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MANAGEMENT OF AGROFORESTRY SYSTEMS FOR BETTER PRODUCTION ABILITY AND DIVERSIFICATION

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SUMMARY

Diversification and sustainability in production are the two main goals to be achieved through short and long term strategies. Management of agroforestry systems in general and tree component in particular, exert strong influence on the performance and production ability of associated components. Our studies over the last 8 years on location-specific agroforestry models developed for upland terraces as well as silvi-pastoral models for sloping, degraded land in the northwestern Himalayas indicate that suitable tree-crop combinations, followed by proper tree canopy management are the deciding factors for making upland temperate agroforestry a viable and profitable landuse system. Proper tree crown management has been found to regulate belowground and aboveground biological interactions for critical resources between the components of the systems, and also maintains vigour and biomass production ability for prolonged duration. Various canopy management practices - maintenance of tree components as hedgerows at different spacings, retention of canopies by the cutting of stems to different heights, and removal of crown to 25, 50 and 75%- have been found to strongly influence performance, production abilities, and physiological status of associated agricultural crops to a large extent. The findings suggest an additional advantage of suitable management approaches in improving production and monetary gains to the hill farming community.

***Key words*: Agroforestry, biological interactions, canopy management, fuel and fodder, production ability, sloppy degraded land.**

INTRODUCTION

Lesser availability of land and ever increasing demand for fuel, fodder, timber and other minor forest products are the main reasons, which compel small and marginal farmers, especially in Southeast Asian countries, to integrate multipurpose tree species on the farmland. Diversification of existing cropping patterns coupled with development of suitable technology packages is required to cope with the increasing demand for diversified agricultural systems. The development of need based agroforestry models, combining important fuel, fodder and commercial timber tree species with food crops and / or medicinal and aromatic herbs, is probably the right approach in order to balance the equilibrium between demand and supply for basic products. There is a wealth of information available on optimizing conventional agricultural and forestry systems. This knowledge has undoubtedly helped to maximize the productivity, but the rising population coupled with falling productivity, land degradation, soil erosion and loss and over-use of cultivable land are some of the major constraints for sustainable production. The existing land use systems with separate allocation to agriculture and forest are inadequate to meet these demands. Agroforestry, growing of trees + crops together on the farmland, provides a

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viable and promising option to these systems with opportunities to diversify as well as increase overall land productivity. It is necessary to develop viable, acceptable, diversified and sustainable cropping systems, which ensure enhanced crop production by maximizing utilization efficiency of resources available. The integration of trees on the farmland paves the way for the improvement and diversification of existing systems, but creates complex biological interactions (Lawson and Kang 1990, Ong *et al*. 1991, Khybri *et al.* 1992, Rao *et al.* 1998, Gillespie *et al*. 2000, Thakur and Singh 2002, 2003, Dutt and Thakur 2004, Thakur and Kumar 2006). Diversification and sustainability in production are the two main goals and there is an opportunity to explore the possibility of growing commercial tree species together with high value cash crops (HVCP) such as medicinal and aromatic herb species, besides conventional agricultural crops on the farmland without compromising quality of products. This study reports the findings of some of the need based agroforestry models developed for the hilly regions.

MATERIALS AND METHODS

The study site is the transitional zone between sub-temperate and sub-tropical with an elevation of 1200-m amsl in the northwestern Himalayas. The area receives an annual rainfall of 1150 mm, most of which is received during the months from July to September. Summer temperature goes up to 36ºC and winter as low as –1ºC. Field crops grown with agroforestry tree species on the farmland included agricultural crops namely wheat, lentil, soybean, blackgram and maize; medicinal and aromatic herbs - *Ocimum sanctum, O. basillicum, Tagetes minuta, Withania somnifera, Spilanthes acmella.* The plant spacings in case of medicinal and aromatic herb species were generally maintained at 30 x 30 cm (plant x plant) and 40 x 40 cm (row x row). Most of the medicinal herb species were grown during the rainy season (July – Oct), whereas agricultural crops as rabi and kharif crops. Improved grasses namely Setaria and Napier hybrids were grown with tree species on the degraded sloping land. All the agrotechniques essential to maintain crops were undertaken.

