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Energy Budget of Traditional Hill Agroecosystems along Altitudinal Gradient in Garhwal Himalaya, India

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Abstract: The present study was carried out to understand the biomass utilization pattern and energy budget of the existing traditional hill agroecosystems, prevalent at three different altitudes, with two villages each (i.e., total six villages) in tropical, sub-tropical and temperate regions of Garhwal Himalaya. The per hectare annual average output: input ratio in these agroecosystems was recorded to be the maximum (1.68) for tropical region, followed by temperate (0.80) and sub-tropical (0.78) regions, because the villages of tropical region were situated in the foothills, where the agriculture land was flat and the peoples usually practiced semi-mechanized agriculture techniques. The maximum productivity (28673.40 kg ha^{-1} yr^{-1}) of crops was recorded for village Ganga Bhogpur of tropical region and the minimum (11713.00 kg $ha^{-1}yr^{-1}$) for village Ghargoan of sub-tropical region. *Triticum aestivum* and *Oryza sativa* were the most contributing crops in the total production. The weed production was higher (1340.80 kg ha^{-1} yr^{-1}) in the village Ganga Bhogpur of tropical region and lower (890.34 kg ha^{-1} yr^{-1}) in village Chunnikhal of temperate region. For raising the energy units of agronomic yield (grain and by-products) many organic substances were being derived from the nearby forests, which eventually increased the over all productivity of the agroecosystems. Farmyard manure was observed to be the main input into the agroecosystems which contributed 85 to 95 % of the total inputs in all the agroecosystems. A sizeable portion of these organic substances was being added *via* animal fodder and bedding leaves for livestock, which was ultimately converted into compost.

Key words: Agroecosystem · Biomass · Productivity · Annual yield · *Garhwal himalaya*

INTRODUCTION

The Himalayan arc is divided into western, central and eastern zones [1]. Garhwal Himalaya along with Kumaon and Nepal Himalaya constitute the Central Himalaya. The agriculture of the Garhwal Himalaya is closely linked with the forestry sector either through its dependence on the forest or directly through traditional agroforestry systems. It is mainly because of small land holdings and moreover farmtrees meet only a small fraction of biomass needs. Forests provide a significant amount of fodder needed to sustain livestock and leaf litter to produce farmyard manure [2]. It was estimated that to sustain the productivity of each ha of crop land in Himalaya, 2-15 ha of forest area might be required [3]. Litter removal and lopping reduce inputs to forest floor but may favour regeneration of some species. Quality of manure derived after composting especially the oak leaves is considered to be the best for agriculture [4] and give higher yield compared to pine needles [2].

Among the natural resources of Garhwal Himalaya, forests are most important both economically and environmentally, but they are depleting at a much faster rate, which is causing sever impediments for the stability of landscapes. The forest patches are being cleared for exercising agricultural practices to cope with mounting population pressure [5]. The rainfed agriculture on steep terraces is the predominant form of land use, while only about 15-20% of the total cultivated land is irrigated. Irrigation is practiced only in the valley areas situated at <1500m asl, where more than two crops are taken in one calendar year. The existing farming system is an outcome of the process of the trial and error, which people of the region have been trying since many generations.

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The variations in climatic conditions, unavailability of reliable market, large family size and fragmented agricultural fields on small terraces of steep slopes have created a need to adopt the subsistence farming systems characterized by substantial diversity and high degree of self-reliance [6-12]. The agriculture is also interlinked with other subsidiary activities such as animal husbandry, horticulture, NTFPs collection etc. and therefore entirely depend on the availability and accessibility of the natural resources (forest ecosystems). In recent past, the traditional agricultural systems have been increasingly perturbed due to a variety of factors e.g. socio-economic and cultural changes, imposition of conservation policies, scarcity in availability of resources, low market facility and off-farm economic avenues.

Although several studies have been carried out to determine cropping pattern, landuse pattern and biomass estimation of Himalayan agroecosystems [2,5,7,13-16] but the studies on amounting energy budget of traditional agroecosystems along altitudinal gradient have not been initiated thus far. Therefore, the present study was aimed to unravel the structure and function, biomass utilization pattern and energy budget of traditional hill agroecosystems of Garhwal Himalaya along an altitudinal gradient.

