Livelihood security through Litchi (*Litchi chinensis* L.)-based agri-horticultural models for resource-poor communities of Indian Sub-Himalaya

Horticulture sector has played a major role in ensuring livelihood security of marginal and resource-poor farmers of India. The diminishing land resources, water-induced land degradation and steep topography are major concerns for sustainable production and livelihood and soil health security in the Indian Sub-Himalayas[1], leading to low productivity. Horticultural enterprises face more challenges for maintaining their profitability and livelihood security under the changing scenario of climate and complex market forces. Approximately 35.2%, 71.7% and 29.0% area of Doon Valley, Uttarakhand and India respectively is degraded due to water erosion[2,3]. Such lands known as bouldery riverbed lands, are either underutilized or under thin vegetation due to undulating topography, shallow soil depth, high gravel content (70.0%), soil (30.0%), poor soil organic carbon (SOC) content, low water-holding capacity, etc. In spite of receiving an average rainfall 1600 mm/yr, soil remains dry during April to June due to erratic nature of the rains. Judicial use of land and water, integrated with other production resources, will improve the resource base and convert such rainfed degraded riverbed lands for sustainable production for livelihood security[4]. The rainfed areas contribute more than 65% of food production and 80% of horticultural production[5]. In such areas, diversification into fruit-based models with a wider range of preferably legume/vegetable/flower crops is the need of the hour for livelihood security of resource-poor farmers and rehabilitation of degraded lands. Studies have shown that fruit-based models are the most suitable to harvest solar energy in a stratified manner, for the conservation of moisture, reduction of soil erosion, addition of organic carbon leading to increased biological activity and maintenance of sustainable income for poor communities[6] and also creation of off-season employment[7]. In this context, litchi (*Litchi chinensis* L.) holds immense potential in the foothills of the lower Himalaya to utilize, conserve and restore degraded land for securing livelihood of resource-poor farmers. It also improves soil health by diversification with preferably legume intercrops. In the foothills of the Himalaya, the soils originated from limestone rich in calcium under humid subtropical climate, are essential for proper growth and production of litchi fruit in Uttarakhand. The state contributes 12% (about 9,000 ha) of total area and 4% (about 19,000 tonnes) of litchi production in India. Intercropping with litchi gives higher economic returns per unit area compared to other farming systems. Most of the research on litchi-based models has been carried out on arable land with assured input supply, but limited information is available on utilization of degraded lands with resource conservation. Thus, the present study was conducted to evaluate the performance of litchi-based agri-horticulture models for livelihood security on degraded lands of the Indian Sub-Himalaya.

The experiment was conducted at Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Research Farm, Selakui, Dehradun, Uttarakhand between 1995 and 2010. The area is located in the sub-tropical zone of Indian Sub-Himalaya at 30°21′N lat., 70°52′E long. at an altitude of 517 m. The study area receives 1600 mm of mean annual rainfall. In general, May and June are the hottest months with minimum and maximum temperatures of 19.0°C and 37.6°C respectively. The coldest months, December and January witness temperature range 3.6–24°C. Sieve analysis of 1 m^3 soil indicates that only 31% of the material is <2 mm in size, while 69% consists of gravels and boulders (weight basis). The texture of soil is sandy loam, which contains 45.13%, 29.73%, 13.74% and 11.40% of coarse sand, fine sand, silt and clay respectively. The soil is slightly acidic in nature (pH 6.5–7.0), has low SOC (0.5%), total N (0.06%), available P (24.49 kg ha^{-1}), available K (116.42 kg ha^{-1}) and high Ca (0.195%).

One-year-old litchi plants (cv. rose scented) were planted in pits (1.0 m^3) filled with 50 kg FYM with recommended dose of chemical fertilizers at a spacing of 8 × 8 m in July 1995. Drip system was installed for irrigating litchi plants during establishment years and thereafter irrigation was applied during moisture stress period (April to mid-June) considering high infiltration rate (26 mm h^{-1}). The experiment was laid out in randomized block design with three replications. The litchi-based agri-horticultural models (AHMs) were established on 16 m × 16 m plots comprising four litchi plants. Five litchi-based AHMs were studied in the first phase, viz. litchi + cowpea–toria (LCT), litchi + sesame–toria (LST), litchi + pigeon pea (LP), litchi + black gram–toria (LBT), and litchi + okra–toria (LOT) in addition to sole litchi (SL). During the second phase (2006–2010), two litchi-based AHMs, viz. litchi + turmeric (LH) and litchi + colocasia (LC) were studied under closed tree canopy. All the intercrops were raised as rainfed crops with recommended package of practice. The canopy spread and fruit yield of litchi were recorded annually in both phases of study. In case of crops, grain or pod yields were recorded plot-wise (16 m × 16 m) annually. The crop residues were recycled back into the fields. The cowpea equivalent yield (CEY) was calculated for different intercrops and converted into equivalent yield of cowpea based on price of the produce using the formula given below for the first phase[8]. Similarly, turmeric equivalent yield (TEY) for the second phase was calculated.