Trees were planted in rows with east-west orientation at different plant spacings. Agroforestry tree species included fuel and fodder species like *Leucaena leucocephala, Morus alba, Grewia optiva, Celtis australis, Bauhinia variegata* on agricultural fields and *Robinia pseudoacasia, Grewia optiva, Leucaena leucocephala* on the sloppy land. Improved clones of *Populus deltoides* were planted on the farmland at 8x3 m, 6x4 m 5x5 m and 4x6 m spacings. *Leucaena leucocephala* and *Morus alba* were maintained as hedgerows with different spacings of plants within hedgerows. Other fuel and fodder trees were given different canopy management treatments, namely cutting of trees at different heights or removing the crown partially. Tree canopy management practices included cutting of trees at 0.5, 1.0, 1.5, 2.0, 3.0 and 3.5 m heights. Other canopy management options included treatments like i) no crown removal, ii) 25% crown removal, iii) 50% crown removal and v) 75% crown removal. The agroforestry models are at different stages of development. The morphological parameters of tree species included in different experiments were; height of *Leucaena* and *Morus* was maintained at 2.5 m, collar diameter 71.21 and 85.06 mm, leaf area index 1.23 and 2.33, respectively. *Populus* height, diameter and LAI were 15.57 mm, 12.29 cm and 1.16, respectively. Height, diameter and LAI of *Grewia* in canopy management experiment was 1.50- 4.50 m, collar diameter 10.15 cm and LAI 2.25, respectively. The height of *Grewia, Celtis, Bauhinia* and *Morus* in another system was maintained between 0.50 to 2.0 m. The LAI ranged between 1.10 to 2.33.

The growth and yield parameters of agricultural as well as medicinal and aromatic herbs, grown with and without agroforestry trees were determined following standard methods. Herbage yield in case of medicinal and aromatic plants was determined after harvesting the crop and expressed as q ha^{-1}. Forage yield was estimated after harvesting. Biomass production (foliage + branchwood) was taken in the month of November every year at the end of each growing season. Data were analysed by using technique of analysis of variance in randomized block design with three replications.

RESULTS AND DISCUSSION

The presence of *Leucaena leucocephala* hedgerows in 4^{th} year of growth, decreased yield of economically important organs of medicinal and aromatic herbs in comparison to control without hedgerows (Table. 1). Decline was greater with the closer plant spacings within the hedgerows. Out of the three plant spacings within the hedgerows; *Leucaena* hedgerows (7 m wide) with 1.5-m plant spacing may be adopted as suitable canopy management practice to successfully cultivate medicinal and aromatic herbs for diversification of farming systems.

The findings in Table 2 indicate that 7-m wide hedgerows of *Morus alba* in their 4th year of growth, affected production ability of wheat and soybean intercrops only at closer plant spacing in the hedgerows. Grain yield of both the crops, grown with hedgerows having plant spacings of 2.0 m and / or 2.5 m, was almost equal to the sole crops without hedgerows. *Morus* hedgerows established with 666 or 533 stems ha^{-1} seem to be suitable combination for diversification of productivity under rainfed conditions with little adverse effect on production (Table 2).

The herbal crops namely *Ocimum sanctum, Spilanthes acmella, Tagetes minuta* and *Withania somnifera* grown in space between poplar trees indicate higher yield reduction in comparison to sole crops (Table 3). The presence of poplar trees were not observed to adversely affect herb yield in all the four medicinal crops between 1-2 m distance from the tree line, especially under tree spacings of 8x3 and 6x4 m. Herb yield reduction in all the species under closer *Populus* spacings (5x5 and 4x6m) varied between 33-46% of control up to 1 m distance from tree rows, while the reduction was 15-31% between 1-2 m distance from the tree rows, Wider tree spacings (8x3 and 6x4 m) did not put any adverse effect on the herb yield (Table 3). Diversification of farming systems by growing medicinal and aromatic crops with timber species on the farmland has been found viable option.

In another agroforestry system, *Morus* (7 year-old), an important fuel and fodder tree species and 7 year old Peach (fruit tree) were combined with wheat – soybean and lentil-blackgram cropping sequences. Crops were grown in the spaces between the rows of woody perennials. The tree combinations did not affect leaf area index of agricultural crops. The values under intercropping were almost equal to sole crops without tree combinations, except in soybean , where crop LAI decreased in plots consisting peach or peach + *Morus* (Fig. 1).

Grain Yield: No adverse effect of tree combinations (*Morus* + Peach) at spacings of 8 x 5 m was observed on total grain yield of wheat, lentil, soybean and blackgram (Fig. 2 A). Total yield of all the four intercrops was equal to the sole crops. This is important since wheat, lentil, soybean and blackgram can be grown successfully with peach and *Morus* combinations, without causing any crop yield reduction (Fig. 2 A).

Table 1. Herbs yield in association with 4-year-old hedgerows of *Leucaena leucocephala* established on the farmland.

