum* green biomass yields continued to increase till the 7th year after planting in all the plots, except in the control plot where yields continued to increase till the 8th year reaching 15.77 Mg ha^{-1} after which yields declined, reaching the lowest value in the 9th year (3.55 Mg ha^{-1}). Biomass yield trends in the plots with managed trees followed a similar trend and reached the lowest values in the 9th year, increased again from the 11th year and declined in the 13th year (Fig. 2b).

Trends indicate that tree management practices did influence biomass yields of grasses and led to reduction in yields along with the site bio-physical conditions that led to high stress levels in the dry periods (February to June every year). These trends are in contrast to an earlier report by Semwal *et al.* (2002) who reported that low lopping intensities did not affect crop yields but high lopping intensities led to higher photosynthetically active radiation (PAR) reaching the crops, and hence higher yields were recorded. This may also be attributed to the tree and understorey combination and site conditions of this study.

Leaf Fodder Production from *G. optiva* Trees

Production of green leaves for use as fodder varied among different treatments and the quantity was less than that produced from trees grown as control (no grass as understorey), indicating the competitive effect of grasses on the trees. In the control plots, the quantity of leaf biomass produced during the first year of treatment in the coppiced trees (1 kg tree^{-1}) increased over time reaching a value of 2.5 kg tree^{-1} by the 4th year. Averaged over 9 years, the quantity of leaf biomass was 1.44 kg tree^{-1} which is equal to 803.44 kg ha^{-1} at the current tree density of 625 trees ha^{-1}. In the pollarded trees, leaf biomass available was 0.526 kg tree^{-1} which increased to 2.55 kg tree^{-1} by the 6th year, after which there was a decline. Averaged over 9 years, leaf biomass of 1.47 kg tree^{-1} or 920.74 kg ha^{-1} could be obtained from pollarded trees. Leaf biomass in lopped trees averaged 0.56 kg tree^{-1} (350 kg ha^{-1}) over a 9 year period, the values increasing from 0.50 kg tree^{-1} in the first year of treatment to 1.17 kg tree^{-1} by the 13th year (Fig. 3a) yielding 355.44 kg ha^{-1}.

Incorporation of *C. fulvus* as the herbage component led to a decline in leaf fodder production in all the treatments. Leaf yields during the first year in the coppiced trees were 32% lower than the control (only tree) plots and remained lower over the entire study period. Averaged over 9 years, leaf biomass was only 0.56 kg tree^{-1}(352.44 kg ha^{-1}), which is 61% lower than the control trees (Fig. 3a). In the pollarded trees, leaf yields at the time of imposition of treatments was 0.53 kg tree^{-1} which is nearly similar to the control trees, and values increased in the second year to 0.96 kg tree^{-1} and later remained higher than the first year values. Averaged over 9 years, leaf yields were 1 kg tree^{-1} (623.52 kg ha^{-1}) which is 32% less than the leaf yields from the control plots. Leaf yields in the lopped trees were 0.18 kg tree^{-1} in the first year which increased to 0.55 kg tree^{-1} by the 5th year and to 0.86 kg tree^{-1} by the 9th year. Averaged over a 9 year period, leaf biomass was 0.43 kg tree^{-1} (272.06 kg ha^{-1}) which is 23% less than the lopped trees in the control plots (Table 2).

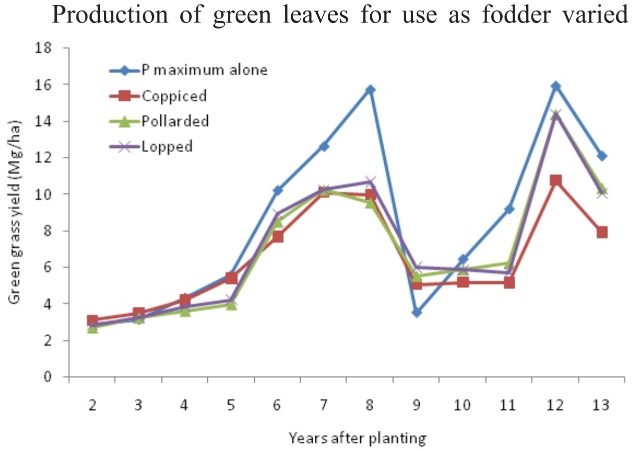

Fig. 2a: Green grass yields (Mg ha^{-1}) obtained from *P. maximum* in association with managed *G. optiva* trees

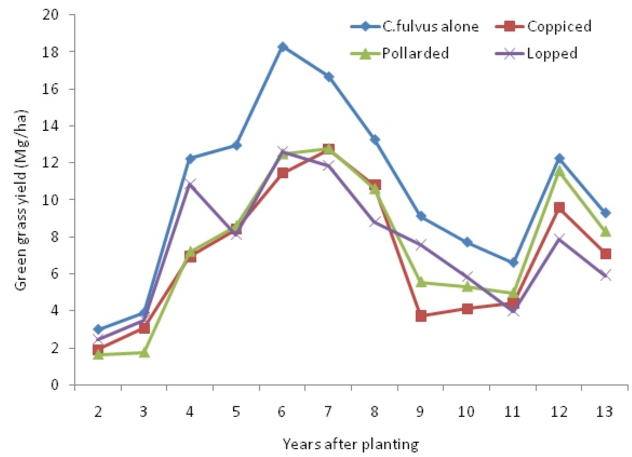

Fig. 2b: Green grass yields (Mg ha^{-1}) obtained from *C. fulvus* in association with managed *G. optiva* trees