$$\text{Cowpea equivalent yield (t ha}^{-1}) = \frac{(\text{Yield of intercrop (t ha}^{-1}) \times \text{Selling price (Rs t}^{-1}))}{\text{Selling price of cowpea (Rs t}^{-1})}.$$

To understand the losses incurred in the yields by cultivating a crop as an intercrop instead of as sole crop, yield reductions in cowpea and turmeric (CEYR/TEYR) over sole crops were calculated by considering average yield of sole crop for both phases. The yield reduction was expressed in percentage. The light intensity was measured with a lux meter in different AHMs at monthly intervals and

Table 1. Canopy spread, light transmission and cowpea equivalent yields of litchi-based agri-horticultural models during the first phase

Intercrop attributes during first phase					
AHM	Attributes	1996	2005	Mean	Correlation
LCT	CS	0.65	4.50	2.41	–0.98 (CS & LT)
	LT	66.51	11.34	34.39	–0.99 (CS & CEY)
	CEY	3.51	1.05	2.32	0.99 (LT & CEY)
LST	CS	0.58	4.35	2.30	–0.96 (CS & LT)
	LT	68.85	13.85	32.22	–0.97 (CS & CEY)
	CEY	1.47	0.1	0.75	0.97 (LT & CEY)
LP	CS	0.6	4.55	2.38	–0.99 (CS & LT)
	LT	66.64	10.65	33.62	–0.98 (CS & CEY)
	CEY	1.33	0.18	0.75	0.97 (LT & CEY)
LBT	CS	0.59	4.43	2.37	–0.98 (CS & LT)
	LT	67.23	13.28	34.35	–0.98 (CS & CEY)
	CEY	2.19	0.33	1.34	0.99 (LT & CEY)
LOT	CS	0.58	4.41	2.33	–0.97 (CS & LT)
	LT	67.62	13.53	33.01	0.31 (CS & CEY)
	CEY	0.98	1.82	2.31	–0.28 (LT & CEY)
CD (5%)	CS	0.22	0.18		
	CEY	0.38	0.02		

Fruit yield and soil moisture during first phase					
AHM	Attributes	2000	2005	Mean	Correlation
LCT	SM	12.75	14.69	13.48	0.90 (SM vs FY)
	FY	1.19	6.54	3.56	0.96 (CS vs FY)
LST	SM	11.13	13.6	11.99	0.82 (SM vs FY)
	FY	0.98	5.52	2.93	0.93 (CS vs FY)
LP	SM	12.54	14.86	13.30	0.89 (SM vs FY)
	FY	1.11	6.10	3.24	0.96 (CS vs FY)
LBT	SM	12.75	14.87	13.45	0.89 (SM vs FY)
	FY	1.14	6.27	3.36	0.95 (CS vs FY)
LOT	SM	11.61	14.05	12.53	0.87 (SM vs FY)
	FY	1.01	5.66	3.08	0.94 (CS vs FY)
SL	SM	10.88	13.45	11.79	0.81 (SM vs FY)
	FY	0.87	5.35	2.82	0.92 (CS vs FY)
CD (5%)		0.12	0.15	–	–
		0.25	0.27	–	–

Second phase					
AHM	Attributes	2006	2010	Mean	Correlation
LH	CS	4.98	7.08	6.02	–0.98 (CS & LT)
	LT	10.60	5.30	8.06	–0.99 (CS & TEY)
	TEY	9.7	5.70	7.91	0.97 (LT & CEY)
LC	CS	4.91	6.98	5.93	–0.96 (CS & LT)
	LT	9.50	4.68	7.55	–0.97 (CS & TEY)
	TEY	9.16	4.25	6.95	0.96 (LT & CEY)
CD (5%)	CS	0.09	0.15	–	–
	TEY	0.55	0.10		

