Effect of bamboo species and mulch materials on turmeric crop production and curcumin contents

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ABSTRACT : Agroforestry with bamboo considerably influences economic development. This system is especially important and significant for developing countries, like India. We examined the performance of turmeric as understory crop with nine treatments comprising of seven leaf mulches with FYM (farm yard manure) plus RDF (recommended doses of fertilizers); FYM and RDF and control under two bamboo species, viz., *Dendrocalamus asper* and *Dendrocalamus hamiltonii* and sole cropping in order to determine the type of mulch and growing conditions that would improve turmeric crop productivity. The results indicate that treatment T_2 (*Artemissia vulgaris* + FYM + RDF) showed best results for most of the growth and yield attributes of turmeric crop viz., plant height (150.9 cm), number of leaves per clump (11.2), leaf length (73.6 cm), leaf breadth (22.2 cm), weight of mother rhizome per plant (70.6 g), weight of primary fingers per plant (43.6 g), number of secondary fingers per plant (2.6), weight of secondary fingers per plant (7.1 g) and yield (12.48 ton ha^{-1}). Sole cropping displayed better results for yield traits for turmeric when compared with *D. asper* and *D. hamiltonii.* Further, soil moisture content (%) reported higher value under *D. hamiltonii*. Light transmission ratio (%) recorded during the investigation period reduced by 40% under bamboo canopy.

Key words: Bamboo species, crop yield, curcumin content, growth traits and light transmission ratio.

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1. INTRODUCTION

Agroforestry, the inclusion of woody perennials within farming systems, has been practiced as a traditional land use and livelihood options since time immemorial. A preliminary estimate indicated that area under agroforestry in India as 25.32 million ha or 8.2% of the total geographical area of the country (Dhyani *et al*., 2014). The estimated total tree green cover by agroforestry in the country is estimated as 1,11,554 sq. km which is 3.39% of country's geographical area. Of which, Himachal Pradesh has 2,303 sq. km tree green cover out of 55,673 sq. km geographical area (FSI, 2013). In agroforestry systems where each plant receives individual care, bamboo shows promising results. Agriculture land near bamboo can be effectively utilized for growing shade loving crops, like ginger, turmeric, large cardamom, orchard grass and dinanath grass upto a distance of 11-15 m from the bamboo rows (Singh *et al.,* 1992).

Turmeric (*Curcuma longa*) is a rhizomatous herbaceous perennial plant of the family Zingiberaceae. It is native to Asia and India, and occupies about 6% of the total area under spices and condiments in India. Commercially, it is traded as a spice, dye, oleo-resin and source of industrial starch. Curcumin is the principal component of turmeric, which has anti-inflammatory, anti-cancer, anti-tumor, anti-bacterial, anti-oxidant, anti-fungal and anti-parasitic properties (Hermann and Martin, 1991; Osawa *et al.,* 1995; Sugiyama *et al*., 1996; Nakamura *et al*., 1998). It is assumed that growth, yield and curcumin content of turmeric vary with the sunlight level. Cultivation of turmeric under *rainfed* conditions involves high risk, as moisture is one of the major biotic factors which affect its production. It is important to evaluate growth and development responses of a plant species to the local climate and edaphic factors for understanding proper cultivation practices (Ishimine *et al.,* 2004; Hossain and Ishimine, 2005). Mulching being one of the important agronomic practices is beneficial in conserving the soil moisture, suppressing the weeds, improving soil fertility (when organic mulch is used) and modifying the soil physical environment (Yoo-Jeong *et al.,* 2003). Forest leaves bio-mulching in the turmeric beds with green/dry leaves is a common practice used by the farmers of Himachal Pradesh under *rainfed* conditions to conserve long time soil moisture, minimize soil evaporation from the higher solar radiation, optimizes soil temperature, enhance germination, reduce soil erosion and control weeds. The use and demand of turmeric is spreading worldwide, hence production of turmeric rich in curcuminoid contents, especially curcumin, must be promoted to meet out the domestic and international demand by increasing both the area

of cultivation and the productivity per unit area. Keeping the above facts in view, trials were conducted to examine the efficiency of different mulching materials and bamboo species on the growth and yield of turmeric crop.

