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Resource use pattern and agroecosystem functioning in Rawanganga micro-watershed in Garhwal Himalaya, India

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Abstract

Agro-ecological resource use pattern in a traditional hill agricultural watershed in Garhwal Himalaya was analysed along an altitudinal transect. Thirty one food crops were found, although only 0.5 % agriculture land is under irrigation in the area. Fifteen different tree species within agroforestry systems were located and their density varied from 30–90 trees/ha. Grain yield, fodder from agroforest trees and crop residue were observed to be highest between 1200 and 1600 m a.s.l. Also the annual energy input- output ratio per hectare was highest between 1200 and 1600 m a.s.l. (1.46).

This higher input- output ratio between 1200–1600 m a.s.l. was attributed to the fact that green fodder, obtained from agroforestry trees, was considered as farm produce. The energy budget across altitudinal zones revealed 95 % contribution of the farmyard manure and the maximum output was in terms of either crop residue (35 %) or fodder (55 %) from the agroforestry component. Presently on average 23 %, 29 % and 41 % cattle were dependent on stall feeding in villages located at higher, lower and middle altitudes respectively. Similarly, fuel wood consumption was greatly influenced by altitude and family size. The efficiency and sustainability of the hill agroecosystem can be restored by strengthening of the agroforestry component. The approach will be appreciated by the local communities and will readily find their acceptance and can ensure their effective participation in the programme.

Keywords: agroecosystem, altitude, energy consumption, energy input–output ratio, agricultural crops, Garhwal Himalaya

1 Introduction

Agriculture in the Himalayan Mountains is closely linked with animal husbandry and natural forests. The loss of forest resources due to commercial exploitation, rapid population growth, forest fires, removal of forest biomass for fuel wood and fodder, is directly depleting the agro-ecological sustainability of the Himalayan Mountains. The sustainability of agroecosystem in different environments depends on site character, plant species used, cropping pattern and farmer's management practices. Studies from the Central Himalayan region (Rai, 1993; Maikhuri *et al.*, 1996; Semwal & Maikhuri, 1996; Maikhuri *et al.*, 2001) reveal that the agriculture practices require massive consumption of forest resources. Earlier studies on this region (Semwal & Maikhuri, 1996) show low energy efficiency of the agroecosystems. Sustainability demands increasing yield per unit area, and if the future generation is to have the same living conditions as we have now we must have the same ratio of agricultural land and forests, which is consistently declining in the region.

Studies show that only 7.473 km^2 (24.9 %) of Garhwal Himalaya is forested and only 4.1 % of the to-

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tal forest have more than 60 % crown cover (Singh *et al.*, 1984). Furthermore 85 % of agricultural rainfed land already suffers from severe erosion and land abandonment due to shallowness of the soil and its acute slope (Negi & Singh, 1990). The consequences of land degradation vary in different sub regions of the Himalaya. Traditional crop diversity, cash crops (especially legumes and potato) and fodder-fuel trees hold the key for food security and sustainable agriculture development in this region (Maikhuri *et al.*, 1996, 2001; Negi & Joshi, 2000).

Fodder collected from the forest (ground herbage and tree leaves) forms the largest component of biomass energy, which plays a significant role in improving the nutritional requirement of livestock in these hills. The socio-economy and topographical situation is such that neither people are able to purchase quality feed from market nor do they have sufficient and proper land as well as technology for the cultivation of nutritive (leguminous) fodder grasses (Sharma *et al.*, 1995). Moreover, there is no regional tradition of fodder (grains or shrubs) cultivation. Sustainable development of agroforestry practices is the only viable solution for sustaining the livestock farming in the hill ecosystems. This is more so as milk is a substantive source of income in the money order based economy (money remitted by serving family members from plains). In addition to milk and drought power, the main produce obtained by the villagers from livestock is the farmyard manure (FYM) which is the only organic fertilizer added to the agriculture fields (Negi & Todaria, 1993). In this region, agriculture is practiced in two seasons Rabi (winter) and Kharif (summer).

The objective of this study was to quantify the contribution of different biomass components. This study was undertaken with the objective to quantify the pattern of biomass production by different components of village ecosystem and to analyse the energy budget of agroecosystem across three altitudinal zones within the Rawanganga micro-watershed. In this study we examined whether the energy input-output ratio varies with altitudinal gradient and which altitudinal gradient is more efficient? We hypothesized that the energy input-output ratio varies significantly along the altitudinal gradient, while the agroecosystems at middle altitude will show the most efficient energy budget.

2 Materials and methods

The Rawanganga micro-watershed is located at 30° 20’ N and 79° 5’ 6” E within an altitudinal range of 800–3189 m a.s.l. in the Ukimath block of Rudraprayag District of Uttarakhand state, India. The micro-watershed has an area of approximately 1850 ha and comprises of 23 villages. It constitutes the catchment area of the Mandakani River, a major tributary stream of the Alaknanda River.