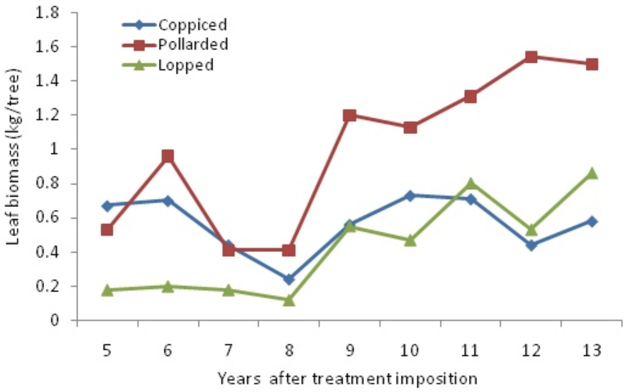

Fig. 3a. Green leaf biomass production from *G. optiva* under different treatments with *C. fulvus* as the understorey grass

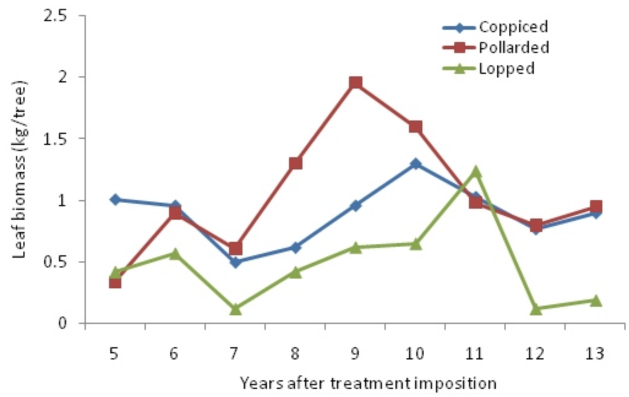

Fig. 3b. Green leaf biomass production from *G. optiva* under different treatments with *P. maximum* as the understorey grass

In coppiced *G. optiva* trees with *P. maximum* as the understorey herbage, the leaf yields in the first year was about 1 kg tree^{-1} which declined to 0.5 kg tree^{-1} in the 3rd year, and increased to 1.30 kg tree^{-1} in the 6th year, and remained at about 1 kg tree^{-1} in the succeeding years (Fig. 3b). Averaged over 9 years, the leaf yields in coppiced trees was 0.87 kg tree^{-1} (544.46 kg ha^{-1}) which is nearly 40% less than the yields from the control plots.

In pollarded trees with *P. maximum*, leaf yields in the first year were 0.33 kg tree^{-1} which increased to 0.9 kg tree^{-1} in the 2nd year, and further to 2 kg tree^{-1} in the 5th year, and declined subsequently. On an average, leaf yields over 9 years was 0.95 kg tree^{-1} (597.3 kg ha^{-1}) which is 35% lower than the yields from trees in the 'no grass' (control) plot. In the lopped trees with *P. maximum*, leaf fodder yields in the first year was 0.42 kg tree^{-1} which increased to 0.56 kg tree^{-1} in the 2nd year, and then to 1.2 kg tree^{-1} by the 7th year (Fig. 3b). On an average of 9 years, leaf biomass produced was 0.66 kg tree^{-1} (419.06 kg ha^{-1}) which is 18% more than the trees growing without grass as understorey (Table 2).

A comparison of the leaf biomass production (kg ha^{-1}) from the various treatment combination indicates (Table 2) that among all treatments, leaf fodder production over 8 years is highest from the pollarded trees even with the association of two fodder grasses as understorey species. Leaf biomass was significantly higher in comparison to coppiced and lopped trees in the tree alone plots and plots with *C. fulvus* and *P. maximum* (row M_o in Table 2). Even if the year of treatment imposition (at the age of 5 years) is excluded (because of the high biomass obtained in that particular year) from estimating the average (row M_t in Table 2), the differences in the leaf biomass produced from pollarded *G. optiva* trees are significantly higher than the other treatments.