1. MATERIALS AND METHODS

The study was conducted on existing agroforestry system comprising of *Dendrocalamus species viz. Dendrocalamus asper* and *Dendrocalamus hamiltonii,* established in the year 2007 at the experimental field of Department of Silviculture & Agroforestry, Dr. Y.S. Parmar University of Horticulture & Forestry, Nauni, Solan, Himachal Pradesh during 2014-15. The experimental field is located at 30^0 51' N latitude and 76^0 11' E longitudes at an elevation of 1200 m above mean sea level in the mid-Himalayan zone. It is situated 15 km south-east of Solan. Climatically, the site lies in the sub-tropical belt but is slightly skewed towards the temperate climate, hence regarded as a transition zone between sub-tropical and temperate climate. The area experiences a wide range of temperature with a minimum of 1 ^{0}C in winter to a maximum of 37 ^{0}C in summer.

The experiment was laid out in split plot design, comprising of two bamboo species spaced at 9×5 m^2 *viz*. *D. asper* (B_1) and *D. hamiltonii* (B_2) and compared with sole cropping (B_3). Turmeric crop was sown in the interspaces of bamboo plantation during 2014, at the spacing of 30 cm × 20 cm in a bed area of 3×3 m^2. Immediately after sowing, recommended doses of fertilizer (RDF)-nitrogen, phosphorus and potash (NPK - 30:28:60 kg ha^{-1}) and leaf mulch were applied, followed by farm yard manure (FYM) @ 20 tonnes ha^{-1}. Different leaf mulch was applied after rhizome planting in the month of May in such a way so as to form about 4 cm layer of mulch thickness. Nine treatments, *viz.* T_1 (*Pinus roxburghii* + FYM + RDF), T_2 (*Artemisia vulgaris* + FYM + RDF), T_3 (*Lantana camara* + FYM + RDF), T_4 (*Celtis australis* + FYM + RDF), T_5 (*Alnus nitida* + FYM + RDF), T_6 (*Ulmus villosa* + FYM + RDF), T_7 (*Toona ciliata* + FYM + RDF), T_8 (FYM + RDF) and T_9 (RDF) were applied during the experimental period. Beds were weeded 45 and 70 days after planting (DAP). Turmeric was harvested in the month of February when leaves turned yellow and started to dry. The mean maximum temperature during the experimental period ranged between 19.53 (January, 2016) and 31.05 ^{0}C (May, 2015). The mean minimum temperature varied between 1.98 (January, 2016) and 20.38 ^{0}C (July, 2015) with highest rainfall of 291.90 mm in the month of July, 2015 and lowest of 0.00 mm in January, 2016.

To evaluate turmeric growth, six plants were randomly selected when turmeric plant was at its peak growing stage and data were recorded on plant height, number of leaves per clump, leaf length, leaf breadth and number of tillers per plant. Per cent rhizome sprouting was calculated by taking data at 45 and 60 DAP and the total added. Plant survival per cent was calculated by using formula, Survival= Number of plant survived × 100 / Total number of planting.

At every sampling, a quadrat of 1×1 m^2 was selected from three random locations per bed per plot excluding the border plants. All turmeric clumps in the selected quadrats were uprooted and number of mother rhizome, weight of mother rhizome, number of primary fingers, weight of primary fingers, number of secondary fingers, weight of secondary fingers and yield were determined. The curcumin content was determined following the method as described by ASTA and the chlorophyll content of turmeric leaf was analyzed following the method of Hixcox and Israeistam (1979). Soil moisture (%) was determined gravimetrically from July to December at two depths (0-20 and 20-40 cm). Per cent soil moisture was calculated by oven drying the soil at 105 ^{0}C. Light transmission ratio (LTR) was recorded from July to December at fortnightly interval at different growth stages of crop for all the treatments with the help of Lux Meter. The data obtained for growth and yield parameters were statistically analyzed by using the analysis of variance (ANOVA) for split-plot design in accordance with the procedure outlined by Gomez and Gomez (1984) and SPSS version 21. Where ever the experimental effects exhibited significance at 5 per cent level of probability, the least significant difference (LSD) was calculated.

2. RESULTS AND DISCUSSION

Growth attributes of turmeric

A perusal of the results indicates that bamboo species significantly affected the plant height, number of leaves and number of tillers of turmeric crop (Table 1). Maximum plant height was recorded under *D. asper* (137.8 cm), followed by *D. hamiltonii* (135.4 cm) and sole cropping (112.5 cm). The increase in height under bamboo canopy may be due to the shade provided by bamboo and reduced LTR beneath *D. asper* and *D. hamiltonii*, respectively than under sole cropping. It is assumed that some physiological process function properly at a reduced light intensity. Safanin *et al.* (1982) also reported that intercropping helps promote the growth of crop due to congenial micro-environment and the shade loving nature of

