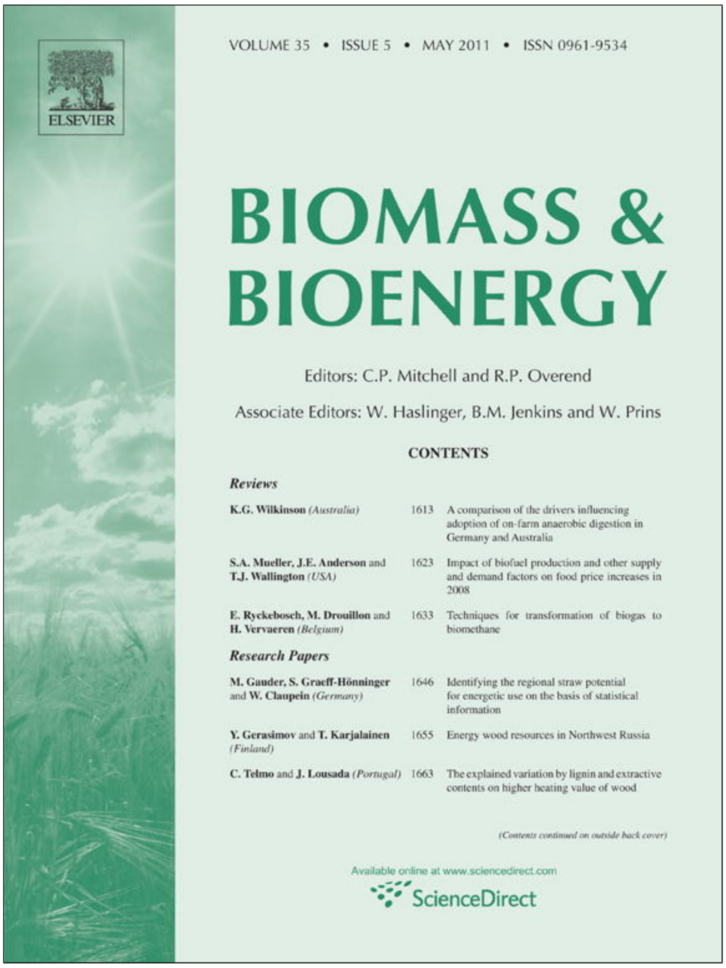

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An investigation into the energy use in relation to yield of traditional crops in central Himalaya, India

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ABSTRACT

Agrobiodiversity and agroecosystem management have changed in central Himalaya due to increasing emphasis on market economy and the motive 'maximization of profit'. Such changes have benefited local people in economic terms, but at the same time increased their vulnerability to environmental and economic risks. The present study addressed the issue of how the ecological functions that are provided by agrobiodiversity translate into tangible benefits for the society. Important characteristics of agrodiversity management are the use of bullocks for draught power, human energy as labour, crop residues as animal feed and animal waste mixed with forest litter as organic input to restore soil fertility levels. The present analysis of resource input–output energy currency in traditional crop production indicated that inputs into different crop systems were significantly higher during kharif season compared to rabi season both under rainfed and irrigated conditions. The maximum input for crop during rabi season (second crop season) was about 31% of that of kharif season (first crop season after fallow) under rainfed conditions. Under irrigated conditions the rabi season input was about 63% of kharif season input. Under rainfed conditions, paddy sole cropping required maximum inputs (231.31 GJ/ha) as compared to mustard sole cropping (11.79 GJ/ha). The present investigation revealed that the total energy inputs and outputs are higher for irrigated agriculture as compared to rainfed system, the difference in inputs is about 5 fold and outputs is about 2 fold. The output–input ratio showed that irrigated systems have higher values as compared to rainfed systems.

1. Introduction

The Himalayan region is vast, gigantic, diverse and one of the youngest mountain systems in the world. The Garhwal Himalayan region is characterized by undulating terrain, sparse human population, small and fragmented land holdings, rainfed subsistence agriculture, low input–low output production system, poor means of transport and communication, women centered agriculture, migration of males in search of off-farm employment, fragile ecosystem, low risk bearing capacity of farmers yet rich in plant and animal diversity. With their wisdom, the local hill people have maintained this fragile hill ecosystem without disturbing it. These people depend chiefly on forest, livestock and traditional agriculture in the hilly tracts for their survival. The forest products and agricultural yields meet the basic energy requirements of the central Himalayan people. A central Himalayan village can be considered as an ecosystem by

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taking into account its biomass production, consumption and energy dynamics in terms of input and output. Mixed farming is the choice of farmers in this hill agroecosystem and livestock is an inseparable component of hill agriculture as it not only supplements the family's income but also contributes to Farm Yard Manure (FYM) which is an essential requirement of largely rainfed agriculture of this region. Agrodiversity plays multiple roles in rural economy and has a strong human dimension as manifested through socio-cultural link and involvement of women.