Table: 2

Effect of tree management practices and inter-cropped grass species on tree leaf fodder production (kg ha^{-1})

Years after planting	Trees alone			Trees with *C. Fulvus*			Trees with *P. Maximum*			LSD
	T_1	T_2	T_3	T_6	T_7	T_8	T_9	T_{10}	T_{11}	
5*	626.25^{a}	328.75^{ab}	312.50^{b}	420.00^{ab}	330.00^{ab}	116.25^{b}	635.62^{a}	209.80^{b}	261.67^{b}	308.58
6	883.95^{a}	654.38^{ab}	340.20^{bc}	437.08^{bc}	598.13^{ab}	128.75^{c}	598.55^{ab}	558.33^{ab}	357.50^{bc}	326.09
7	942.70^{b}	2155.20^{a}	138.95^{c}	273.55^{bc}	255.20^{bc}	114.80^{c}	304.80^{bc}	382.30^{bc}	73.13^{c}	706.64
8	1542.30^{a}	630.20^{b}	89.38^{b}	149.38^{b}	255.20^{b}	77.08^{b}	250.00^{b}	287.50^{b}	62.50^{b}	842.05
9	489.58^{c}	1041.67^{ab}	320.83^{c}	352.08^{c}	750.00^{bc}	341.67^{c}	602.08^{bc}	1225.00^{a}	387.50^{c}	451.80
10	662.50^{bcde}	1593.75^{a}	312.50^{e}	456.25^{cde}	706.25^{bcd}	293.75^{e}	812.50^{bc}	1000.00^{b}	406.25^{de}	382.93
11	861.25	651.05	681.88	443.13	820.83	505.83	646.88	616.05	777.50	NS
12	454.38	601.87	269.38	274.80	962.70	335.00	482.50	501.88	701.67	NS
13	768.13	629.80	733.33	365.63	933.33	535.42	564.58	594.80	743.75	NS
Mean$_t$	825.60^{ab}	994.74^{a}	360.81^{bc}	343.99^{bc}	660.21^{abc}	291.54^{c}	532.74^{abc}	645.73^{abc}	438.73^{bc}	556.00
Mean$_o$	803.44^{ab}	920.74^{a}	355.44^{cd}	352.44^{cd}	623.52^{abc}	272.06^{d}	544.16^{bcd}	597.30^{abcd}	419.06^{cd}	350.24

*Note: (1) Treatment mean followed by same letter within each row are not significantly different at 5% probability level. (2) T_1, T_2 and T_3 are treatments with coppicing, pollarding and 75% lopping of G. optiva trees, respectively. T_6, T_7 and T_8 are treatments in the same sequence with C. fulvus as the understorey grass species and T_9, T_{10} and T_{11} are with P. maximum as the understorey grass species in the same sequence. (3) M_o indicates overall mean and M_t indicates mean after excluding the 5th year biomass data which is the year treatment was imposed. Tree density is 625 trees ha^{-1}. * Treatments on trees were imposed in the 5th year after planting.*

Woody Biomass Production from Managed *G. optiva* Trees

Woody biomass available after imposition of treatments (in the 5th year of establishment) revealed high values in the first year. Subsequently, yields in the coppiced 'tree alone' plots declined from 5.5 kg tree^{-1} to 1.94 kg tree^{-1} by the 6th year and then showed an increase reaching 3.13 kg tree^{-1} by the 9th year. Association of *C. fulvus* led to a decline in this treatment with average yields reaching 2.50 kg tree^{-1} (1.10 Mg ha^{-1}; excluding the first year) while it was 3.45 kg tree^{-1} (2.17 Mg ha^{-1}) in the control plots. In the pollarding treatment, woody biomass yields declined till the 4th year and then increased, yielding on an average about 2.65 kg tree^{-1} (1.67 Mg ha^{-1}) which is about 37% lower than the yields from the control (no grass) plots (2.64 Mg ha^{-1}). Similarly, in case of lopped trees with *C. fulvus,* after an initial decline in yields, increases were observed in the 5th year reaching a value of 2.16 kg tree^{-1} in the 8th year. On an average, yields of 1.31 kg tree^{-1} (0.83 Mg ha^{-1}) were recorded over a period of 8 years (2002-2009) which is 22% lower than the yields from trees in the control plot (1.06 Mg ha^{-1}; Table 3).

Association of *P. maximum* as an understorey fodder grass showed similar patterns with yields on an average (of 8 years) being 1.59, 1.64 and 1.65 Mg ha^{-1} in coppicing, pollarding and lopping treatment, respectively, in comparison to control plots (no grass as understorey) where yields were 2.17, 2.64 and 1.06 Mg ha^{-1}, respectively, which is 36% and 38% lower in case of the first two treatments and 55% higher in the last treatment.

Woody biomass yields (Mg ha^{-1}) from the control plots and plots with grasses are presented in Table 3. Trends indicate that yields after treatment imposition declined in general for the first 3-4 years and then slowly improved, with higher average yields being obtained from the pollarded trees in combination with *C. fulvus* and in the lopped trees in combination with *P. Maximum.*

A comparison of the woody biomass production (Mg ha^{-1}) from the various treatment combination indicates (Table 3) that among all treatments, woody biomass production over 8 years is highest from the pollarded trees even with the association of two fodder grasses as understorey species. Woody biomass obtained by pollarding was significantly higher in comparison to coppiced and lopped trees in the tree alone plots and plots with *C. fulvus* and *P. maximum* (row M_o in Table 3). Even if the year of treatment imposition (at the age of 5 years) is excluded (because of the high biomass obtained in that particular year) from estimating the average (row M_t in Table 3), the differences in the woody biomass produced from pollarded *G. optiva* trees are significantly higher than the other treatments, although the difference between lopped and pollarded trees (after excluding the year of imposing treatment) is not significant. This can be attributed to the age of the trees which have attained optimum canopy dimensions (after 10 years) which is being lopped every year.