Table 1. Effect of bamboo species, mulch material and their interaction on growth parameter

Bamboo species	Mulch material									Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	
Rhizome sprouting (%)										
B_1	61.8	64.5	58.3	70.1	61.8	66.6	72.9	59.7	50.0	62.8
B_2	60.4	61.7	61.1	65.9	61.7	62.4	70.8	54.8	49.3	60.9
B_3	63.8	70.1	61.1	64.5	61.7	68.7	69.4	52.7	34.7	60.8
Mean	62.0	65.5	60.1	66.9	61.8	65.9	71.0	55.7	44.6	
LSD0.05	Mulch material = 6.53			Bamboo species = NS			Interaction = NS			
Plant height (cm)										
B_1	148.4	158.8	111.7	141.6	144.7	145.8	142.2	142.9	103.7	137.8
B_2	144.9	163.0	128.8	141.3	147.8	140.5	134.0	129.0	89.3	135.4
B_3	128.3	130.9	105.9	110.2	124.0	108.2	114.2	106.9	84.2	112.5
Mean	140.6	150.9	115.5	131.0	138.8	131.5	130.1	126.3	92.4	
LSD0.05	Mulch material = 5.84			Bamboo species = 12.74			Interaction = 15.68			
Number of leaves plant-1										
B_1	11.2	9.6	8.4	11.8	10.1	11.5	10.1	10.2	7.4	10.0
B_2	10.1	13.1	8.8	7.4	7.9	9.0	7.5	9.1	6.8	8.9
B_3	12.1	11.0	9.6	14.4	13.6	13.1	12.2	8.4	5.4	11.1
Mean	11.1	11.2	8.9	11.2	10.5	11.2	9.9	9.2	6.6	
LSD0.05	Mulch material = 1.23			Bamboo species = 1.22			Interaction = 2.33			
Leaf length (cm)										
B_1	63.5	70.3	55.3	73.1	72.5	71.8	69.2	71.6	55.0	66.9
B_2	72.0	81.3	68.3	71.7	72.0	69.6	66.2	64.6	53.6	68.8
B_3	65.0	69.2	56.7	59.6	67.2	59.6	62.2	57.4	47.9	60.5
Mean	66.8	73.6	60.1	68.1	70.6	67.0	65.9	64.5	52.2	
LSD0.05	Mulch material = 3.13			Bamboo species = NS			Interaction = 8.43			
Leaf breadth (cm)										
B_1	20.4	21.7	17.3	20.8	20.5	21.0	21.6	20.6	18.7	20.3
B_2	22.5	23.7	21.3	21.4	22.1	21.5	21.0	20.2	18.5	21.4
B_3	21.5	21.2	19.9	20.9	20.8	20.5	20.8	19.4	17.4	20.3
Mean	21.5	22.2	19.5	21.0	21.1	21.0	21.1	20.1	18.2	
LSD0.05	Mulch material = 0.79			Bamboo species = NS			Interaction = 2.00			
Number of tillers plant^{-1}										
B_1	2.1	1.6	1.4	1.9	1.7	1.9	1.5	1.6	1.4	1.7
B_2	1.5	2.0	1.3	1.3	1.2	1.4	1.3	1.5	1.3	1.4
B_3	2.0	1.8	1.6	2.5	2.3	2.3	2.1	1.4	1.0	1.93
Mean	1.9	1.8	1.4	1.9	1.8	1.9	1.6	1.5	1.2	
LSD0.05	Mulch material = 0.23			Bamboo species = 0.14			Interaction = 0.40			

crop. Kumar (2004) recorded higher plant height of turmeric under intercropping with tamarind plantation compared to sole cropping. Maximum number of leaves (11.1) was recorded under sole cropping, followed by *D. asper* (10.0) and *D. hamiltonii* (8.9). Similar findings on number of leaves were reported by Vikram and Hegde (2014), where number of leaves per plant was significantly higher in sole cropping at all the stages of growth compared to intercropping under cashew plantation. Maximum number of tillers per plant (1.9) was recorded under sole cropping, followed by *D. asper* (1.7) and *D. hamiltonii* (1.47). Sole cropping was found to have more number of tillers per plant. Lalitha Bai (1981) also observed negative effect of shade levels on tillering.