The climate of the study area is mainly influenced by the summer Monsoon, which generally starts during late June and continues till mid-September. The climatic factors like atmospheric temperature, rainfall and humidity affect the vegetation of the area. In the Rawanganga micro-watershed, agriculture is practiced on terraces carved out of steep slopes between 1000 to 2000 m a.s.l. To understand the altitudinal effect on agroecosystem attributes, the micro-watershed was divided into three altitudinal zones: low (800–1200 m a.s.l.), middle (1200–1600 m a.s.l.), and high (above 1600 m a.s.l.). This classification is determined by climatic conditions of the area. The area between 800–1200 m a.s.l. is affected by sub-tropical climate, between 1200–1600 m by sub-temperate and above 1600 m by temperate climate. The vegetation varied along this altitudinal gradient. For a detailed study on resource use pattern and agroecosystem functioning, five representative villages were selected at each altitudinal zone (in total 15 villages). The household survey focused on family size (small, medium and large), socio-economic status, livestock holding, distance to forest and irrigation practices. Using a structured questionnaire for each village, a complete inventory was made at household level. A total of 135 households were identified to obtain the following categories of major information: (1) cropping pattern, (2) irrigated and rainfed area under different crop cultivation, (3) labour inputs in terms of man-days and bullock-days, (4) fertilizer inputs in terms of compost and chemicals (5) seed input, (6) agronomic yield and yield of crop residue, (7) requirements of fodder and its source for livestock (both stall-fed and grazing) and (8) sources and requirement of fuel wood.

Using a weight survey method, the quantities of fuel wood consumption of the sampled households were measured over a period of 24 hours (Mitchell, 1979; Negi & Todaria, 1993). Quantification of fuel wood use was made to assess, among others, the consumption in cooking, lighting and space heating during the summer, rainy and winter season. The energy value of consumed fuel wood was obtained by multiplying it with 16.8×10^5 MJ kg^{-1} using Mitchell methodology (Mitchell, 1979). Information on the time and type of labour spent for fuel wood collection was also assessed on household level.

The quantity of fodder consumption was measured by the same procedure as followed for fuel wood consumption. For the purpose each household was surveyed exclusively for stall-feeding of cattle, and the feed given was measured. The biomass consumed through grazing in the forest was estimated equal to the difference in fodder consumed by totally stall-fed animals and by those that were sustained through the normal practice of stall-feeding and simultaneously through grazing.

The duration of sedentary, moderate or heavy work carried out by males and females for various activities (Leach, 1976) and used bullock power were noted. To know the biomass per head load, three head loads of fodder, firewood and compost from each family size (viz. small, medium, large family) were weighed in the villages during different seasons, viz. rainy, winter and summer.

The calorific value of compost was considered equivalent to the organic material used as an input. However, it did not include the energy needed to collect the material to prepare it. The bullock labour input consisted of food energy value required for maintaining the bullocks. The labour input consisted of agricultural activities such as ploughing and preparation of seed beds, weeding, harvesting and threshing. The energy budget in all cases was calculated separately for each crop, following the parameters of Negi *et al.* (1989). The input values were calculated in terms of work (human power and bullock power) as man-days and bullock days, and also in term of quantities of seed, compost, chemical fertilizers and biocides. The outputs were calculated in the form of crops yield and yield of the crop residue. The crops considered as marginal to the major field crop were excluded from this calculation. The output and input values were converted into energy values by multiplying the quantities/day using the calorific equivalents defined by Mitchell (1979). The energy efficiency of each subsystem was calculated as input-output ratio. The crop yield was calculated as the randomly measured crop density for all crops at the time of the crop harvest across the three-altitudinal zones. The density derived for each crop species was based on 20 quadrates (50×50 cm size). Three plots (50×50 cm) of main crops were harvested and separated for crop product, namely grain and residue. The yield was calculated on per hectare basis. Fodder production from the bunds of the agricultural fields was estimated using the harvest method. Here 20 quadrates (50×50 cm size) were randomly placed after Monsoon season when the above ground biomass was at its maximum. Weeds, growing along with various crops during summer and winter cropping seasons and being used either as fodder or recycled back in the system, were also measured by placing 20 quadrates (50×50 cm). To evaluate the green fodder yield from different agroforestry species, 20 quadrates (10×10 m size each) were placed randomly within each village and species density of agroforestry trees was determined. Thereafter, three average-sized individuals of each tree species were harvested to assess the value of the green fodder at the time of maturity of the leave fodder. The total fodder yield results from the tree density multiplied by produced green fodder. The energy value of fodder obtained from crop field bunds, weeds, and tree leaves was converted into calorific values following Mitchell (1979) approach. The biomass utilization pattern (energy sinks and fluxes) in the agroecosystem is depicted in the Figure 1.