Second phase					
AHM	Attributes	2006	2010	Mean	Correlation
LH	SM	14.78	16.41	15.21	0.92 (SM & FY)
	FY	7.40	11.79	9.09	0.80 (CS & FY)
LC	SM	14.56	16.05	14.76	0.90 (SM & FY)
	FY	7.26	10.99	8.55	0.73 (CS & FY)
SL	SM	13.35	15.12	13.92	0.88 (SM & FY)
	FY	6.26	10.86	8.03	0.63 (CS & FY)
CD (5%)	SM	0.25	0.15	–	–
	FY	0.25	0.14		

AHM, Agri-horticultural model; LCT, Litchi + cowpea–toria; LST, litchi + sesame–toria; LP, Litchi + pigeon pea; LBT, Litchi + black gram–toria; LOT, Litchi + okra–toria; LH, Litchi + turmeric; LC, Litchi + colocasia; SL, Sole litchi; CS, Canopy spread of litchi (m); LT, Light transmission (%) under litchi canopy; CEY, Cowpea equivalent yield (t ha^{-1}); TEY, Turmeric equivalent yield (t ha^{-1}); SM, Annual mean soil moisture (cm); FY, Fruit yield of litchi (t ha^{-1}).

light transmission (%) was calculated under open conditions. Soil moisture content was determined every month from October to mid-June during the years 1995 to 2010 up to 100 cm depth using gravimetric method[9]. SOC was determined by Walkey and Black method[9].

Primary data of seeds, litchi seedlings, fertilizers, farmyard manure, pesticides, irrigation, labour and machinery hours utilized and outputs like yields of intercrop and fruit crop were recorded for each cropping season and annually of fruit plantations through systematic monitoring. They were converted into monetary values and expressed to a common unit, i.e. USD (US Dollar) using government or farm gate price over the period of study. Year-wise total cost and total returns per hectare were estimated to calculate benefit : cost ratio (BCR), net present value (NPV) and payback period (PBP) at a discounted rate (8.0%) for 15 years of experimentation for each fruit-based model. The data were subjected to standard analysis of variance technique for randomized block design[10]. Statistical analysis was done for the individual year data as well as pooled data over the years for different parameters. The mean effect of treatments was compared at $P < 0.05$ level of significance.

The maximum intercrop yields were harvested in the year 1996–97 and thereafter declined, and the lowest yields were obtained in 2005 when the canopy of the litchi tree closed (Table 1) and light transmission was reduced from 68% (1996) to 11.3% (2005). The mean CEYs were harvested in the order LCT = LOT > LBT > LP = LST models during the first phase. The mean maximum and minimum yield reductions were observed to be 48.9% (32.2% LT) and 33.9% (34.39% LT) for LST and LCT models respectively, in the first phase. In the second phase, mean TEYs of 7.91 (18.73% yield reduction) and 6.95 t ha^{-1} (24.01% yield reduction) were obtained with mean light transmission of 8.1% and 7.6% in LH and LC models respectively, over SL model (2006–2010). Significant negative correlations (r; –0.96 to –0.99 and –0.97 to –0.99) were recorded between CS and LT as well as CS and CEY respectively, in all the models. The correlations (r) between CEY and LT were positive (0.97–0.99), which indicated that CEY reduced over the years due to lesser availability of light among all models. The yield reduction of intercrops in the later stages appears to be due to increase in CS and lesser LT, which resulted in lesser availability of photosynthetically active radiation (PAR) transmitted through the tree canopy[8,11]. Cowpea grown with litchi tree performed well and recorded minimum yield reduction (33.87%) because cowpea grows well even in poor soils[12], is economically profitable with fruit tree-based models[13] and tolerates higher shade compared to other intercrops[14]. The yield reduction of intercrops was more under the tree canopy than away from the tree in fruit-based models[15]. Likewise in the second phase, negative correlations were observed (–0.96 and –0.98) and (–0.97 and –0.99) between CS and LT as well as CS and TEY in LC and LH models respectively. The study revealed that turmeric plant needs less photoperiod (<8 h) than colocasia (>8 h) for production of better photosynthates and bulb[16]. Trees conserved about 10% higher soil moisture most of the time under shade[17].