Mulched plots performed better over control plots for all growth parameters. Among treatments, T_2 showed maximum value in most growth parameters, *viz*. plant height (150.9 cm), number of leaves (11.2), leaf length (73.6 cm) and leaf breadth (22.2 cm). Mishra (2000) reported increased turmeric height in plots treated with mulch material. Similar findings was reported by Kushwah *et al.* (2013) on ginger crop, where mulching with palas leaf gave the maximum plant height of ginger. Plants growing under shaded condition tend to increase their leaf surface area to capture more and more light to fulfill their photosynthetic needs. Similarly, Bhuiyan *et al.* (2012) also reported that leaf length and breadth of turmeric was increased gradually with the increase of shade levels. Similar findings were also reported by Chandra (2014). Further, interactions between mulching and bamboo species proved significant in influencing all growth parameters, except for rhizome sprouting (Table 1). Height (163.0 cm) of turmeric plant was found to be significantly higher in the plant raised under the *D. asper* canopy and supplied with the mulch of *A. vulgaris*+FYM+RDF than most of the treatments, excepting B_1T_2 combination. The number of leaves per plant did not display consistent trend in the various interaction treatments. Whereas, leaf length and number of tillers per plant were significantly higher under the sole cropping treatment at all levels of mulch treatments. In general, the leaf breadth was significantly higher in the treatments involving the mulch treatments with or without bamboo canopy over the un-mulched plots.

Yield attributes of turmeric

Data in Table 2 clearly indicate that bamboo species had significantly influenced the yield parameters of turmeric, except weight of mother rhizome and final yield. Maximum number of mother rhizome per plant (1.1), number of primary fingers (4.0), weight of primary fingers (39.0 g), number of secondary fingers (2.1) and weight of secondary fingers (5.8) were recorded in sole cropping, followed by *D. hamiltonii* and *D. asper*, respectively. Bhuiyan *et al*. (2012) observed maximum number of mother rhizome per plant, weight of mother rhizome per plant under 70% LTR to that of the open conditions. Vikram and Hegde (2014) also reported higher number of primary rhizome under sole cropping as compared to under cashew plantation. The present results are in accordance with the findings of Gill *et al*. (2004), who also reported more number of fingers lets in sole turmeric crop as compared to poplar-turmeric interface. They also reported that number of finger lets decreased with the increase in poplar tree age. Vikram and Hegde (2014) observed significantly higher fresh weight of rhizome per clump, number of secondary rhizome and clump size under sole cropping compared to cashew based intercropping.

All the mulch treatments had perceptible influence on yield parameters of turmeric. In general, plants treated with *A. vulgaris*+FYM+RDF (T_2) showed significantly higher values for most of yield traits, *viz*. weight of mother rhizome (70.6 g), weight of primary rhizome (43.6 g), number of secondary rhizome (2.6), weight of secondary rhizome (7.1 g) and yield (12.48 ton ha^{-1}). Increase in number of rhizome and weight of rhizome could be due to beneficial effects of mulching. Similar observation was also made by Alam *et al.* (2003) and Sanyal and Dhar (2008). Increased yield under mulching can be owed to uniform germination, conservation of soil moisture and better weed control and thereby conservation of nutrients status than RDF+FYM treatment. Mathai *et al.* (1976) also reported the same. Interactions between bamboo and mulch had a significant influence on yield attributes of turmeric (Table 2). In interaction effect, the number (3.6) as well as weight of the secondary rhizome per plant (11.0) were maximum in the turmeric raised under the canopy of *D. hamiltonii* and supplied with the mulch treatment of *A. vulgaris*+FYM+RDF, which was found to significantly higher than most of the treatment combinations, barring few exceptions. Whereas, maximum yield (15.22 ton ha^{-1}) was recorded in sole crop and supplied mulch of *P. roxburghii*+FYM+RDF.

Biochemical attributes of turmeric

Bamboo species have shown significant effect on curcumin content and chlorophyll 'b' (Table 3).

Table 2. Effect of bamboo species, mulch material and their interaction on yield parameter