Table 1: *Energy values for certain agricultural materials on fresh weight basis (based on Mitchell, 1979).*

Category	*MJ kg^{-1}*	*MJ day^{-1}*
Grains	6.2	
Pulses	17.0	
Oilseeds (mustard, sesame)	23.1	
Tubers (potato)	3.9	
Leafy vegetables	2.8	
Vegetables	2.4	
Milk (cow and buffaloes)	4.2	
Rhizome (ginger, turmeric)	2.8	
Green fodder	3.9	
Tree and shrub leaves	4.2	
Hay	14.5	
Leguminous hay	14.9	
Straw	13.9	
Fuel wood	19.7	
Compost	7.3	
Fertilizer	30.3	
One man-day		16.7
One bullock-day		72.2

3 Results

Agriculture is the main occupation of the people of Rawanganga micro-watershed. The micro-watershed has an area of 1850 ha land and 30 percent of it is under agriculture. The micro-watershed represents a gradient of altitudes with a wide variation in microclimates and terrains resulting in a congregation of large number of agricultural practices in a small area. The irrigated land represents only 0.5 % of the total agricultural area. Nev-

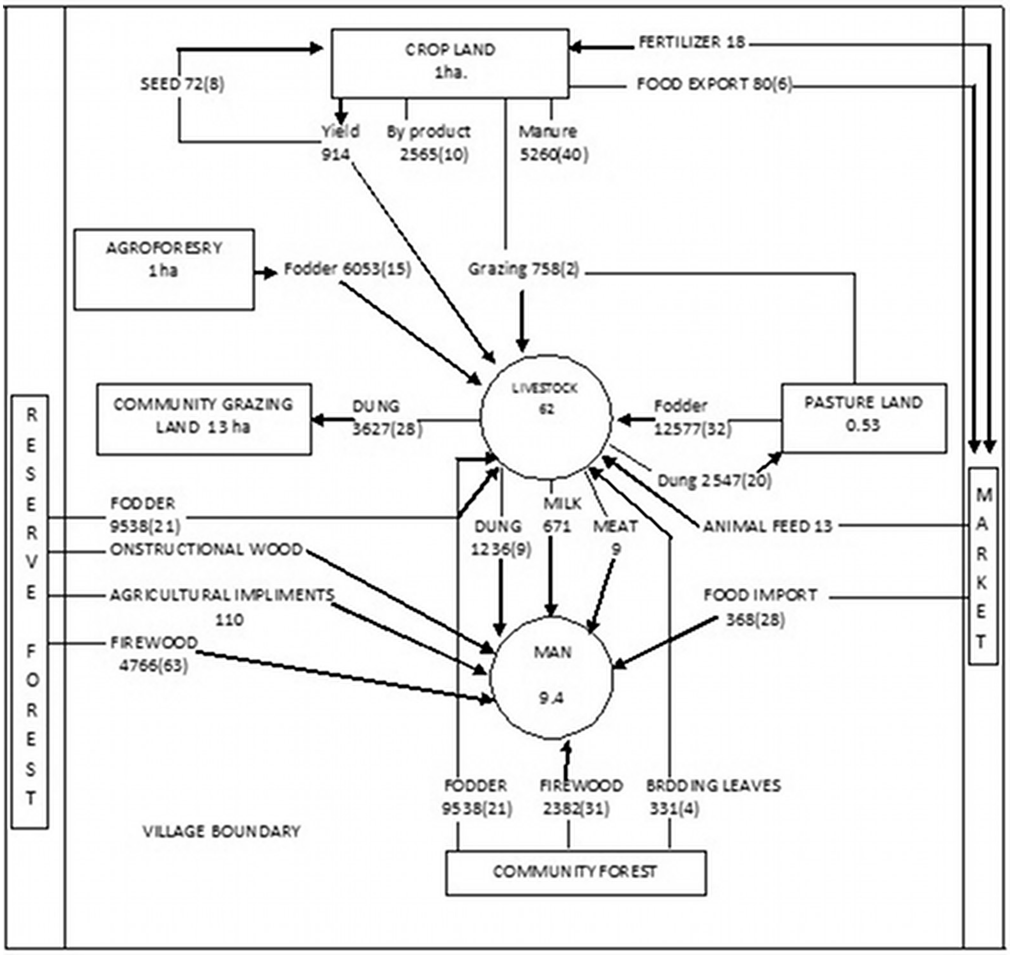

Fig. 1: *Biomass utilization pattern of various components of Agro-ecosystem in Rawanganga micro- watershed in the lower altitudinal zone. All values are given in kg. wt (usable form)* ha^{-1} *of cultivated land. Values given in parentheses indicate the percent contribution to the total demand of respective resource.*

ertheless up to 31 food crops are grown in this micro-watershed (Table 2). A number of multipurpose tree species having agroforestry importance (mainly fodder and fuel wood) are widely cultivated in the entire micro-watershed (Table 3).

Agriculture in the Rawanganga micro-watershed is practiced as a composite system of agriculture, animal husbandry, horticulture and agroforestry, marking no specific trend or composition. *Oryza sativa* (paddy) and *Triticum aestivum* (wheat) are the main cereal crops cultivated during Kharif & Rabi seasons respectively. *Echinochloa frumentacea* and *Eleusine coracana* are grown during Kharif season in association with a variety of pulses and form the staple diet of the people. In addition to these major crops, a number of other crops such as grain, tuber, vegetable, oil seed, pulses and spices are also grown (Table 2). After the paddy is harvested in October-November, the fields are either left fallow or wheat and mustard are grown. There is approximately 30 days variation in sowing and harvesting of the same crop between lowest altitude (800 m) and highest altitude (2000 m).

The natural fodder sources include vegetation growing in pastureland, agriculture terrace bunds, roadside, riverside stretches, forest and especially cultivated agroforestry zones. Grass species in this area grow abundantly during the rainy season. Also a number of multipurpose tree species are widely cultivated in the entire micro-watershed (Table 3).