Plant spacings in hedgerows	*Tagetes minuta*			*Ocimum basilicum*		
	Fresh yield of leaves and flowers (q ha^{-1})	Dry yield of leaves and flowers (q ha^{-1})	Production efficiency (kg ha^{-1}day^{-1})	Fresh yield of leaves and flowers q ha^{-1})	Dry yield of leaves and flowers (q ha^{-1})	Production efficiency (kg ha^{-1}day^{-1})
T_1 (0.50 m)	24.24	10.14	49.41	23.60	6.73	33.65
T_2 (0.75 m)	31.13	11.70	56.93	34.85	10.03	60.33
T_3 (1.50 m)	35.87	14.20	63.33	52.11	15.20	89.60
T_4 (Control)	75.15	22.24	101.40	81.98	26.42	132.50
Mean	41.59	14.57	67.76	48.13	14.59	79.02
LSD 0.05	10.36	3.38	12.01	7.99	2.87	21.04

Table 2. Yield of wheat and soybean in association with 4-year-old hedgerows of *Morus alba* on the agricultural field.

Plant spacings in headgerows	Wheat			Soybean		
	Thousand grain weight (g)	Total plant yield (gm^{-2})	Grain yield (q ha^{-1})	Thousand grain weight (g)	Total plant yield (gm^{-2})	Grain yield (q ha^{-1})
T_1 (1.50 m)	45.3	382	23.2	146	50.4	18.2
T_2 (2.00 m)	46.4	415	25.2	147	54.3	18.5
T_3 (2.50 m)	47.9	448	25.8	152	56.9	19.2
T_4 (Control)	49.6	483	26.7	156	59.0	19.5
Mean	49.3	432	25.2	150	55.2	18.9
LSD 0.05	1.10	16.9	1.1	2.1	3.0	0.8

Table 3. Impact of *Populus* trees planted at different spacings on the yield of herbal species (q/ha) during two consecutive years. D_1 (1 m) and D_2 (2 m) are distances from tree rows.

Tree herb species spacings	*Ocimum sanctum*			*Spilanthes acmella*			*Tagetes minuta*			*Withania somnifera*		
	D_1	D_2	Mean	D_1	D_2	Mean	D_1	D_2	Mean	D_1	D_2	Mean
First year												
8 x 3 m	57.8	73.8	65.8	26.7	33.0	29.9	18.7	24.6	21.7	1.17	1.78	1.48
6 x 4 m	57.0	70.9	64.0	24.9	31.5	28.3	17.8	22.7	20.3	1.18	1.67	1.42
5 x 5 m	53.4	67.7	60.6	23.7	29.6	26.7	16.3	20.6	18.5	1.13	1.57	1.35
4 x 6 m	48.9	65.3	57.1	21.9	28.0	25.0	15.4	19.2	17.3	1.09	1.52	1.31
Control (no trees)	80.9	80.9	80.9	36.2	36.2	36.2	28.6	28.6	28.6	1.95	1.95	1.95
Mean	59.6	71.7		26.7	31.7		19.4	23.1		1.30	1.70	
LSD 0.05												
Tree spacings		1.63			1.79			1.85			0.09	
Distance		1.03			0.50			0.54			0.06	
Spacings x Distance		2.31			1.12			1.20			0.14	
Second year												
8 x 3 m	71.3	90.7	81.0	31.3	39.3	35.3	22.4	28.1	25.3	1.47	1.94	1.71
6 x 4 m	68.1	88.5	78.3	30.3	37.7	34.0	20.3	27.0	23.7	1.44	1.78	1.61
5 x 5 m	66.5	87.0	76.8	28.0	35.3	31.6	18.7	24.3	21.5	1.42	1.66	1.55
4 x 6 m	63.4	82.8	73.1	25.3	33.3	29.3	18.1	23.1	20.7	12.9	15.6	14.3
Control (no trees)	105.8	105.8	105.8	40.6	40.6	40.6	33.7	33.7	33.7	2.0.4	20.4	20.4
Mean	75.0	91.0		31.1	37.2		22.7	27.3		1.53	1.80	
LSD 0.05												
Tree spacings		1.63			1.65			1.20			0.08	
Distance		1.04			0.48			0.76			0.05	
Spacings x Distance		2.30			1.09			1.69			0.12	

Fig. 1. Effect of tree combinations on leaf area index under *Morus* and peach based agroforestry systems. T_1 (4 *Morus* trees $plot^{-1}$), T_2 (4 Peach trees $plot^{-1}$), T_3 (2 *Morus* + 2 Peach trees $plot^{-1}$), T_4 (Sole crop). $LSD_{0.05}$ to compare treatment effects. Wheat (0.12); Lentil (0.15); soybean (0.19); and Blackgram (0.12).