MATERIALS AND METHODS

Study Area and Climate: Six villages, two each in tropical (Ganga Bhogpur and Kunow), sub-tropical (Bhainswara and Ghargoan) and temperate (Dhaulana and chunnikhal) regions were selected for the study. The tropical region was located in the Gohri Forest Range of Rajaji National Park at 30° 6' N latitude and 70° 38' E longitude between elevations of 300-400 m above sea level (asl). The mean annual temperature in this region was over 24°C, whereas mean January temperature was over 18° C. The toal annual precipitation in this zone was 1350 mm. The cold season was very short and there was no frost and snow. The sub-tropical region was located in the District Tehri Garhwal at 30° 29' N latitude and 78°24' E longitude between the elevations of 900 to 1300 m asl. The mean annual temperature I n this region was between 17°C to 23°C, whereas mean January temperature was between 10°C to 15°C. The total annual precipitation was 960 mm. The cold season was definite but there was no sever frost. The snow fall was also rare. The temperate region was located 40 km North-East to Srinagar city of Garhwal Himalaya at 30° 23' N latitude and 78° 20' E longitude, between the elevations of 1900m to 2300m asl (Fig. 1). The mean annual temperature in this region ranged between 7°C to 15°C, whereas mean January temperature between -1°C to 7°C. The total annual precipitation in this zone was 1600 mm. The area was characterized by pronounced winter season with much frost and snow. The entire regions represent a typical monsoon belt and hence this season accounts for three-quarters of the annual rainfall. The three different altitudes were selected so as to represent the whole array of variations in the agroecosystems of Garhwal Himalaya. Generally in a year, two crops i.e., Kharif (April-October) and Rabi (November-March) are taken in all the three regions, but due to early maturity of crops in tropical region a third crop (Zayed) between winter and summer (i.e., spring) is also taken. *Oryza sativa, Eleusine coracana, Vigna mungo, Glycine soja, Echinochloa frumentacea* were the important crops of Kharif season, however *Triticum aestivum, Hordeum vulgare, Brassica campestris, Pisum s tivum* were of Rabi of winter season and *Brassica rugosa* in the tropical region along with some other vegetables and crops were grown as Zayed crops of spring season.

Methodology: The analysis of agroecosystems was done by the methods suggested by Mishra and Ramakrishnan [17,18], Maikhuri and Ramakrishnan [14] and Maikhuri [19]. A complete inventory was made at household level for each village. Data on human population, livestock and other factors were based on inquiries involving all households. Information was collected on: (i) cropping pattern; (ii) cultivated land under irrigated and rainfed conditions; (iii) labour inputs in terms of bullock days and person days; (iv) chemical fertilizer input; (v) farmyard manure input; and (vi) seed input. All the information gathered was cross-checked for further confirmation by repeated field visits over a period of 12 months. The data on cultivable land was collected from State Revenue Department and also verified personally from the villagers. Input of market products such as use of fertilizers in agriculture fields were known with the help of villagers, on per hectare basis. The energy input of fertilizers was converted into caloric values as per method described by Mitchell [20]. The human and bullock labour inputs consisted of food energy value required to meet the maintenance costs and those of the labour devoted to collection and agricultural activities, i.e., ploughing, preparation of seed beds, weeding, harvesting and threshing was calculated by using the energy equivalents and respective components as suggested by Mitchell [20].

Table 1: Physiographic and demographic status of the villages

	Region/Village					
	Tropical region		Sub-tropical region		Temperate region	
Parameter	Ganga Bhogpur	Kunow	Bhainswara	Ghargoan	Dhaulana	Chunnikhal
Human population	895	245	242	150	308	156
Livestock population	660	210	80	108	203	94
Altitude (masl)	300-350	300-400	900-1200	1200-1300	1900-2400	2000-2300
Aspect	SW	SW	SW	SW	SE	SE
Agriculture land (ha)	225	15	24.42	18.32	50.16	14.32
Actual cultivated land (ha)	225	15	24.42	18.32	50.16	14.32
Cultivated land (ha) household^{-1}	1.49	0.3	0.48	0.49	0.96	0.48
Irrigated land (ha) household^{-1}	1.49	-	0.16	0.03	-	-
Average family size (number of individuals)	5.93	4.9	4.74	4.05	5.92	5.2
Human density ha^{-1} cultivated land	0.25	0.06	0.10	0.12	0.16	0.09
Livestock household^{-1}	4.32	4.2	1.57	2.92	3.90	3.13
Cultivated land livestock^{-1}	0.34	0.07	0.30	0.17	0.25	0.25