These trees provide fodder, fuel wood and fruits. Density of these multipurpose trees (MPTs) varies from 30–90 per ha in the agroecosystems along the altitudinal gradient. The most important agroforestry species in the micro-watershed are *Celtis australis*, *Ficus roxburghii*, *Ficus palmate*, *Ficus cunia*, *Prunus cerasoides*, *Quercus leucotrichophora*, and *Q. glauca*.

Table 2: *Sequential sowing and harvesting time of important crops in Rawanganga micro-watershed.*

Crops	*English name*	*Local name*	*Sowing time*	*Harvesting time*
Cereals and millet				
Oryza sativa	Paddy	Sat (Dhan)	March–April	October–November
Triticum aestivum	Wheat	Gahun	November–December	April–May
Hordeum vulgare	Barley	Jau	November–December	April–May
Eleusine coracana	Finger millet	Mandwa	April–May	October–November
Echinocloa frumentacea	Barnyard millet	Jhangora	April–May	October–November
Setaria italica	Foxtail millet	Kauni	April–May	October–November
Amaranthus appoleracea	Amaranth	Chaulai	April–May	October–November
Zea mays	Maize	Maikaee	April–May	October–November
Pulses				
Glycine soja	Bhat	Bhat	April–May	October–November
Glycine max	Soyabean	Soyabean	April–May	October–November
Macrotyloma uniflorum	Horse gram	Gahat	April–May	October–November
Pisum sativum	Pea	Mater	April–May	October–November
Vigna ungiculata	Cowpea	Sonta	April–May	October–November
Cajanus cajan	Pigeon pea	Tor	April–May	October–November
Cicer arientinum	Gram	Chana	April–May	October–November
Lens esculenta	Lentil	Masoor	April–May	October–November
Vigna mungo	Black gram	Kalidal	April–May	October–November
Oil seed				
Brassica campestris	Mustard	Sarson	October–November	March–April
Brassica nigra	Mustard black	Rada	October–November	March–April
Sesamum indicum	Sesame	Til	March–April	October–November

Table 3: *Tree species in traditional agroforestry system and their utility in Rawanganga watershed.*

Species name	*Local name*	*Family*	*Utility value*
Aesculus indica	Panger	Sapindaceae	fuel, soap oil, timber
Alnus nepalensis	Utis	Betulaceae	timber, fuel, animal bedding
Cederla toona	Toon	Meliaceae	fuel, timber
Celtis australis	Kharik	Ulmaceae	fuel, fodder, timber
Ficus cunia	Khaina	Moraceae	fodder, fuel
Ficus palmate	Bedu	Moraceae	fodder, fuel, fruit edible
Ficus roxburghii	Timla	Moraceae	fodder, fuel, fruit edible
Ficus nemaralis	Thelka	Moraceae	fodder, fuel
Fraxinus micrantha	Angu	Rosaceae	fuel, timber
Lyonia ovalifolia	Anyar	Eriaceae	fodder, fuel, timber
Myrica esculenta	Kaphal	Myriaceae	fuel, edible fruit, timber
Pyrus lanata	Maul	Rosaceae	agric. implement, fuel, fruit edible
Prunus cerasoides	Payan	Rosaceae	fodder, agric. implement, fuel, fruit edible
Quercus leucotrichophora	Banj	Fagaceae	fodder, fuel, timber, animal bedding
Sapindus mukorossii	Reetha	Sapindaceae	fuel, soap substitute

Table 4: *Agronomic Yield (kg ha^{-1}) of different crops in Rawanganga micro-watershed.*

Crops	*Low altitude*			*Middle altitude*			*High altitude*		
	Grain	*Crop residue*	*Total*	*Grain*	*Crop residue*	*Total*	*Grain*	*Crop residue*	*Total*
Paddy	870	2428	3298	1058	1527	2585	625	1879	2522
Wheat	616	2154	2770	1368	2732	4100	432	2154	2586
Mustard	523	–	523	472	–	472	180	–	186
Barnyard Millet	530	1966	2496	1041	5038	6079	864	3410	4274
Finger millet	1030	8223	9253	1076	11191	12267	464	2130	2594
Pulses	1962	1544	3506	476	–	476	206	–	206
Minor crop	869	2677	3546	428	2321	2749	441	1727	2168

Another source of fodder is the residue of crops like paddy, wheat, barnyard millet, finger millet, foxtail millet and pea. The crop residue forms supplementary forage for the livestock. Every household stores hay or the byproducts of the crop residues. These crop residues are dried and stored and are thus available for use the year-round and is of particular importance within the lean period (winter).

Most of the crops as paddy, wheat, barnyard millet and finger millet have shown higher grain yield kg/ha at middle altitudinal villages and lower yield at village situated at lower attitudes (Table 4). In contrast, pulses and other minor crops have maximum grain yield at lower altitudinal zone.