Presence of 7 year-old Peach and *Morus*, individually or in combinations did not significantly affect production efficiency of wheat, lentil, soybean and blackgram under rainfed conditions during this study. Production efficiency of wheat and soybean was slightly lower, when grown as intercrops, whereas there was no impact of woody perennials on the production efficiency in lentil and blackgram (Fig. 2 B).

Morus alba hedgerows established with inter-row spacing of 7 m and within row plant spacings of 1.5, 2.0 and 2.5 m, during their 4th year of growth, were found to differentially influence grain yield of maize (Table 4). For example grain yield was 40.81q ha^{-1} in open plots (without hedgerows), which declined to 27.66 q ha^{-1} (up

Fig. 2. Effect of tree combinations on grain yield (A) and production efficiency (B) under *Morus* and peach based agroforestry systems. T_1 (4 *Morus* trees $plot^{-1}$), T_2 (4 Peach trees $plot^{-1}$), T_3 (2 *Morus* + 2 Peach trees $plot^{-1}$), T_4 (Sole crop). $LSD_{0.05}$ to compare treatment effects. A, Wheat (0.52); Lentil (0.69); Soybean (0.52); and Blackgram (0.26) . B, Wheat (0.71); Lentil (0.54); Soybean (0.52); and Blackgram (0.34).

Table 4. Effect of *Morus* hedgerow spacings on yield attributes of maize with respect to distance from hedgerows. The 0.5 m and 1.5 m are the distances from the hedgerows.

Spacings/Distance	1000 grain weight (g)			Grain yield (q ha^{-1})		
	0.5 m away	1.5 m away	Mean	0.5 m away	1.5 m away	Mean
T_1 (1.5 m)	207.20	220.10	213.60	27.66	28.92	28.29
T_2 (2.0 m)	217.30	224.70	221.00	32.93	34.57	33.75
T_3 (2.5 m)	228.40	232.50	230.40	36.27	38.30	37.28
T_4 (Control)	237.30	237.30	237.30	40.81	40.81	40.81
Mean	222.60	228.65		34.42	35.65	
$LSD_{0.05}$	2.23	0.11		1.42	1.86	

to 0.5 m away from hedgerows) and 28.98 q ha^{-1} (1.5m away from tree rows) under hedgerows with plant to plant within row spacing of 1.5 m (Table 4). The reduction in yield compared to control was comparatively greater at closer distance (0.50 m) than at distance 1.5 m away from the tree rows. The yield reduction beneath hedgerows with tree spacings of 1.5 m up to 0.5 m distance from hedgerows was 31.8% over control (without hedgerows), which declined to 27% up to 1.5 m distance from hedgerows (Table 4). It was true for other yield-related parameters.

Figure 3 indicates the production ability of Setaria and Napier grasses grown on the sloppy degraded land alongwith hedgerows of *Robinia pseudoacacia*. Hedgerows of *R. pseudoacacia* with alley width of 4m during 3rd year of establishment reduced forage yield up to 1-m distance from the hedgerows. Napier hybrid produced substantially higher forage biomass in comparison to Setaria. Plant spacings within the hedgerows did not influence forage yield (Fig. 3).

Fig. 3. Dry forage production of Setaria and Napier growing as alley components with hedgerows of *Robinia pseudoacacia*. $LSD_{0.05}$ to compare critical differences between distances from hedgerows and spacing in Setaria (0.01); and Napier (0.11).

The impact of managed and unmanaged tree canopies on the production ability of agricultural crops under *Morus* based agroforestry system was prominent. The partial removal of crown helped crops to maintain greater production in comparison to crop plants growing beneath unmanaged canopies (Fig. 4). Crop yield reduction was found to be lesser with increasing percentage of removal of crown from no crown removal to 75% crown removal. This relationship indicates that canopy management is essential in order to allow adequate amount of photosynthetically active radiation beneath tree canopies, which drives production processes in agricultural crops. Different canopy management options were tried to manage tree canopies in order to minimise competition with crops as well as to maintain vigour and biomass production potential of tree species. In this experiment *Grewia optiva* trees were managed by cutting stems at 1.5, 3.0 and 4.5 m height. Different quantity of foliage and branchwood biomass was produced at different cutting heights. Stems cut at higher height produced greater aboveground biomass in comparison to stems cut at lower height (Fig. 5).