Masl- meter above sea level, ha^{-1}- Per hecter

Biomass and productivity of agricultural crops and weeds were determined by direct harvest method, when the crops and weeds were at their peak biomass (maturity) and crops were ready in Rabi (winter) and Kharif (summer) seasons, respectively. The qualitative and quantitative analysis of the crops was done using 10 (50 cm x 50 cm) quadrats, using ten replicates for each crop. Fresh weight was converted into dry weight on the basis of plant samples, oven dried at 80°C for 24 hours. The yield per hectare, in all cases, was calculated on the basis of the yield taken from the entire plot [14].

The energy budget was calculated separately for each crop, following Maikhuri and Ramakrishnan [14]. In all cases, the input values were calculated in terms of work (human and bullock power) as man-days and bullock-days and quantities of seed and fertilizers. The output was calculated as yield of crop and by-products separately. In addition to this, green fodder obtained from weeds and agroforestry tree species was also considered as an auxiliary output of the agroecosystems. The energy values of outputs and inputs were calculated based on the caloric equivalents as reported by Mitchell [20] (Table 1). The caloric equivalents were based on data of Pimentel *et al.* [21] and Gopalan *et al.* [22]. The energy efficiency of each system was calculated as output: input ratio.

RESULTS

The detailed structure of the villages has been presented in Table1. Energy values for different items used in the villages (expressed as dry wt. MJ kg^{-1}) are presented in Table 2. The appropriate times of sowing and harvesting of crops are given in Table 3. The annual average energy input in six different agroecosystems was estimated in terms of human and bullock labour, quantity of seed, farmyard manure and fertilizer, while the energy output from the system was grain and crop residues (Table 4).

Table 2: Energy values for different items used in the villagess (expressed as dry wt. MJ kg^{-1})

C Category	MJ kg^{-1}	MJ day^{-1}
[a]Grain	16.2	-
[a]Pulses(various beans)	17.1	-
[a]Straw	14.0	-
[a]Musturd oil	39.5	-
[c]Rice barn	16.4	-
[a]Greeen fodder	15.8	-
[b]Seasmum	26.6	-
[c]Vegetable waste	16.4	-
[a]Tree and shrubs leaves	16.8	-
[a]Fuelwood	16.8	-
[a]Leaf vegetable	15.8	-
[a]Root and tuber	15.3	-
[a]Fruits	9.1	-
[c]Farmyard manure	7.3	-
[c]Goat dung	2.0	-
[c]Cow dung	2.1	-
[a]One man day^{-1}	-	16.6
[a]One bullock day^{-1}	-	72.4

[a]Mitchell (1979), bGopalan *et al.* (1978), cMaikhuri and Ramakrishnan (1991)

In the tropical region, the maximum production of *Triticum aestivum* was 2606±49 kg ha^{-1}yr^{-1}and the minimum (146±8 kg ha^{-1}yr^{-1}) of *Brassica rugosa*. Similarly in sub-tropical region the highest (2664±98 kg ha^{-1}yr^{-1}) and the lowest (240±13 kg ha^{-1}yr^{-1}) production values were observed for *Triticum aestivum* and

Table 3:s Sequential sowing and harvesting of some important crops in the selected villages