3.1 Energy budget of crops

The highest total energy input in the agroecosystem of 9.183×10^5 MJ ha^{-1}yr^{-1} was recorded at the high altitudinal zone and the lowest at the lower altitudinal zone (5.555×10^5 MJ ha^{-1}yr^{-1}). But the total energy output was found to be maximum (10.55×10^5 MJ ha^{-1}yr^{-1}) at the middle altitudinal zone followed by that of the higher and lower altitudinal zones (7.70×10^5 MJ|, ha^{-1}yr^{-1}). Farmyard manure was observed to be the main energy input for the agroecosystem. Its share makes up to about 94, 93 and 96 % of total energy input at lower middle and higher altitudinal zones, respectively. Crop by-products contributed to the maximum in terms of total energy output, which was accounted 38.6, 43.2 and 24.0 % of total output for lower, middle and higher altitudinal zones, respectively (Table 5).

Energy budget of agroecosystem across the three different altitudinal zones reveals that the manure consists of about 95 percent of the total input. The use of bullock labour (0.42 %) and chemical fertilizer (1.07 %) is negligible. Maximum output was recorded in terms of either crop residue (35 %) or fodder (55 %) from agroforestry components which indicates that the fodder production for livestock is the major output from the agroecosystem. The overall input-output ratio was found to be highest (1.46) for middle-altitudinal zone and the lowest (1.02) for the high altitudinal zone. And it was estimated that output- input ratios was very low in cases when only agronomic yield was considered (Tables 5 & 6).

Table 5: *Total annual energy output and input pattern and output/input ratio for different crops in three altitudinal zones in Rawanganga micro-watershed.* *

Parameters	*800–1200 m.a.s.l*	*1200–1600 m.a.s.l*	*< 1600 m.a.s.l*
Input			
Human labour	0.2 (2.7)	0.19 (2.6)	0.13 (1.5)
Bullock labour	0.03 (0.5)	0.04 (0.5)	0.02 (0.2)
Seed	0.07 (1.3)	0.13 (1.7)	0.1 (1.1)
Manure	5.3 (94.7)	6.8 (93.7)	8.8 (96.1)
Fertilizer	0.04 (0.8)	0.1 (1.5)	0.1 (1.0)
Total	5.56	7.2	9.2
Output			
Agronomic yield	0.91 (11.7)	0.9 (8.4)	0.7 (7.2)
Crop residue	3.0 (38.8)	4.6 (43.2)	2.3 (24.0)
Fodder from agroforestry tree/weed and grasses	3.8 (49.3)	5.1 (48.4)	6.5 (68.8)
Total	7.7	10.6	9.9
Output/Input ratio			
Agronomic yield	0.2	0.12	0.07
Agronomic yield + crop residue	0.7	0.75	0.32
Agronomic yield + crop residue + fodder	1.4	1.46	1.02

* Values in MJ × 10^5 ha^{-1} y^{-1}; Values in parenthesis are the percentage contribution to total energy output and input of the respective parameter.

Table 6: *Crop wise energy input and output values at three altitudinal zones in Rawanganga micro-watershed (MJ kg^{-1} ha^{-1}).*

Parameters	Total quantity (MJ kg^{-1} ha^{-1} day^{-1})*																							
	Oryza sativa			*Triticum aestivum*			*Brassica campestris*			*Echinochloa frumentacea*			*Eleusine coracana*			*Pulses*			*Mixed crop*			*Potato*		
	A	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*	*A*	*B*	*C*
Input																								
Human labour (i) Cultivation	137 (2288)	110 (1837)	140 (2338)	67 (1119)	139 (2321)	104 (1732)	129 (2154)	178 (2973)	120 (1703)	50 (835)	95 (1587)	57 (952)	214 (3574)	368 (6146)	61 (1019)	209 (3490)	86 (1434)	73 (1219)	125 (2088)	96 (1603)	69 (1152)	–	–	210 (3507)
(ii) Maintenance of crop field	47 (785)	31 (518)	43 (718)	–	–	–	–	–	–	11 (184)	71 (1186)	25 (418)	32 (534)	116 (1937)	20 (334)	–	–	–	27 (511)	20 (334)	32 (534)	–	–	40 (668)
Bullock labour	18 (1309)	18 (1309)	20 (1454)	13 (945)	44 (3199)	27 (1963)	37 (618)	44 (3199)	15 (1091)	14 (1018)	41 (2981)	17 (1236)	30 (2181)	53 (3853)	20 (1454)	91 (6606)	42 (3053)	10 (427)	25 (1818)	19 (1381)	14 (1018)	–	–	25 (1818)
Seed	105 (1701)	104 (1685)	135 (2187)	61 (988)	263 (4261)	130 (2106)	30 (692)	83 (1967)	23 (531)	25 (465)	112 (1814)	97 (1571)	74 (1199)	174 (2819)	113 (1831)	52 (884)	53 (901)	22 (374)	158 (2560)	100 (1620)	73 (1182)	–	–	300 (1170)
Manure	10009 (73066)	9610 (70153)	15412 (122508)	7304 (53319)	17496 (127720)	8841 (64539)	10187 (74365)	20277 (148022)	11574 (84490)	–	–	–	–	–	6865 (50115)	–	–	–	9322 (6805)	6692 (48851)	5514 (40252)	–	–	4757 (34726)
Fertilizer	80 (2424)	74 (2442)	64 (1939)	–	–	–	–	–	–	34 (1032)	162 (4909)	108 (3272)	14 (424)	87 (2363)	100 (3030)	–	–	–	–	–	–	–	–	–
Total	(81573)	(77744)	(131044)	(56371)	(137501)	(70340)	(77829)	(15161)	(87815)	(3534)	(12477)	(7449)	(7912)	(17118)	(57783)	(10990)	(5388)	(2330)	(7502)	(53789)	(44138)	–	–	(41889)
Output																								
Agronomic yield	870 (14094)	1058 (17010)	625 (10125)	616 (9979)	1368 (22161)	432 (6998)	523 (12066)	472 (11186)	180 (4153)	530 (8586)	1041 (16864)	684 (11080)	1030 (16686)	1076 (17431)	464 (10465)	1962 (33364)	476 (8092)	206 (3502)	869 (1407)	628 (10174)	441 (7144)	–	–	2206 (8603)
Crop residue	2428 (35206)	1527 (22141)	1897 (27506)	2154 (16240)	2732 (39614)	2154 (31233)	–	–	–	1966 (28507)	5038 (73051)	3410 (49445)	8223 (119234)	11191 (162269)	2130 (30885)	1544 (22388)	–	–	2677 (2881)	2321 (33654)	1727 (25041)	–	–	–
Total	(49300)	(39151)	(37631)	(26219)	(61775)	(38231)	(12066)	(11186)	(4153)	(37093)	(89915)	(60525)	(135920)	(179700)	(41350)	(55742)	(8092)	(3502)	(5298)	(43828)	(32185)	–	–	(8603)
Net return	(32273)	(38593)	(93413)	(30152)	(75726)	(32109)	(65763)	(144975)	(83662)	(–33559)	(–77438)	(–53076)	(–128008)	(-162582)	(16433)	(–44752)	(–2704)	(1182)	(–2213)	(9961)	(11953)	–	–	(33286)
Out/input ratio	(0.60)	(0.50)	(0.28)	(0.46)	(0.55)	(0.54)	(0.15)	(0.07)	(0.04)	(10.49)	(7.20)	(8.12)	(17.17)	(10.49)	(0.71)	(5.07)	(1.50)	(1.50)	(0.17)	(0.81)	(0.72)	–	–	(0.20)