The intercrops improved soil moisture, canopy spread and fruit yield of litchi significantly than sole litchi plant (Table 1). Among the five models, LCT increased fruit yield of litchi by 26.41% over sole litchi fruit yield (3.24 t ha^{-1}). All the AHMs recorded higher soil moisture over sole litchi up to 100 cm soil depth. In the second phase, LH and LC models produced higher fruit yield by 13.09% and 6.43% and soil moisture by 9.33% and 6.06% respectively, than sole litchi. Fruit yield of litchi increased with increasing age, but drastically reduced (30.6–40.3% and 24.6–34.7%) over mean yield of both phases during winters of 2003 and 2007 due to occurrence of sub-zero temperature (–1.0°C and –3.8°C). In the second phase, litchi canopy spread was positively correlated with fruit yield (0.97 to 0.98) and (0.35 to 0.48) among all the models during the first and second phase respectively. The maximum fruit yield was recorded with LCT model, because it added more bio-litter which decomposed quickly and added more carbon as well as nitrogen to the soil[18] and improved soil health, maintained soil structure[19] and provided yields on a sustainable basis[8,20].

Litchi-based AHMs improved SOC over initial values recorded in the respective phase (Figure 1). LCT model enhanced maximum SOC by 37.9% followed by LBT (34.5%), LP (32.8%), LOT (27.6%), LST (17.2%) and minimum with SL model (13.8%) during the first phase. Likewise, 45.9% higher SOC was recorded with LH model followed by LC model (32.8%) and minimum value of 19.7% with SL model during the second phase. In general, organic matter content was higher under the fruit-based models than in open area[21]. The LCT model recorded maximum SOC enhancement compared to all other models[22]. Similar increases in soil health have been reported in litchi[7], aonla[23], mango[8] and other fruit-based AHMs[24,25].

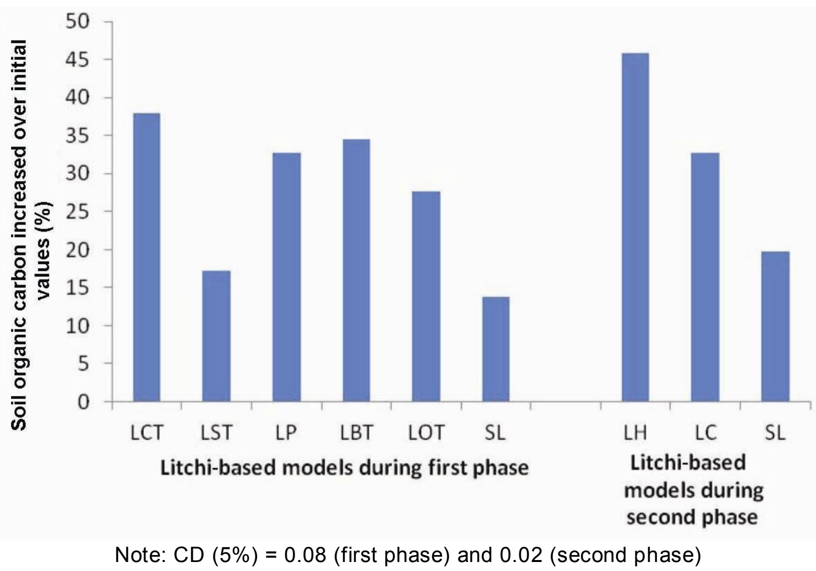

Figure 1. Increase in soil organic carbon in different litchi-based models during both phases.

Table 2. Economic evaluation of litchi-based agri-horticultural models (USD ha^{-1})

Economic parameter	Litchi based agri-horticultural models					
	SL	LCT/LH	LST	LBT	LOT/LC	LP
Net present value (USD*)	19,872	23,983	20,698	21,900	22,775	21,013
B : C ratio	3.5	4.70	5.00	5.80	4.60	5.50
Payback period (years)	7.0	5.0	4.0	4.0	5.0	4.0

*1 USD = INR 54.03.