Total Biomass Production

Over a period of 9 years (2001-2009), total biomass production from the treated trees were compared with control. Maximum biomass (leaf and woody material) was obtained from pollarded trees in the control plot followed by that obtained from coppiced and lopped trees, respectively. With the inclusion of grasses like *C. fulvus* and *P. maximum* as understorey components, yields from trees declined by

Table: 3
Effect of tree management practices and inter-cropped grass species on woody biomass production (Mg ha^{-1})

Years after planting	Trees alone			Trees with *C. Fulvus*			Trees with *P. Maximum*			LSD
	T_1	T_2	T_3	T_6	T_7	T_8	T_9	T_{10}	T_{11}	
5*	11.85^{a}	4.30^{bc}	1.20^{d}	6.73^{b}	3.03^{cd}	0.55^{d}	10.72^{a}	2.75^{cd}	1.37^{d}	2.72
6	3.47^{a}	3.15^{ab}	1.61^{cd}	2.10^{bc}	2.92^{ab}	0.44^{d}	3.36^{a}	2.69^{abc}	1.64^{c}	1.20
7	2.27^{b}	3.42^{a}	0.33^{c}	0.53^{c}	0.60^{c}	0.33^{c}	0.75^{c}	0.87^{c}	0.31^{c}	0.66
8	3.03^{a}	2.38^{a}	0.29^{b}	0.76^{b}	0.78^{b}	0.20^{b}	0.62^{b}	0.68^{b}	0.40^{b}	1.59
9	1.56^{abc}	2.88^{a}	0.90^{bc}	1.20^{bc}	2.01^{ab}	0.60^{c}	1.66^{abc}	2.53^{a}	1.16^{bc}	1.32
10	1.21^{c}	2.88^{a}	0.99^{c}	1.12^{c}	1.44^{bc}	1.28^{c}	1.60^{bc}	1.93^{b}	1.05^{c}	0.62
11	1.63	1.49	1.33	0.87	1.61	1.16	1.31	1.11	2.10	NS
12	2.25^{bc}	2.90^{ab}	1.59^{bc}	1.19^{c}	2.15^{bc}	1.35^{c}	1.97^{bc}	1.45^{c}	3.62^{a}	1.32
13	1.95	1.98	1.45	1.05	1.88	1.28	1.45	1.67	2.88	NS
$Mean_t$	2.17^{a}	2.64^{a}	1.06^{b}	1.10^{b}	1.67^{ab}	0.83^{b}	1.59^{ab}	1.64^{ab}	1.65^{ab}	2.11
$Mean_o$	3.24^{a}	2.81^{a}	1.08^{cd}	1.73^{bc}	1.83^{bc}	0.79^{d}	2.60^{ab}	1.74^{bc}	1.62^{cd}	0.89

*Note: (1) Treatment mean followed by same letter within each row are not significantly different at 5% probability level. (2) T_1, T_2 and T_3 are treatments with coppicing, pollarding and 75% lopping of G. optiva trees, respectively. T_6, T_7 and T_8 are treatments in the same sequence with C. fulvus as the understorey grass species and T_9, T_{10} and T_{11} are with P. maximum as the understorey grass species. (3) M_o indicates overall mean and M_t indicates mean after excluding the 5th year biomass data which is the year treatment was imposed. Tree density is 625 trees ha^{-1}. *Treatments on trees were imposed in the 5th year after planting.*

21-38%, but the highest total biomass was still obtained from pollarded trees with the understorey grasses. Averaged over 9 years, the biomass production from the three combinations is given in Table 4. Perusal of the table indicates that leaf fodder and woody biomass production was the highest from pollarded *G. optiva* trees in comparison to the other two treatments. Grass yields (Mg ha^{-1}) was nearly similar in all the treatments in case of *C. fulvus,* while in case of *P. maximum* the yields with pollarded and lopped *G. optiva* trees were higher than that obtained from plots with coppiced trees.

A common effect of trees on grasses is to reduce the herbaceous yield beneath the canopy, although this effect is not consistent and in certain cases even 'increases' have been reported - in a *Albizzia lebbeck– P. maximum* association (Lowry *et al.,* 1988) or in *Panicum antidotale* where number of tillers increased under shade of *Melia azadirachta* (Barsila *et al.,* 2013). Tree canopy may modify the micro-climate in general, reduce solar radiation, moderate temperature regime, increase humidity and affect the quality and quantity of forages (Watson *et al.,* 1984). Further, it has been reported that C_4 plants are well adapted to warm temperature, low soil moisture and high light conditions (Kephart *et al.,* 1992). Narendra *et al.* (2011) reported that at different pruning levels, significantly higher clump diameter, tiller numbers, fresh and dry weight of grasses were recorded in periodically pruned trees as compared to 'no pruning' or 'pruning once only'. Our results also indicate that tiller height and tiller numbers in both grasses increased significantly till the 5th year when the canopy was opened and then declined gradually by the 8th year, as has been reported earlier by Singh *et al.* (2008). It appears that under the given site conditions, grasses will survive till the 7-8th year and grow again from new ramets that establish themselves under conducive site conditions.