*A: 800–1200 m, B: 1200–1600 m and C: > 1600 m; Values in parenthesis indicate energy value (MJ kg^{-1} ha^{-1})

As there were significant differences in the energy input output ratio along the altitudinal gradient the first hypothesis of the research was accepted. Agronomic yield along with crop residue and fodder yield show maximum energy efficiency at middle altitude thus proving the second hypothesis.

The crop wise output input ratio (O/l ratio) reveals that in the lower altitudinal zone finger millet and barnyard millet were highly profitable crops in terms of energy efficiency ratio, whereas *Brassica* was found to be energy inefficient (Table 6). In the middle altitudinal zone, again finger millet and barnyard millet were found to be highly profitable whereas *Brassica* was the least profitable crop. In other words, to cultivate each energy unit of *Brassica*, an input of 14 energy units is required. Also the high altitudinal zone, barnyard millet was found to be the most profitable crop and *Brassica* was the least profitable. Here, each energy unit of *Brassica* production requires 25 unit of energy input.

3.2 Fuel wood energy consumption

Major use of wood in the entire watershed is for household work: cooking, preparation of local beverage, cooking food concentrates for cattle and for keeping houses warm during winter season. A considerable volume of biomass was consumed in meeting the fuel wood requirements of the people (Table 7).

Table 7: *Estimated fuel wood energy consumption at different altitudinal zones in Rawanganga micro-watershed.*[*]

Altitudinal Zone (m a.s.l.)	*Fuel wood (kg/person)*			*Annual Consumption of fuel wood (kg)*
	Summer	Winter	Rainy	
800–1200	2.0 (40.0)	3.2 (64)	1.2 (23.0)	781.1 (15388)
1200–1600	1.5 (30.0)	2.7 (53.0)	0.8 (16.0)	616.8 (12151)
> 1600	2.1 (41.0)	3.5 (69.0)	1.2 (24.0)	823.7 (16226)
Total	1.9 (37.0)	3.1 (62.0)	1.2 (21.0)	740.0 (14578)

[*] Numbers in parentheses indicate value in MJ

The lowest quantity of fodder was collected during winter in the lower altitude and the highest during summer in the higher altitude villages (Table 8).

The quantity of fodder consumed in different seasons across the three-altitudinal zones in the micro-watershed reveals that, during rainy season the fodder consumption was found to be the highest (17.5, 21 & 8.7 kg animal^{-1} day^{-1}) and during summer, the lowest (7.6, 8.0 & 6.2 kg animal^{-1} day^{-1}) in lower, middle and higher altitudinal villages, respectively. Fodder consumption (per animal/day) in the lower and middle altitude was markedly higher as compared to that recorded for higher altitude. The total annual consumption of fodder was found to be the highest (5 t) at the middle altitude and lowest (2.9 t) in higher altitude villages.