			Villages											
			Tropical				Sub-tropical				Temperate			
			Ganga Bhogpur		Kunow		Bhainswara		Ghargoan		Dhaulana		Chunnikahl	
Crop species	English name	Local name	Sowing	Harvesting	Sowing	Harvesting	Sowing	Harvesting	Sowing	Harvesting	Sowing	Harvesting	Sowing	Harvesting
Kharif crop														
Oryza sativa	Paddy	Dhan	July	Oct.	June	Sep.	June	Oct.	June	Sep.	May	Oct.	-	-
Eleusine coracana	Finger millet	Kodo	July	Oct.	June	Oct.	Jun	Oct.	Jun	Oct.	Jun	Sept.	Jun	Sept.
Vigna mungo	Black gram	Kalidal	-	-	-	-	July	Oct.	July	Sept.	-	-	-	-
Glycine soja	Bhatt	soya	-	-	-	-	Jun	Oct.	-	-	-	-	-	-
Echinochloa frumentacea	Barnyard millet	Jhangora	-	-	-	-	-	-	-	-	Jun	Sept.	-	-
Curcuma longa	Turmeric	Haldi	July	Nov.	-	-	-	-	-	-	-	-	-	
Zinziber officinalis	Zinzer	Adarkh	July	Nov.	-	-	-	-	-	-	-	-	-	-
RABI CROP														
Triticum aestivum	Wheat	Gehun	Dec.	April	Oct.	April	Nov.	April	Oct.	April	Oct.	May	Oct.	April
Hordeum vulgare	Barley	Jau	Oct.	April	Oct.	April	Nov.	April	Oct.	April	Oct.	May	Oct.	April
Brassica campestris	Sarson	mustard	Oct.	March	Oct.	March	Nov.	April	Oct.	March	Oct.	April	Oct.	April
Pisum sativum	Pea	Mater	Oct.	March	Oct.	March	Nov.	April	Oct.	March	Oct.	April	Oct.	April
Allium cepa	Onion	Onion	-	-	-	-	Nov.	May	-	-	-	-	-	-
ZAYED CROP														
Brassica rugosa	Sarson	mustard	Oct.	Dec.	Oct.	Dec.	-	-	-	-	-	-	-	

Table 4: Comparative energy budget of crops at three different altitudes in selected village (MJ ha^{-1} X10^5)

Climatic zone / villages												
Tropical	Crops	A	B	C	D	E	Total	F	G	Total	O/I ratio	Average O/I ratio
Ganga Bhogpur	*Triticum aestivum*	0.09	0.22	0.09	3.41	0.60	4.41	4.22	6.48	10.70	2.43	1.68
	Hordeum vulgare	0.07	0.19	0.07	2.19	-	2.52	1.10	1.91	3.01	1.19	
	Brassica campestris	0.02	0.17	0.08	1.82	-	2.09	1.50	2.70	4.20	2.00	
	Pisum sativum	0.02	0.17	0.08	1.82	-	2.09	1.72	3.47	5.19	2.48	
	Oryza sativa	0.12	0.34	0.07	2.67	0.60	3.80	2.35	4.27	6.62	1.74	
	Eleusine coracana	0.02	0.07	0.04	1.82	-	1.95	2.81	6.50	9.31	4.77	
	Brassica rugosa	0.07	0.15	0.06	2.67	-	2.95	0.59	0.55	1.14	0.38	
	Total	0.41	1.31	0.49	16.4	1.2	19.81	14.29	25.88	40.17	14.99	
Kunow	*Triticum aestivum*	0.07	0.19	0.09	3.89	-	4.24	3.33	3.37	6.70	1.58	
	Hordeum vulgare	0.07	0.17	0.07	2.19	-	2.50	0.92	1.79	2.71	1.08	
	Brassica campestris	0.02	0.15	0.06	2.92	-	3.15	0.69	1.64	2.33	0.74	
	Oryza sativa	0.07	0.15	0.08	2.67	-	2.97	1.40	2.04	3.44	1.16	
	Eleusine coracana	0.22	0.07	0.04	1.82	-	2.15	1.01	3.66	4.67	2.17	
	Brassica rugosa	0.02	0.15	0.03	3.41	-	3.61	0.39	0.33	0.72	0.19	
	Total	0.47	0.88	0.37	16.9		18.62	7.74	12.83	20.57	6.92	
Sub tropical												
Bhainswara	*Triticum aestivum*	0.08	0.19	0.08	6.08	-	6.43	4.31	4.76	9.07	1.41	0.78
	Hordeum vulgare	0.07	0.15	0.05	5.47	-	5.74	0.62	1.19	1.81	0.31	
	Brassica campestris	0.07	0.15	0.06	6.08	-	6.36	0.64	0.84	1.48	0.23	
	Oryza sativa	0.11	0.32	0.07	5.47	-	5.97	1.92	4.77	6.69	1.12	
	Eleusine coracana	0.07	0.07	0.04	3.65	-	3.83	2.23	3.69	5.92	1.54	
	Glycine soja	0.04	0.04	0.07	2.68	-	2.83	1.81	1.47	3.28	1.16	
	Total	0.44	0.92	0.37	29.43		31.16	11.53	16.72	28.25	5.77	
Ghargoan	*Triticum aestivum*	0.08	0.22	0.08	5.47	-	5.85	1.24	4.15	5.39	0.92	
	Hordeum vulgare	0.07	0.32	0.05	4.86	-	5.30	0.42	1.11	1.53	0.29	
	Brassica campestris	0.07	0.19	0.06	4.86	-	5.18	0.60	0.73	1.33	0.26	
	Oryza sativa	0.08	0.19	0.07	4.86	-	5.20	0.61	2.26	2.87	0.55	
	Eleusine coracana	0.07	0.15	0.04	3.04	-	3.30	1.18	2.10	3.28	0.99	
	Vigna mungo	0.07	0.19	0.05	3.65	-	3.96	1.31	1.37	2.68	0.68	
	Total	0.44	1.26	0.35	26.74		28.79	5.36	11.72	17.08	3.69	