Bamboo species	Mulch material									Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	
Number of mother rhizome plant^{-1}										
B_1	1.02	1.02	1.06	1.10	1.11	1.03	1.06	1.12	0.93	1.05
B_2	1.06	1.25	1.28	1.14	1.01	1.19	1.04	1.08	0.93	1.11
B_3	1.18	1.10	1.20	1.15	1.16	1.17	1.07	1.34	1.04	1.16
Mean	1.09	1.12	1.18	1.13	1.09	1.13	1.06	1.18	0.96	
LSD0.05	Mulch material = 0.05			Bamboo species = 0.05			Interaction = 0.10			
Weight of mother rhizome (g) plant^{-1}										
B_1	52.77	66.70	53.37	62.28	59.13	59.43	58.91	58.15	33.98	56.08
B_2	56.38	82.46	62.88	58.60	51.36	66.14	57.39	55.01	38.11	58.70
B_3	80.21	62.90	64.08	45.12	60.55	61.39	56.83	64.01	30.98	58.45
Mean	63.12	70.69	60.11	55.33	57.01	62.32	57.71	59.06	34.36	
LSD0.05	Mulch material = 6.94			Bamboo species = NS			Interaction = 12.43			
Number of primary rhizome plant^{-1}										
B_1	2.98	3.55	2.96	3.58	3.27	2.98	3.42	3.30	2.20	3.14
B_2	3.33	4.01	4.27	3.69	2.96	3.35	3.48	2.58	1.71	3.27
B_3	4.69	4.08	4.22	3.56	4.71	5.07	5.64	2.73	1.76	4.05
Mean	3.66	3.88	3.81	3.61	3.65	3.80	4.18	2.87	1.89	
LSD0.05	Mulch material = 0.50			Bamboo species = 0.59			Interaction = 1.00			
Weight of primary rhizome (g) plant^{-1}										
B_1	23.85	35.12	22.90	30.61	23.42	25.81	27.95	25.93	10.07	25.07
B_2	26.28	47.69	30.78	29.07	20.96	26.22	25.84	22.23	8.26	26.37
B_3	59.40	48.09	32.01	27.03	55.65	48.45	43.04	26.10	11.44	39.02
Mean	36.51	43.63	28.56	28.90	33.34	33.49	32.28	24.75	9.92	
LSD0.05	Mulch material = 9.04			Bamboo species = 8.24			Interaction = 16.76			
Number of secondary finger plant^{-1}										
B_1	1.70	1.97	1.46	2.14	1.46	1.65	2.00	1.80	1.52	1.74
B_2	2.15	3.61	2.88	1.76	3.07	1.51	1.54	0.99	1.20	2.08
B_3	3.29	2.29	2.03	1.49	2.93	2.38	2.63	1.67	0.86	2.17
Mean	2.38	2.62	2.12	1.80	2.49	1.85	2.06	1.48	1.19	
LSD0.05	Mulch material = 0.70			Bamboo species = 0.27			Interaction = 1.18			
Weight of secondary rhizome (g) plant^{-1}										
B_1	2.66	3.81	2.23	4.47	1.27	3.47	2.71	2.50	1.85	2.78
B_2	3.97	11.07	5.45	3.27	2.99	2.16	2.68	1.79	1.67	3.89
B_3	8.88	6.59	3.45	2.80	10.33	5.68	7.46	5.30	1.83	5.81
Mean	5.17	7.16	3.71	3.51	4.86	3.77	4.28	3.20	1.79	
LSD0.05	Mulch material = 2.16			Bamboo species = 0.83			Interaction = 3.61			
Yield (ton ha^{-1})										
B_1	7.82	10.41	7.32	10.95	8.29	9.48	10.58	8.26	3.63	8.53
B_2	8.24	14.00	9.69	9.57	7.44	9.36	9.52	6.97	3.79	8.73
B_3	15.22	13.02	9.78	7.67	12.14	12.74	11.73	7.95	2.45	10.30
Mean	10.43	12.48	8.93	9.40	9.29	10.53	10.61	7.72	3.29	
LSD0.05	Mulch material = 1.50			Bamboo species = NS			Interaction = 2.89			

Maximum content of chlorophyll 'b' (0.57 mg g^{-1}) was recorded under sole cropping, followed by *D. asper* (0.53 mg g^{-1}) and *D. hamiltonii* (0.47 mg g^{-1}). Maximum curcumin content in turmeric was recorded in crop grown under *D. hamiltonii* (1.75 %), followed by *D. asper* (1.70 %) and sole cropping (1.46%). These were significantly different from each other. Curcumin content was found to be higher when shade was provided. However, the degree of relative light intensity required for better turmeric cultivation may vary with the place, year and irradiance level. Hossain *et al.* (2009) reported that turmeric is a partial shade tolerant plant that could be cultivated at 59-73% relative leaf area index (RLI) for higher curcumin content. Jayaraj (1990) also reported increase in curcumin content at 25% shading. Mulch treatments markedly influenced the curcumin content of turmeric crop reporting maximum value (1.90%) under treatment T_6 (*U. villosa* + FYM + RDF). Sanyal and Dhar (2008) also observed highest yield and curcumin content with a combination of mulching and application of N and K @ 120 and 160 kg ha^{-1}, respectively. The interaction effect was found significant, except in chlorophyll 'b' (Table 3). Maximum chlorophyll 'a' was recorded under in B_2T_3 combination (0.78 mg g^{-1}) and its minimum value was recorded in B_2T_8 combination (0.44 mg g^{-1}). Whereas, maximum total chlorophyll content (1.34 mg g^{-1}) was found under treatment combination of B_1T_4 and minimum (0.82 mg g^{-1}) under B_2T_8.