Fig. 4. Relationship between crop yields and canopy management under agroforestry systems. $LSD_{0.05}$ to compare crop yield and crown removal (3.15).

In another experiment the canopy of 6-year old *Morus* trees was managed by partial crown removal. The removal of crown resulted in decreased production of foliage and branchwood biomass. Unmanaged canopy of *Morus* produced much higher biomass in comparison to trees with 75% crown removal (Fig. 6). However, crown removal permitted adequate transmission of photosynthetically active radiation (PAR) beneath canopies, which regulated production process in agricultural and medicinal crops. This is essential because shade negatively affects crop production (Thakur and Dutt 2003).

The vigour and biomass production ability of *Grewia optiva*, *Celtis australis*, *Bauhinia variegata* and *Morus alba*, important fuel and fodder tree species, managed

Fig. 5. Effect of canopy management on biomass yield in *Grewia optiva* for two consecutive years. Un-manag (no canopy management). $LSD_{0.05}$ to compare critical differences between biomass yield and cutting heights. Leaf (4.30); and Branch (4.52).

Fig. 6. Biomass production and canopy management in *Morus alba* growing with agricultural crops on the farmland. Tree spacing (8 mx5 m, 250 plants per ha). $LSD_{0.05}$ to compare differences between biomass yield and crown removal. Leaf (0.56); and Branch (2.04).

by cutting stems at 0.5, 1.0, 1.5 and 2.0 m was monitored for 3 years after canopy treatments (Fig. 7). Plants of *Grewia* and *Morus* cut at 1.5 and / or 2.0 m produced higher biomass in comparison to *Celtis* and *Bauhinia*. Decline in biomass production over the years was greater in *Celtis* and *Bauhinia* in comparison to *Grewia* , while no decline was observed in *Morus*. This indicates the intrinsic abilities of individual tree species to respond to canopy management practices in subsequent years. The tree species with better ability to tolerate coppicing or pollarding treatments will make better agroforestry tree.

The findings of different experiments conducted by trying various tree-crop combinations and different

Fig. 7. Effect of canopy management on biomass production in four fuel and fodder tree species up to three years after management treatments. $LSD_{0.05}$ to compare differences during first, second and third year of treatments. *Grewia* (10.10, 9.00, 1.60); *Celtis* (1.10, 0.80, 0.30); *Bauhinia* (1.40, 1.20, 0.40); *Morus* (11.10, 8.10, 1.90) for 1st, 2nd and 3rd year, respectively.

canopy management options indicate potential benefits of growing multipurpose tree species in combination with the high value cash crops, especially medicinal and aromatic herbs on the farmland. However, the efficiency of any agroforestry system seems to be mainly driven by the appropriate canopy management practices. The suitable tree canopy management options have minimized competition between the components for critical resources and also maintained vigour and biomass production ability of tree species for longer duration. Reports exist for strong tree-crop competition for resources like water, light, nutrients etc., resulting adverse effects on the production ability of arable crops (Duguma *et al*. 1988, Jha *et al*. 1991, Gillespie *et al*. 2000, Thakur and Dutt 2004). Physiological data, for example, photosynthesis, transpiration, water use efficiency, light transmission ratio for components under different agroforestry systems (data not included) indicated that shade appeared to be more critical for crop production, although root competition can not be ruled out completely. Many previous reports describe dominance of tree components under agroforestry systems (Lawson and Kang 1990, Ong *et al.* 1991, Williams and Gordon 1995, Jose *et al.* 2000, Thakur and Dutt 2003, Rao *et. al*. 2004). However, the management of tree canopy minimizes competition to the agricultural crops, which is desirable *per se*. The above and below ground interactions reflect the resource sharing pattern of the associated crops and trees and thus, control productivity. The findings of the present investigation suggest that lower herbal and crop yields beneath canopies relative to that farther away from the tree trunk, is the result of lesser availability of photosynthetically active radiation beneath tree canopies.

Diversification of farming systems combining fuel, fodder and commercial timber tree species with the high value cash crops under agroforestry intervention, followed by suitable canopy management practices, seems to be a viable option for boosting income of farmers. *Populus* planted at 8x3m and 6x4m proved suitable tree spacings for no or little adverse effect on growth and production of medicinal and aromatic herbal crops; unmanaged canopies can cause yield reduction between 20-60%; heading back of tree canopies at 2 m or 75% crown removal minimises competition with the crops; productivity of degraded land is increased by growing improved grasses with hedgerows of multipurpose tree species.

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