Table 4: Continued

Temperate												
Dhaulana	*Triticum aestivum*	0.08	0.15	0.08	10.34	-	10.65	2.43	5.08	7.51	0.70	0.80
	Hordeum vulgare	0.06	0.15	0.05	4.25	-	4.51	0.84	1.60	2.44	0.54	
	Brassica campestris	0.05	0.07	0.06	6.08	-	6.26	0.69	1.31	2.0	0.31	
	Pisum sativum	0.05	0.07	0.09	6.08	-	6.29	0.80	2.58	3.38	0.53	
	Oryza sativa	0.10	0.15	0.07	5.47	-	5.79	1.74	5.20	6.94	1.19	
	Eleusine coracana	0.05	0.07	0.04	3.65	-	3.81	1.52	2.85	4.37	1.15	
	Echinochloa frumentacea	0.05	0.15	0.04	3.04	-	3.28	0.48	2.02	2.50	0.76	
	Glycine soja	0.05	0.15	0.07	4.25	-	4.52	1.24	1.87	3.11	0.69	
	Total	0.49	0.96	0.50	43.16		45.11	9.74	22.51	32.25	5.87	
Chunni khal	*Triticum aestivum*	0.06	0.17	0.08	6.69	-	7.00	2.33	3.88	6.21	0.89	
	Hordeum vulgaris	0.05	0.17	0.05	3.65	-	3.92	1.26	1.99	3.25	0.83	
	Brassica campestris	0.05	0.15	0.06	3.65	-	3..91	0.61	1.45	2.06	0..53	
	Pisum sativum	0.05	0.15	0.09	3.04	-	3..33	0.88	2.39	3.27	0.98	
	Eleusine coracana	0.04	0.04	0.04	2.43	-	2.55	1.49	1.70	3.19	1.25	
	Glycine soja	0.04	0.04	0.09	2.68	-	2.85	1.11	1.50	2.61	0.91	
	Total	0.29	0.72	0.41	22.14		23.56	7.68	12.91	20.59	5.39	

A= Human ; B= bullock; C= seed; D=compost; E= fertilizer; F= agronomic yield; G= crop residue

Table 5: Average annual yield production (mean ± SE) (Yield kg ha^{-1} yr^{-1}) of crops in the selected villages

	Tropical		Sub-tropical		Temperate	
Climatic zone / villages	Ganga Bhogpur	Kunow	Bhainswara	Ghargoan	Dhaulana	Chunnikhal
Triticum aestivum	2606±49	2056±47	2664±98	768±37	1506±65	1440±99
Hordeum vulgare	680±24	570±26	386±32	258±10	520±22	782±65
Brassica campestris	566±29	258±20	240±13	228±15	260±10	230±16
Pisum sativum	1006±47	-	-	-	470±43	518±26
Oryza sativa	1454±112	866±87	1184±101	1008±114	1076±53	-
Eleusine coracana	1738±113	628±111	1378±47	738±42	940±27	920±39
Brassica rugosa	224±12	146±8	-	-	-	-
Vigna mungo	-	-	-	768±51	-	-
Glycine soja	-	-	-	-	726±36	648±34
Echinochloa frumentacea	-	-	-	-	298±24	-