Across the three seasons, on average 23 % cattle were dependent on stall feeding in the high altitude villages, 29 % at lower, whereas, 41 % cattle in mid altitude zone (Table 9). In the winter season, the highest stall feeding was recorded in middle altitude villages and lowest in higher altitude villages. In the winter season, highest grazing was observed in high altitude villages and lowest in the middle altitude villages. During the summer season, the highest percentage of stall feeding was observed again at the middle altitudinal zone and the lowest at high altitudinal zone. Maximum grazing during the summer season was noticed at the high altitude zone and minimum at the middle altitude zone. In the rainy season the highest stall feeding was observed in the middle altitude and the lowest in high altitude villages. Distance travelled by the cattle for grazing was noticed the longest for the villages of the middle altitudinal zone. The lowest distance for grazing is covered during the winter (as there is no greenery around, the cattle are just released for roaming and drinking water). As the days are longer and fodder resources also scarce during the summer the maximum time is spent on grazing in this season.

Villagers collect fodder from the surrounding forests and farmlands. Mainly women and children are involved in this work. On an average, 7 men, 164 women and 37 children were involved for fuel/fodder collection during the winter, 8 men, 56 women and 7 children during the summer and 30 men, 77 women and 24 children were used during the rainy season across three altitudinal zones. It takes on average five hours per day for each household in the lower and middle, and three hours at the higher altitude zone, to collect a head load of fodder and fuel wood. Although the quantity of fodder required varied with the number and size of the livestock per household, on an average, at least one collection per day is obligatory. Beside the labour expenditure as mentioned above, the daily household and agriculture work are equally labour oriented.

Table 8: *Fodder collection (household^{-1} day^{-1}) from different sources at different altitudinal zones in Rawanganga micro-watershed.*

Seasons	*Sources*	*Altitudinal zone (m a.s.l.)* 800–1200 *Dry*	800–1200 *Green*	1200–1600 *Dry*	1200–1600 *Green*	> 1600 *Dry*	> 1600 *Green*
Winter	Agriculture	00.0	00.0	00.0	00.0	00.0	00.0
	Pasture/wasteland	15.0±0.31	00.0	22.0±2.1	00.0	30.0±4.1	00.0
	Agroforestry	00.0	10.2±0.2	00.0	20.0±1.2	00.0	20.4±6.0
	Forest	20.0±0.92	40.0±2.2	39.0±3.8	40.0±4.8	30.0±3.1	38.9±1.4
	Total	35.0	50.2	59.0	60.0	60.0	59.30
Summer	Agriculture	00.0	35.0±2.5	00.0	30.0±2.2	00.0	37.9±3.3
	Pasture/wasteland	10.0±0.62	30.0±2.7	30.2±3.9	25.0±1.8	42.0±1.4	57.2±6.3
	Agroforestry	00.0	10.2±0.8	00.0	10.0±0.2	00.0	17.5±1.6
	Forest	32.0±1.90	18.2±1.3	40.1±4.1	25.2±0.8	36.0±4.4	42.7±3.2
	Total	42.0	83.5	70.3	90.2	78.0	155.3
Rainy	Agriculture	00.0	25.0±2.3	00.0	40.3±3.4	00.0	60.0±4.3
	Pasture/wasteland	00.0	30.0±3.5	00.0	37.2±4.3	00.0	40.3±2.1
	Agroforestry	00.0	00.0	00.0	12.0±0.2	00.0	16.2±1.0
	Forest	00.0	32.7±4.6	00.0	35.0±3.2	00.0	36.9±1.8
	Total	00.0	87.7	00.0	124.5	00.0	153.4
	Mean across season	38.5	73.5	64.7	91.6	69.0	107.2

Table 9: *Fodder consumption (kg animal^{-1} day^{-1}); contribution (%) of stall-feeding and grazing; time and distance travelled during grazing; labour input (days) in terms of men, women and children; time and distance travelled for collection of fuel and fodder during different seasons in three transects of Rawanganga micro-watershed.*

Parameters	*Altitudinal zone (m a.s.l.)* 800–1200 *A*	800–1200 *B*	800–1200 *C*	1200–1600 *A*	1200–1600 *B*	1200–1600 *C*	> 1600 *A*	> 1600 *B*	> 1600 *C*
Fodder consumption (kg animal^{-1} day^{-1})	15.4±1.74	7.6±2.1	17.5±1.31	15.3±1.8	8.0±0.9	21.0±2.4	8.0±0.7	6.92±1.0	8.65±0.9
Stall-feeding (%)	47.2	19.2	19.00	66.9	32.2	23.3	37.82	13.18	18.2
Grazing (%)	52.7	80.8	81.00	33.1	67.8	76.8	62.18	86.82	81.77
Grazing time (h)	3.0±0.2	6.0±0.3	4.0±0.2	2.5±0.1	8.0±0.5	4.5±0.2	4.5±0.6	6.0±0.2	5.0±0.3
Distance travelled (km)	0.5	6.0	4.0	1.0	5.0	5.0	0.5	4.5	4.5
Labour input for fuel / fodder collection (days)									
Men	05	04	18	03	06	32	13	14	40
Women	139	37	66	179	58	90	176	73	74
Children	29	06	09	42	00	28	41	14	36
Time consumed for fuel/fodder collection (h)	8.0	6.0	2.0	6.0	4.0	2.0	4.0	3.0	2.0
Distance travelled (km)	12.0	8.0	1.5	8.5	6.0	0.5	4.0	4.5	0.5