Table 3. Effect of bamboo species, mulch material and their interaction on the biochemical properties of turmeric crop

Bamboo species	Mulch material									Mean
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	
Curcumin content (%)										
B_1	1.81	1.62	1.91	1.57	1.99	2.07	1.54	1.57	1.26	1.70
B_2	1.92	1.80	1.96	1.50	1.50	2.11	1.79	1.86	1.30	1.75
B_3	1.86	1.31	1.40	1.52	1.63	1.51	1.51	1.56	0.83	1.46
Mean	1.86	1.58	1.76	1.53	1.71	1.90	1.61	1.66	1.13	
LSD0.05	Mulch material = 0.07			Bamboo species = 0.03			Interaction = 0.11			
Chlorophyll 'a' (mg g^{-1})										
B_1	0.55	0.59	0.66	0.71	0.51	0.68	0.59	0.67	0.56	0.61
B_2	0.58	0.64	0.78	0.46	0.53	0.57	0.52	0.44	0.52	0.56
B_3	0.52	0.61	0.63	0.64	0.61	0.66	0.60	0.60	0.77	0.63
Mean	0.55	0.61	0.69	0.60	0.55	0.63	0.57	0.57	0.62	
LSD0.05	Mulch material = 0.14			Bamboo species = NS			Interaction = 0.19			
Chlorophyll 'b' (mg g^{-1})										
B_1	0.50	0.55	0.58	0.63	0.45	0.60	0.50	0.54	0.46	0.53
B_2	0.53	0.53	0.52	0.43	0.43	0.50	0.46	0.38	0.45	0.47
B_3	0.48	0.52	0.62	0.56	0.57	0.55	0.62	0.52	0.72	0.57
Mean	0.50	0.53	0.57	0.54	0.48	0.55	0.53	0.48	0.54	
LSD0.05	Mulch material = NS			Bamboo species = 0.06			Interaction = NS			
Total chlorophyll (mg g^{-1})										
B_1	1.05	1.14	1.24	1.34	0.96	1.29	1.08	1.20	1.02	1.15
B_2	1.11	1.17	1.30	0.89	0.96	1.06	0.99	0.82	0.97	1.03
B_3	1.00	1.13	1.24	1.20	1.18	1.20	1.22	1.13	1.50	1.20
Mean	1.05	1.15	1.26	1.14	1.03	1.18	1.10	1.05	1.16	
LSD0.05	Mulch material = NS			Bamboo species = NS			Interaction = 0.31			

Moisture content

Data demonstrated in Figure 1-4 revealed that bamboo species, mulch treatments, soil layer and interval significantly influenced the soil moisture (%). Higher soil moisture was reported under bamboo canopy than sole cropping. This can be possibly due to the positive effect of canopy which limits the light transmission that results in the lower evaporation rate. Singh (2007) also observed higher soil moisture under mulch and FYM treatment. This might be due to incorporation of crop residue and organic manures, which were found to improve soil water plant relationship. These results are also in conformity with the findings of Agele *et al.* (2010). In present study, it was found that soil moisture content decreased in upper surface layer, which may be due to maximal utilization by agricultural crop in upper horizons. Similar findings were also reported by Vanlalhluna and Sahoo (2009).

Light transmission ratio

The observations regarding LTR were made in order to estimate the difference in amount of light utilization by plants under bamboo species and open field conditions during different months from July to December. The data presented in Figure 5 and 6 revealed that bamboo species and time interval significantly influenced the LTR. Average LTR was higher in sole cropping when compared with intercropping (Figure 5). LTR as recorded at different time interval (Fig. 6) shows that there is gradual increase in LTR (%) from August to October and thereafter showed a steady decline up to December. In our study, it was seen that there is reduction in the yield though non-significant under bamboo canopy vis-à-vis sole cropping. This means that present level of the shade under the bamboo canopy is more or less optimum for turmeric production and beyond this level yield can be declined significantly.