- indicate no production

Table 6: Productivity (kg ha^{-1} yr^{-1}) of annual components (crops and weeds)

	Climatic zone / villages					
	Tropical Region		Sub-tropical Region		Temperate Region	
Components	Ganga Bhogpur	Kunow	Bhainswara	Ghargoan	Dhaulana	Chunnikhal
Crop						
Root	2127.40	1565.00	1584.00	1301.00	2156.00	1527.00
Shoot	26546.00	13937.00	13354.00	10412.00	21906.00	13788.00
Sub-total	28673.40	15502.00	14938.00	11713.00	24062.00	15315.00
Weed						
Root	119.79	91.00	113.80	75.30	78.00	68.67
Shoot	1221.00	1080.00	1075.00	1220.00	922.00	821.62
Sub-total	1340.80	1171.00	1188.80	1295.30	1000.00	890.34

Brassica campestris, respectively. In temperate region the maximum production of *Triticum aestivum* was 1506±65 kg $ha^{-1}yr^{-1}$ and the minimum (230±16 kg $ha^{-1}yr^{-1}$) of *Brassica campestris*. Amongst the crops, the maximum proportion of grain yield was obtained from *Triticum aestivum* and *Oryza sativa* except village Chunnikhal of temperate region (Table 5), where the production of *Triticum aestivum* (1440±99 kg $ha^{-1}yr^{-1}$) was followed by *Eleusine coracana* (920±39 kg $ha^{-1}yr^{-1}$), because the agricultural land was solely rainefed in nature and production of *Oryza sativa* was not possible.

Agricultural crop productivity (root and shoot components) over a period of one year has been summarized in Table 6. The shoot components contributed 90% of the total crop productivity. The maximum contribution of shoot components was observed for the village Ganga Bhogpur (92%) in tropical region, which could be due to good irrigation facilities. In the sub-tropical region, the maximum contribution of shoot components was 89.39% and 88.89% for the villages Bhainswara and Ghargoan, respectively. Besides this, in the temperate region, the contribution of shoot components was recorded between 90-91%. In general, the maximum crop biomass (28673.40 kg $ha^{-1}yr^{-1}$) was estimated for village Ganga Bhogpur of tropical region, whereas the minimum (11713.00 kg $ha^{-1}yr^{-1}$) for village Ghargaon of sub-tropical region. In each selected village, *Triticum aestivum* and *Oryza sativa* contributed the major portion of the total crop biomass (except village Chunnikhal of temperate region). Thus, although shoot biomass was similar, but the maximum crop biomass (shoot + grain) was gradually decreased from tropical to sub-tropical and temperate regions in Garhwal Himalaya.

The contribution of weeds productivity has been mentioned in Table 6. The total productivity of weeds in the tropical region ranged from 1171.00 kg $ha^{-1}yr^{-1}$ to 1340.80 kg $ha^{-1}yr^{-1}$. In the sub-tropical region, the minimum productivity (1188.80 kg $ha^{1}yr^{1}$) was recorded for village Bhainswara due to the competing high density of agricultural crops, while the maximum weed production (1295.30 kg $ha^{1}yr^{1}$) was recorded from the village Ghargaon, which eventually resulted in low productivity of agricultural crops. Amongst all the sites, the lowest range of weed production was recorded in the temperate region (Chunnikhal; 890.34 kg $ha^{-1}yr^{-1}$ and Dhaulana; 1000.00 kg $ha^{-1}yr^{-1}$).