A: Winter season, B: Summer season and C: Rainy season

4 Discussion

An analysis of agroecosystem functioning and resource use pattern across three altitudinal zones in Rawanganga micro-watershed indicates that each zone has its own peculiarities. In the present study, the output-input ratio for different crops at different altitudinal zones exhibits higher efficiency ratios than reported earlier (Ralhan *et al.*, 1991) for certain agroecosystems of Central Himalaya. These values are also higher than 0.68–1.61 reported by Houpii (1986) for different ecosystem of the Jatai basin of China. This can be attributed to the fact that the green fodder obtained from agroforestry trees was considered as farm produce in the present study. The herbaceous vegetation growing on the bunds together with weed was also considered as an auxiliary output which consequently enhanced the energy output-input ratio of the studied agroecosystems.

In the study area stall feeding and grazing are the common practices and cattle are mainly stall fed in lower and middle altitudinal zones, as forests are located at far away distance in these zones, and they do not have a good fodder base. As we move from the lower to the higher altitudes the distance travelled and time spent on collecting fodder is greatly reduced owing to the presence of more forests at higher altitudes. The high altitude villages are in close vicinity of the forest and therefore collect more fodder as compared to lower altitude villages where forests are far away. Further grazing in the nearby forests is higher in the high altitudinal zones. However, during the rainy season when fodder grows naturally in nearby places, both the distance travelled and time spent on collecting fodder is reduced at all the three altitudinal zones. Traditional systems operating around the world are very much alive and support not only the resilient ecosystems and the concomitant biodiversity without imposing public costs (Toledo *et al.*, 2003), but also have the potential solutions to food security and water shortage problems. In addition the systems work towards to improving soil health, reducing pesticide use and providing benefits to the rural poor (Pretty *et al.*, 2003).

In the recent years comprehensive data has been generated on the increasing demand of fuel wood and fodder required to maintain the non-viable hill agroecosystem in the Central Himalayan region (Sen *et al.*, 2002; Semwal *et al.*, 2004). Fuel wood is also estimated to account for 69 % of the total biomass use worldwide (Fernandes *et al.*, 2007). Farmyard manure derived from the forest and livestock component (consisting of animal urine and excreta) contributed more than 95 % to the total inputs.

The energy input in term of human labour and bullock labour is important in the agroecosystem of the region (Gairola & Todaria, 1997). Maximum human energy is consumed in manure preparation (Semwal & Maikhuri, 1996). Therefore, scientific studies are required to minimize the labour intensive production of farmyard manure and to develop alternative means to replenish soil fertility, such as mulching with weeds (Kandpal & Negi, 2003). The work efficiency of bullocks in this region is generally lower as compared to that of many other regions of the country. Introducing appropriate modification to the agricultural implements could also enhance the efficiency of the bullock labour.

The population of micro-watershed depends on the forest for fuel wood as a primary source of energy. The present study shows that fuel wood consumption-pattern at three altitudinal zones ranged between 0.8 and 3.5 kg capita^{-1} day^{-1} in different seasons. These values are higher as compared to the values reported earlier for the rural communities of the western Himalaya (1.5 kg capita^{-1} day^{-1}) by Pandey & Singh (1984). However for the North-eastern parts of India (tribal communities), Maikhuri (1991) reported higher values ranging from of 3.1 to 10.4 kg of fuel wood consumption per person and day. The higher fuel wood consumption in the present study is largely due to the greater availability of fuel wood resources and also due to the lack of non-conventional energy sources like cooking gas and electricity. The fuel wood consumption in the present study was greatly influenced by the altitude, season of the year and the family size (Bhatt *et al.*, 1994). It is important to mention here that if the current trend of fuel wood consumption pattern continues there will be a scarcity of fuel wood supply in the near future. Developing agroforestry component in the degraded land, along with providing tangible ecosystem service to the local communities, could accompany significant carbon sequestration, a global environmental benefit. Traditional agroforestry system is thoroughly well developed in the rainfed agriculture of the region. The higher density of *Pyrus lanata* indicates that this is the most preferred species among the households of the micro-watershed. Moreover; the traditional rainfed agriculture on raised terraces has passed through a process of agricultural intensification. But this has also in turn reduced the crop species diversity (Rao & Pant, 2001). The multipurpose trees not only provide green fodder during the lean period but also give fuel wood, fibre and fruit (Negi & Joshi, 2001). This component of the hill agroecosystem can be further strengthened with the incorporation of nitrogen-fixing and soil binding species and other economically important taxa available in the native vegetation of the region.

Agroforestry is observed to be appropriately developed at all altitudinal zones. Trees are the permanent feature of the landscape, and the local people also utilize non-timber tree products, e.g. dwarf bamboo for basket making. Absence of stumps in and around the farmlands suggested that trees were not felled. Among all agroforestry tree species, *Celtis australis*, *Ficus roxburghii*, *Ficus palmata* and *Pyrus lanata* were found to be the most dominant species throughout the Rawanganga micro-watershed. But a modern input in terms of high yielding genotypes into agroforestry is needed if the system is to become more environmentally sustainable.

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