Production decreases in competing mixtures can be attributed to asymmetric competition and resource pre-emption (Kumar *et al.,* 2001) and this may be more prominent in 'nutrient' rich sites, and conversely in degraded sites, understorey components may show better or 'at par' productivity. Apparently, it appears from the results obtained, that both tree and grass components have shared resources harmoniously (Rao *et al.,* 1998). An earlier study (Raizada *et al.,* 2002) had indicated high organic matter build up in the top soil (0-7.5 cm) in *G. optiva* plantations, which was attributed to high turnover rates of litter. It appears that the shallow rooted grasses have utilized this enriched soil layer to accumulate increased biomass even under the partial shade of the trees. The impact of canopy opening and regeneration was evident during the study with yields increasing gradually after the 9th year, when more light was available to the understorey grasses and rapid vertical growth in tillers took place.

Several workers have investigated the tree-grass competition interface, in which grasses compete for resources in the top soil layers while trees have access to deeper soil layers. Depending on particular situations, trees and grasses may compete for resources where the root systems overlap (Belsky, 1994). While tree roots draw nutrients from deeper layers, the high density of fine roots of trees and grasses in the top 15-30 cm layer may also reduce nutrient leaching (safety net hypothesis; Divakara *et al.,* 2001) or may even improve sub-soil nutrient recovery (Kumar and Divakara, 2001). In studies by Raizada *et al.* (2013) in similar site conditions, it was reported that 80% of the fine roots were confined within 0-20 cm soil layer at 1 m radius around the trees, with 47% of this confined to 0-10 cm incase of *G. optiva*. Even at 2 m distance, 77% of the total fine root biomass was confined to 0-20 cm layer, constituting 64% in the 0-10 cm layer in case of *G. optiva*. However, the complex interactions and competition for resources (water, nutrients and space) are difficult to conclude by simple examination of spatial understorey patterns.

In contrast to higher economic returns normally expected from silvi-pastoral systems in the developed countries (Clason, 1995) by sale of timber, livestock or hay, silvi-pastoral systems in the developing countries are a low input biomass production system that produces renewable energy sources and provides fodder for livestock in fodder scarce regions so commonly observed in the developing countries. Management practices suggested are easy to implement and

Table: 4
Biomass availability (average of 2001-2009) from silvi-pastoral systems under three management practices and two fodder grasses grown as understorey

	Trees alone			Trees with *C. Fulvus*			Trees with *P. Maximum*		
	T_1	T_2	T_3	T_6	T_7	T_8	T_9	T_{10}	T_{11}
Leaf biomass (kg ha^{-1})	803.44	920.74	355.44	352.44	623.52	272.06	544.16	597.30	419.06
Woody biomass (Mg ha^{-1})	3.24	2.81	1.08	1.73	1.83	0.79	2.60	1.74	1.62
Green grass (q ha^{-1})	-	-	-	138.74	140	138	120.5	130	132

Note: T_1, T_2 and T_3 are treatments with coppicing, pollarding and 75% lopping of G. optiva trees, respectively. T_6, T_7 and T_8 are treatments in the same sequence with C. fulvus as the understorey grass species and T_9, T_{10} and T_{11} are with P. maximum as the understorey grass species. Tree density is 625 trees ha^{-1}.

do not require high levels of technical skill, which increases the potential of its adoption. The results indicate that tree management by pollarding is a suitable practice for obtaining significant quantities of green grass and tree fodder, which may vary over years due to rainfall and nutrient availability, and the total yields are higher than that obtained from coppicing and lopping. This practice can be popularized as in case of alder (*Alnus nepalensis*) in north-east India which are pollarded continuously for many years in combination with crops (Dhyani,1998; Rathore *et al.,* 2010) or as a conservation measure (Dabral, 2002) in areas affected by slash and burn (swidden) agriculture. Pollarding is also a well-known canopy management practice in *Erythrina poeppigiana* trees raised in coffee plantations (Russo and Budowski, 1986) and more recently reported in *Salix fragilis* from India (Rawat *et al.,* 2010).

4. CONCLUSIONS

Old river bed lands in the north-west Himalayas can be rehabilitated for fodder and woody biomass production by a managed silvi-pastoral system with *G. optiva* trees (at a density of 625 trees ha^{-1}) pollarded (at a height of 1.5 m) and suitable fodder grasses like *C. fulvus* and *P. maximum* raised as understorey herbage species. It is expected that that such a managed land use practice will lead to significant improvement in soil physico-chemical properties that might assist in the initiation or facilitation of secondary succession with native forest species and their gradual establishment on the river banks.