Correlation

Karl Pearson's coefficient of correlation was worked out between different growth and yield parameters, soil moisture and LTR (Table 4). Yield showed highest correlation coefficient

Table 4. Simple correlation coefficient (r) among growth, yield and biochemical traits of turmeric crop in a bamboo based agroforestry system

	Sprout -ing	height	No of leaves	Leaf length	Leaf breadth	No of tillers	No of mother	Wt of mother	No of primary	Wt of primary	No of secon-dary	Wt of secon-dary	Curcu-min	Chl 'a'	Chl 'b'	Total chl	Yield	Mois-ture	LTR
Sprouting	1																		
Height	.419**	1																	
No of leaves	.419**	.269*	1																
Leaf length	.439**	.910**	.340**	1															
Leaf breadth	.392**	.739**	.394**	.818**	1														
No of tillers	.379**	.129	.927**	.166	.271*	1													
No of mother	.068	.056	.274*	.146	.233*	.192	1												
Wt of mother	.296**	.527**	.451**	.542**	.535**	.321**	.546**	1											
No of primary	.467**	.132	.593**	.230*	.328**	.530**	.377**	.594**	1										
Wt of primary	.234*	.238*	.641**	.333**	.404**	.570**	.376**	.750**	.793**	1									
No of secondary	.115	.314**	.434**	.412**	.489**	.340**	.223*	.621**	.655**	.756**	1								
Wt of secondary	.031	.165	.518**	.287**	.361**	.447**	.387**	.648**	.668**	.862**	.836**	1							
Curcumin	.350**	.544**	.240*	.490**	.377**	.146	.245*	.460**	.174	.125	.100	.050	1						
Chl 'a'	-.156	-.112	.016	-.082	-.058	-.023	.148	-.021	.091	.031	.123	.122	-.122	1					
Chl 'b'	-.157	-.208	.070	-.213	-.160	.036	.073	.024	.207	.087	.114	.179	-.217	.760**	1				
Total chl	-.166	-.170	.046	-.154	-.113	.009	.121	-.003	.151	.060	.124	.158	-.176	.947**	.928**	1			
Yield	.599**	.432**	.647**	.508**	.521**	.547**	.395**	.843**	.797**	.879**	.669**	.709**	.301**	-.041	.012	-.019	1		
Moisture	.359**	.718**	.015	.681**	.546**	-.118	.164	.389**	.055	.054	.150	-.036	.582**	-.270	-.390**	-.349**	.248*	1	
LTR	-.042	-.532**	.311**	-.409**	-.172	.364**	.326**	.015	.389**	.416**	.118	.358**	-.425**	.141	.304**	.235*	.239*	-.555**	1

with weight of primary rhizome (0.879), followed by weight of mother rhizome (0.843) and number of primary rhizome (0.797). Shashidhar *et al*. (1997) also reported positive correlation of fresh rhizome yield with all growth and yield parameters. Similarly, Tomar *et al.* (2005) also found plant height, leaf length and number of secondary rhizomes had significant positive association with rhizome yield. Our results also showed a positive significant correlation between yield and curcumin (0.301), yield and moisture content (0.248) and yield and LTR (0.239). These findings are in accordance with the results of Mohamed *et al.* (2014), who observed that rhizome yield of turmeric had significant correlation with total curcumin. Kittur *et al.* (2016) also observed strong functional relation between rhizome yield and understory PAR with high coefficient of determination (r^2=0.88). Patil *et al.* (2005) reported positive correlation in grain yield of winter sorghum with soil moisture at different stages of crop growth.