All the litchi-based models performed well and indicated that the practice was economically viable and profitable in respect of NPV, BCR and PBP (Table 2). Cultivation of cowpea–toria, okra–toria and pigeon pea as intercrops was successful up to the first 10 years among different fruit-based models, beyond which it was no longer economical and therefore had to be discontinued. Hence, shade-tolerant intercrops after 10 years (turmeric and colocasia) were introduced for cultivation with litchi. All the models recorded higher NPV, BCR and less PBP than the SL plantation. Among all the AHMs, LCT/LH models recorded maximum net present value (USD 23,983 ha^{-1}) compared to SL model (USD 19,872 ha^{-1}). Intercropping with litchi for 10 years resulted in higher BCR (>5.0) than BCR for 15 years of intercropping (<5.0), which indicated that intercropping particularly for longer duration with litchi reduced the economic benefits due to lower returns from the intercrops. In this study, all the AHMs registered higher BCR in 15 years of intercropping than SL plantation. PBP of the models was observed in the range 4.0–5.0 years for all the AHMs, except SL model (7 years). On the whole, intercropping with litchi is successful up to 15 years with suitable crops. Litchi is a slow-growing tree, which transmits light through the canopy for intercrops. These intercrops provide additional returns and contribute to reduce PBP. Besides additional income, the intercrops also improve soil health on degraded lands. The increased returns from tree–crop combinations have also been reported in mango with intercropping of legumes and oilseed crops[13].

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Chemical weathering of biotite in the Ganga Alluvial Plain

It is conceived that the physical and chemical weathering processes of the Himalaya release huge amounts of sediment and dissolved load, which are transported to the Indian Ocean. This has affected the character of sea water during the last 40 million years[1]. The sediment eroded in the Himalaya comes to the Ganga Alluvial Plain, where it is stored over a reasonable length of time. Part of this sediment is preserved to make alluvial deposits of the plain, and part is moved to the Bay of Bengal. Sediments of the Ganga Alluvial Plain show much higher weathering indices than the sediments coming from the Himalayan source[2]. Recently, chemical weathering of the sedimets of Ganga Alluvial Plain has been highlighted[3,4]. In the present study, we describe the chemical weathering of biotite grains of the Gomati River sediments and release of various elements in dissolved load.

The interactions between minerals and water play an important role in geochemical processes, i.e. soil formation, elemental mobility, bio-mineralization, nutrient availability, etc.[5]. The study of chemical weathering processes of minerals in natural system is essential to estimate the release of various elements into solution. To understand the pattern of chemical weathering of the Ganga Alluvial Plain, the Gomati River Basin has been selected. The basin experiences humid sub-tropical climate, characterized by monsoon rainfall and large temperature fluctuations (2°C to 47°C) from winter to

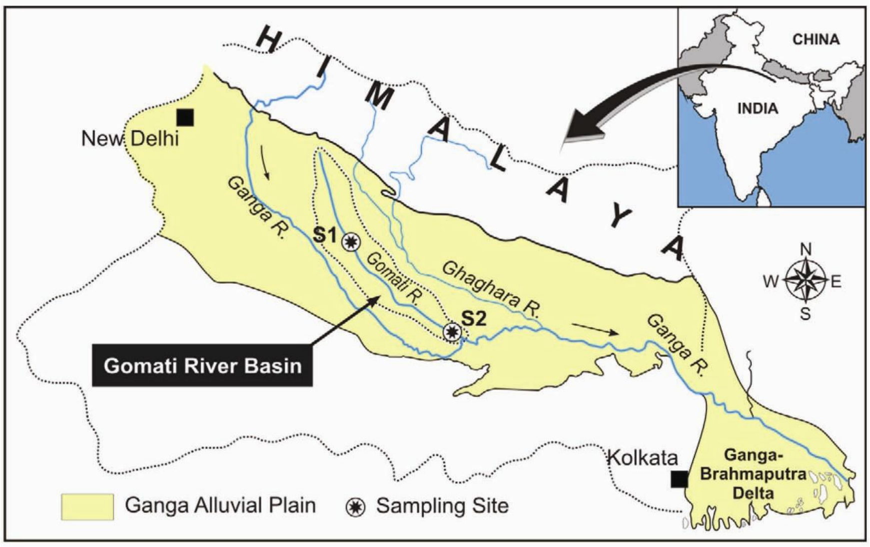

Figure 1. Map of the Gomati River Basin showing sampling locations of river sediment (S1–Naimeserayan) and river water (S2–Chandwak) used in the present study.