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REFERENCES

Arora, Y.K. and Vishanatham, M.K. 1995. Alternate land use systems for marginal and boulder riverbed lands. In: *Torrent Menace: Challenges and Opportunities*. Central Soil and Water Conservation Research and Training Institute, Dehradun. Sastry, G., Sharda, V.N., Juyal, G.P. and Samra J.S. (eds), pp 159-163.

Balocchi, O.A. and Philips, C.J.C. 1997. Grazing and fertilizer management for establishment of *Lotus suliginosus* and *Trifoliumsubterraneum* under *Pinusradiata* in Southern Chile. *Agrofor. Syst.,* 37: 1-14.

Barsila, S.R., Devkota, N.R. and Barsila, I. 2013. Persistency of common fodder grasses under *Meliaazedarach* based silvo-pastoral system. *Global J. Sci. Frontier Res.,* 13(a) (online ISSN: 2249-4626).

Belsky, A.J. 1994. Influence of trees on savanna productivity: tests of shade, nutrients and tree grass competition. *Ecol.,* 75: 922-932.

Bharadwaj, S.P. and Singh, P.N. 1981. *Soils, Land Capability and Land Use Characteristics of Soil Conservation Research Farm, Dehradun.* Bulletin No.7-14/D-11, Dehradun, 23p.

Cerdà, A., Giménez-Morera, A. and Bodí, M.B. 2009. Soil and water losses from new citrus orchards growing on sloped soils in the western Mediterranean basin. *Earth Surf. Proces. Landfor.,* 34: 1822-1830 (doi: 10.1002/esp.1889).

Choudhury, B.U., Fiyaz, A.R., Mohapatra, K.P. and Ngachan, S. 2014. Impact of land uses, agro-physical variables and altitudinal gradient on soil organic carbon concentration of North Eastern Himalayan region of India. *Land Degrad. Dev.* (doi: 10.1002/ldr.2338).

Clason, T.R. 1995. Economic implications of silvipastures on southern pine plantations. *Agro.Syst.,* 29: 227.

Crosson, P. 1994. Degradation of resources as a threat to sustainable production. Paper presented at the First World Congress of Professionals in Agronomy, Santiago, Chile, Sept. 5-8.

Dabral, P.P. 2002. Indigenous techniques of soil and water conservation in north eastern region of India. In: *Proc. of the 12th ISCO Conference*, Beijing, pp 90-96.

De la Paix, M.J., Lanhai, L., Xi, C., Ahmed, S. and Varenyam, A. 2013. Soil degradation and altered flood risk as a consequence of deforestation. *Land Degrad. Dev*, 24: 478-485.

Deb-Roy, R. 1994. Common agroforestry systems and their management for optimizing production. In: *Agroforestry Systems for Degraded Lands.* Vol. I. (eds.) P. Singh, P.S. Pathak and M.M. Roy. Oxford and IBH Publishing, New Delhi, pp 379-387.

Dhyani, S.K. 1998. Tribal alders: an agroforestry system in the North Eastern hills of India. *Agrofor. Today,* 10(4): 14-15.

Divakara, B.N., Kumar, B.M., Balachandran, P.V. and Kamalam, N.V. 2001. Bamboo hedgerow systems in Kerala, India: Root distribution and competition with trees for phosphorus. *Agrofor. Syst.* 51: 189-200.

Gupta, R.A. 1992. The economics of tree crops on marginal agricultural lands with special reference to the hot region in Rajasthan, India. *Int. Tree Crops J.* 2: 155-194.

Izzo, M., Araujo, N., Aucelli, P.P.C., Maratea, A. and Sánchez, A. 2013. Land sensitivity to Desertification in the Dominican Republic: an adaptation of the ESA methodology. *Land Degrad. Dev.,* 24: 486-498.

Jafari, R. and Bakhshandehmehr, L. 2013. Quantitative mapping and assessment of environmentally sensitive areas to desertification in central Iran. *Land Degrad. Dev.* (doi: 10.1002/ldr.2227).

Jones, M., Sinclair, F.L. and Grime, V.L. 1998. Effects of tree species and crown pruning on root length and soil water content in semi-arid agroforestry. *Plant and Soil,* 201: 197-207.

Kraaijvanger, R. and Veldkamp, T. 2014. Grain productivity, fertilizer response and nutrient balance of farming systems in Tigray, Ethiopia: A multi-perspective view in relation to soil fertility degradation. *Land Degrad. Dev.* (doi: 10.1002/ldr.2330).

Kephart, K.D., Buxton, D.R. and Taylor, S.E. 1992. Growth of C_3 and C_4 perennial grass in reduced irradiance. *Crop Sci.,* 32: 1033-1038.

Kukal, S.S., Saha, D., Sharma, P. and Sharma, B.D. 2014. Profile distribution of carbon fractions under long-term rice-wheat and maize-wheat production in alfisols and inceptisols of Northwest India. *Land Degrad. Dev.* (doi: 10.1002/ldr.2299).