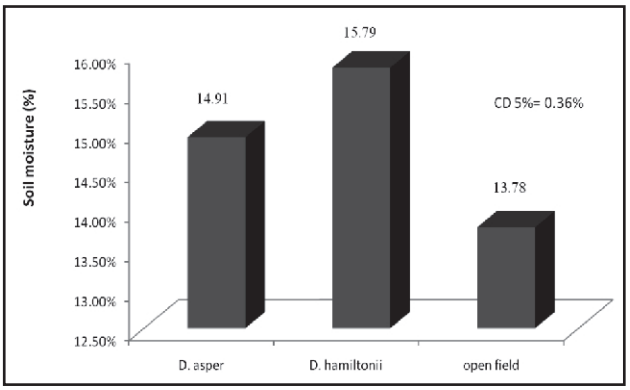

Fig. 1. Average moisture content (%) under different bamboo species

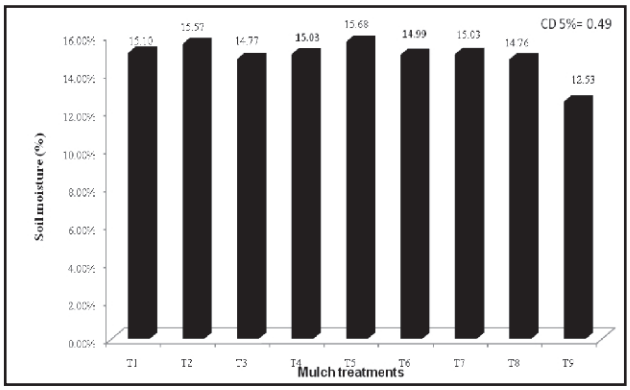

Fig. 2. Average moisture content (%) in different mulch treatment

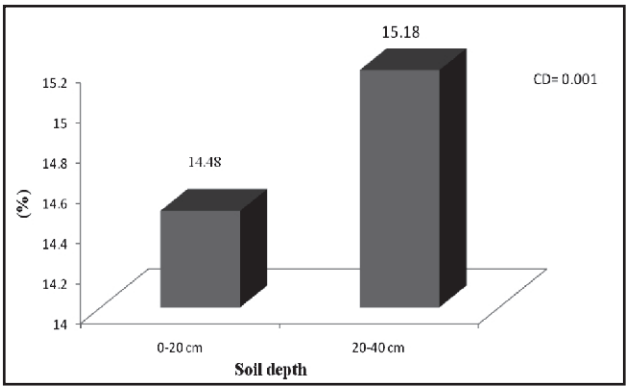

Fig. 3. Average soil moisture (%) at different depth

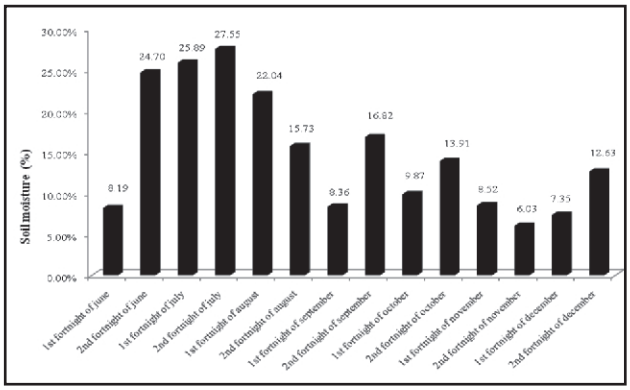

Fig. 4. Soil moisture content (%) at different intervals of time

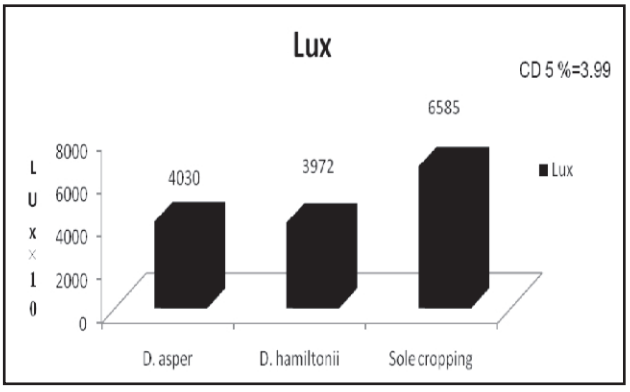

Fig. 5. Average LTA under different bamboo species

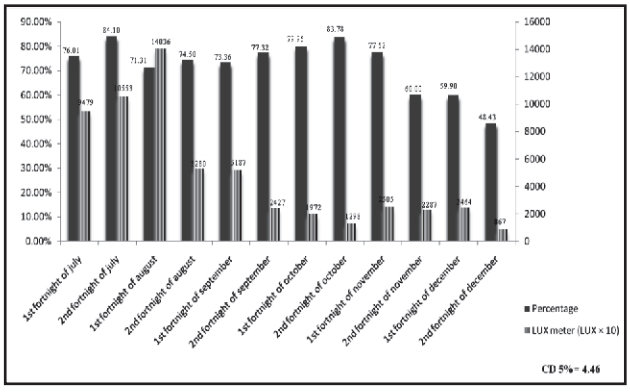

Fig. 6. LTR at different interval of time

3. CONCLUSION

From the present study, it can be concluded that canopy of bamboo reduced the yield of turmeric (15.24-17.18%) but this reduction was duly compensated by increase in the curcumin content, which was 16.44-19.86% higher under *D. asper* and *D. hamiltonii than open conditions. Mulches of the species, like A. vulgaris* and *P. roxburghii*, which gave the best yield response in turmeric crop are also easily available in the Himalayan region and hence recommended for large scale adoption.

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