The maximum energy input value to the agroecosystems (45.11 x 10^5 MJ $ha^{-1}yr^{-1}$) was recorded for village Dhaulana of temperate region and the minimum (18.62 x 10^5 MJ $ha^{-1}yr^{-1}$) for village Kunow in tropical region. On the other hand, the maximum output value from the agroecosystems (40.17x10^5 MJ $ha^{-1}yr^{-1}$) was recorded for the village Ganga Bhogpur of tropical region, while, minimum (17.08 x 10^5MJ $h^{-1}yr^{-1}$) for village Ghargoan of sub-tropical region. Farmyard manure input was about 85 to 95 % of total inputs in all the agroecosystems. The maximum average output and input ratio (1.68) was recorded for tropical agroecosystems and the minimum (0.78) for sub-tropical agroecosystems. The output and input ratios varied widely from 0.19 for *Brassica rugosa* in village Kunow to 4.77 for *Eleusine coracana* in Ganga Bhogpur of the tropical region. In the sub-tropical agroecosystems the minimum output: input ratio (0.23) was recorded for *Brassica campestris* and the maximum (1.54) for *Eleusine coracana* in village Bhainswara. In temperate agroecosystems the output: input ratio ranged between 0.31 (*Brassica campestris*) for village Dhaulana to 1.25 (*Eleusine coracana*) for village Chunnikhal.

The total output and input ratios across all the crops in the study areas was ordered as; tropical (1.68)>temperate (0.80)>sub-tropical (0.78). In tropical agroecosystems, output was observed higher than the input (due to good irrigation facilities particularly in the village Ganga Bhogpur), whereas in sub-tropical and temperate agroecosystems, input was higher than output. Chemical fertilizer input (1.2 X 10^5 MJ $ha^{-1}yr^{-1}$) was restricted only to village Ganga Bhogpur of tropical region.

DISCUSSION

Agricultural is the main occupation of most of the people in all the three regions and very few households were landless [23]. Net cultivation area was observed to be the highest in the village Ganga Bhogpur of tropical region, whereas, the least in village Chunnikhal of temperate region. Paucity of irrigation facilities has restricted the production of grains particularly in the rainfed condition. The villages were analyzed for energy budget and it was recorded that Ganga Bhogpur (tropical), Bhainswara (sub-tropical) and Dhaulana (temperate) villages produced sufficient food grains due to good irrigation facilities, whereas Kunow, Ghargoan and Chunnikhal villages have shown lower production of crops due to prevalence of rainfed condition.

The average output: input ratio across all the study regions was observed as 1.68 for tropical, 0.78 for sub-tropical and 0.80 for temperate regions. These values were quite higher than the reported value (0.43) by Pandey and Singh [24] for Central Himalaya. The maximum human labour was available in village Dhaulana of temperate region (0.49X 10^5 MJ yr^{-1}) whereas, minimum in Chunnikhal (0.29 X 10^5 MJ yr^{-1}). These values were more or less similar to those reported by Semwal and Maikhuri [25] and Ralhan *et al.* [13] for other parts of Garhwal Himalaya.

Farmyard manure, which is derived from the forest and livestock components (consisting of dung, animal urine bedding leaves and feed left-over) contributed as a significant input (more >50%) to the agricultural fields. Traditionally, farmyard manure is the main source for replenishing soil fertility after crop harvest. However, in recent years due to rapid deforestation in the Himalayan regions, it has become difficult to collect large quantities of organic material from the forest, which in turn, has contributed to the nutrient depletion and soil degradation in the arable land. As far as the quality of the organic manure is concerned, it was observed that partially decomposed material is being used for this purpose. This type of organic input add humus to the soil, but is poor in nutrients [26]. Therefore, there is a need to advise the farmers, how to achieve rapid decomposition/composting of organic material, particularly at higher altitudes, where environmental factors hinder the decomposition process. Mixed cropping also enhances the productivity per unit area and is significant in conserving the diversity of agroecosystems. It also provides continuous cover to the land, which minimizes the water loss due to evaporation [25]. Other water conservation techniques such as mulching, contour bunding and grass bunding also help conserve nutrients in agroecosystems. Tree species growing naturally in agroecosystems not only provide green fodder during lean periods, but also give fuel wood, fodder, fiber and fruits. These components of the hill agroecosystems should therefore be introduced in agroforestry practices, which will help in minimizing the existing pressure on the conventional forests for basic requirements.

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