Kumar, B.M. and Divakara B.N. 2001. Proximity, clump size and root distribution pattern in bamboo: A case study of *Bambusaarundinacea* (Retz.) Willd., Poaceae, in the Ultisols of Kerala, India. *J. Bamboo Rattan,* 1: 43-58.

Kumar, B.M., George, S.J. and Suresh, T.K. 2001. Fodder grass productivity and soil fertility changes under four grass + tree associations in Kerala, India. *Agroforest.Syst.,* 52: 91-106.

Kumar, P. 2004. *Economics of soil erosion, issues and imperatives from India*. Concept Publishing Company, New Delhi.

Lal, R. and Stewart, B.A. 1990. Soil Degradation: A global threat. Advances in Soil Science 11: XIII-XVII.

Lowry, J.B., Lowry, J.B.C. and Jones, R.J. 1988. Enhanced grass growth below canopy of *Albizzialebbeck*. *Nitrogen Fixing Tree Research Reports,* 6: 45-46.

Maji, A.K., Obi Reddy, G. and Sarkar, D. 2010. *Degraded and wastelands of India – Status and Spatial Distribution*. ICAR and NAAS, New Delhi.

Mandal, D. and Sharda, V.N. 2013. Appraisal of soil erosion risk in the Eastern Himalayan region of India for soil conservation planning. *Land Degrad. Dev.,* 24: 430-437.

Mathew, T., Kumar, M., Suresh, B.V.K. and Maheshwaran, K. 1992. Comparative performance of four multipurpose trees associated with four grass species in the humid regions of southern India. *Agrofor. Syst.,* 17: 205-218.

Mishra, A.K., Tiwari, H.S. and Bhatt, R.K. 2010. Growth, biomass production and photosynthesis of *C. ciliaris* L. under *Acacia tortilis* (Forssk.) Hayne based silvo-pastoral system in semi-arid tropics. *J. Environ. Biol.,* 31(6): 987-993.

Nair, P.K.R. 1983. *Soil productivity aspects of agroforestry*. ICRAF, Nairobi, Kenya.85p.

Narendra, A.G., Madiwalar, S.L. and Channabasappa, K.S. 2011. Studies on *Acacia auriculiformis* based silvo-pastoral system. *Karnataka J. Agric. Sci.,*24(3): 350-353.

Okorio, J., Byenkya, S., Wajja, N. and Peden, D. 1994. Comparative performance of seventeen upper storey tree associated with crops in the high lands of Uganda. *Agrofor. Syst.,* 26: 185-203.

Raison RJ, MyersBJ, Benson ML. 1992. Dynamics of *Pinusradiata* foliage in relation to water and nitrogen stress I. Needle production and properties. *For.Ecol. Manag,* 52: 139-58.

Raizada, A., Ghosh, B.N., Jayaprakash, J. and Singh, C. 2014. Biomass production, carbon sequestration and water transmission properties as influenced by densified plantations raised on old river bed lands in the north-west Himalayas. *Indian J. Soil Cons.,* 42(1): 85-97.

Raizada, A., Singh, C. and Singh, G. 2002. Production, nutrient dynamics and breakdown of leaf litter in six forest plantations raised on gravelly flood plains in the lower western Himalayas. *J. Trop. For. Sci.,* 14(4): 499-512.

Raizada, A., Jayaprakash, J., Rathore, A.C. and Tomar, J.M.S. 2013. Distribution of fine root biomass of fruit and forest tree species raised on old river bed lands in the north-west Himalaya. *Trop. Ecol.,* 54(2): 251-261.

Rao, M.R., Nair, P.K.R. and Ong C.K. 1998. Biophysical interactions in tropical agroforestry systems. *Agrofor. Syst.,*38: 3-50.

Rathore, A., Saroj, P.L., Lal, H., Sharma, N.K., Jayaprakash, J., Chaturvedi, O.P., Raizada, A., Tomar, J.M.S. and Dogra, P. 2013. Performance of mango based agri-horticultural models under rainfed situation of Western Himalaya, India. *Agrofor. Syst.* (doi: 10.1007/s10457-013-9646-5).

Rathore, S.S., Karunakaran, K. and Prakash, B. 2010. Alder based farming system: A traditional farming practice in Nagaland for amelioration of *jhum* land. *Ind. J. Trad. Knowl.,* 9(4): 677-680.

Rawat, Y.S., Subhash, C.R., Vishvakarma, Oinam, S.S., Todaria, N.P. and Maikhuri, R.K. 2010. *Salix fragilis* L.: Pollarding potential in dry temperate environment of the north-western Himalaya, India. *Range Manage. Agrofor.,* 31(1): 1-6.

Robinson, J.B. 1991. The growth of *Chlorisgayana* within and adjacent to a plantation of *Euclayptusgrandis*. *Trop. Grassl.,* 25: 287-290.

Russo, R.O. and Budowski, G. 1986. Effect of pollarding frequency on biomass of *Erythrinapoeppigiana* as a coffee shade tree. *Agrofor. Syst.,* 4: 145-162.

Saha, D. and Kukal, S.S. 2013. Soil structural stability and water retention characteristics under different land uses of degraded lower Himalayas of north-west India. *Land Degrad. Dev* (doi: 10.1002/ldr.2204).

Salvati, L., Zitti, M. and Perini, L. 2015. Fifty years on: Long-term patterns of land sensitivity to desertification in Italy. *Land Degrad. Dev.,* (doi: 10.1002/ldr.2226).

Samra, J.S., Dhyani, B.L. and Sharma, A.R. 1999[a]. *Problems and Prospects of Natural Resource Management in the Indian Himalayas: A Base Paper*. CSWCRTI, Dehradun, India.

Samra, J.S., Vishwanatham, M.K. and Sharma, A.R. 1999[b]. Biomass production of trees and grasses in a silvopasture system on marginal lands of Doon valley of north-west India. 2. Performance of grass species. *Agrofor. Syst.,* 46: 197-212.

Saroj, P.L., Awasthi, O.P. and Tomar, D.S. 2004. Evaluation of peach based agri-horti system in degraded foothills of the Himalayan sub-tropics. *Trop. Agric.,* 81(3):167-174.

Semwal, R.L., Maikhuri, R.K., Rao, K.S., Singh, K. and Saxena, K.G. 2002. Crop productivity under differently lopped canopies of multipurpose trees in Central Himalayas, India. *Agrofor. Syst.,* 56: 57-63.

Sharda, V.N., Dogra, P. and Prakash, C. 2010. Assessment of production losses due to water erosion in rainfed areas of India. *J Soil Water Conserv.,* 65(2): 79-91.

Sharda, V.N. 2010. *Central Soil and Water Conservation Research and Training Institute - Vision 2030.* Published by CSWCRTI, Dehradun, Uttarakhand. 36p.

Singh, C., Raizada, A., Vishwanathan, M.K. and Mohan, S.C. 2008. Evaluation of management practices for a *Grewia optiva* – hybrid Napier based silvi-pastoral system for rehabilitating old river bed lands in the north-western Himalayas. *Int. J. Ecol. Environ. Sci.,* 34(4): 319-327.

Singh, S. 2005. Management of degraded lands for sustainable agricultural production – An overview. In: *Watershed Management for Sustainable Production, Livelihood and Environmental Security – Issues and Options*. Lead papers presented at the National Conference on Watershed Management, May 19-21, 2005. Soil Conservation Society of India and G.B. Pant University of Agriculture and Technology, Pantnagar, pp 35-41.

Sushanth, K., Bhardwaj, A. and Rao, B.K. 2019. Assessment of erosion prone areas at hillslope level using WEPP model - A case study in *Patiala-ki-Rao* watershed of Shivalik foot-hills, India. *Indian J. Soil. Cons.,* 47(2):186-193.

Tesfaye, M.A., Bravo-Oviedo, A., Bravo, F., Kidane, B., Bekele, K. and Sertse, D. 2014. Selection of tree species and soil management for simultaneous fuelwood production and soil rehabilitation in the Ethiopian central highlands. *Land Degrad. Dev.* (doi: 10.1002/ldr.2268).

Vishwanatham, M.K., Samra, J.S. and Sharma, A.R. 1999. Biomass production of trees and grasses in a silvo-pasture system on marginal lands of Doon valley of north–west India 1. Performance of tree species. *Agrofor. Syst.,* 46: 181-196.

Wang, T., Yan, C.Z., Song, X. and Li, S. 2013. Landsat images reveal trends in the aeolian Desertification in a source area for sand and dust storms in China's Alashan plateau (1975–2007). *Land Degrad. Dev.,* 24: 422-429.

Walker, J., Robertson, J.A., Penridge, L.K. and Sharpe, P.J.H. 1986. The influence of an *Acacia karoo* tree on grass productivity in its vicinity. *J. Grassland Soc. Southern Afr.,* 4(3): 83-84.

Walters, G.L., Maetris, A. and Pearson, H.A. 1982. Forage response to overstorey reduction on loblolly-short leaf-pine hardwood forest range. *J. Range Manage.,*35(4): 443-446.

Warjri, J.E. 2019. Estimation of soil erosion using revised universal soil loss equation in upper Umiew catchment, East Khasi hills, Meghalaya. *Indian J. Soil Cons.,* 47(2): 156-162.

Watson, V.H., Hagedorn, C., Kroight, W.E., Pearson, H.A. 1984. Shade tolerance of grass and legume germplasm for use in the southern forest range. *J. Range Manage.,* 37: 229-232.

Wilson, J.R. 1996. Shade stimulated growth and nitrogen uptake by pasture grasses in a subtropical environment. *Aus. J. Agric. Res.,* 47(7): 1075-1093.

Yan, X. and Cai, Y.L. 2015 Multi-scale anthropogenic driving forces of Karst rocky desertification in south-west China. *Land Degrad. Dev.,* 26: 193-200 (doi: 10.1002/ldr.2209).