Much of our understanding of agriculture in the Himalaya is based on the analysis of traditional knowledge and subsistence economy based farming systems [1]. The traditional agricultural systems in the region are increasingly influenced by technological innovations, the market economy and off-farm economic avenues. Such changes induced by external factors are confined to some pockets of the region which are endowed with ecological advantages for cash crops together with policies supporting new production systems. Agriculture continues to be biggest employment provider in the region [2] and improvements in crop yields are restricted due to availability of manure, moisture and labour [3]. As the traditional societies are constantly perfecting their resource use patterns, understanding the energy and economic efficiencies of resource use in agricultural system will help us in achieving the goal of sustainable development.

The analysis of resource flows has a long standing tradition. The economic analysis of resources proposed by Leontief [4] has been widely applied to various systems. Application of this technique for agricultural system or total village ecosystems of which agriculture is a component is common element for cropping systems research and ecological understanding. Such studies from the region [3,5] and elsewhere [6–12] helped in management of production system to improve the resource economies. However, the numbers of such studies are limited for traditional cropping systems as it was generally believed that such systems are less efficient than the modern systems. The use of this output input analysis methodology requires suitable indicators to classify the ecological and economic efficiencies [13]. This will enable one to use them in effective ecosystem analysis and management.

The present study analyzes the inputs and outputs in terms of energy that assess the net balances at per unit level and for entire agricultural area in the village by monitoring at crop, crop season and crop cycle levels.

2. Materials and methods

In central Himalayas a typical, mid altitude village "Langasu-Uttaron" (30° 17.368′N latitude and 77° 16.868′E longitude) was selected for the present study, where cultivated land is the nucleus of the surrounding settlements with 90% population engaged in agriculture. Participatory rural appraisal (PRA) and face to face interview methodology was used to discern the traditional perception on ecosystem diversity, land use intensification and biodiversity–environment–livelihood relationships [10–12]. All households ($N = 140$) in the village were surveyed to collect information on land holding size, area under different crops, crop composition and crop rotation. The information was collected through informal discussions with knowledgeable members of the family.

The agroecosystems analysis was carried out during the period of April 2003 to May 2006. However, agricultural productivity was assessed only during the period of April 2004 to May 2005. The boundary of the village was defined with help of Revenue Department maps. Land use and cropping patterns were noted in different seasons and the area covered by each crop during the study year was estimated by measurements. Home garden crops were not recorded due to the conjunction of species. Each household was visited at least 5–6 times during each crop season and resource inputs and outputs were recorded. Necessary collection of samples was done in entire village agroecosystem during each visit.

Inputs like manure, bullock power hours, human labour hours and seeds; and outputs likes biological/economic yield and yield of byproducts were estimated for all crop systems accounting for >95% of cropped area in a given land use type during the period of study. Three plots of each crop system in both rainfed and irrigated land use were randomly selected and all inputs were quantified. A permanent plot (0.5 × 0.5 m) with three replicates was established in cultivation areas of each crop system. Weeds of each crop system at weeding time were especially collected from these plots. Care was taken to ensure similar aspect and topographic conditions to minimize the errors in analysis [2].

Manure input to a plot was estimated by weighing the manure heaps in these plots. Human labour was monitored in terms of hours devoted to different activities of agriculture by male and female workers. Animal (bullock) labour input was estimated by monitoring the time taken to plough a given plot. For output quantification of each crop twenty random quadrates of 0.5 × 0.5 m size were studied. Crops were harvested at maturity and separated into edible, fodder and left over (roots + 15 cm stubble) components. All these components of crop(s) were dried at 65 ± 5 °C for 72 h in hot air oven and weighed. Similarly, for weed species biomass was estimated. All the inputs and outputs measured at quadrate/plot level were used to derive per hectare values.

Standard energy coefficient values [6,14] were used to obtain energy equivalents of inputs and outputs per hectare (Annexure 1). Energy input/output budgeting was done at two levels: (a) individual crop system in each agroecosystem and (b) mean attributes per unit area of different agroecosystem types on a seasonal and annual basis.

Mean input/output attributes of a given agroecosystem type were obtained based on input/output attributes of individual crop system. Annual inputs and outputs for different land use types were obtained by summing up the land use specific input and output values for rabi and kharif season for irrigated and rainfed land agroecosystem.

3. Results

Analysis of resource input–output in energy currency in traditional crop production indicated that inputs into different crop systems are significantly higher during kharif season compared to rabi season both under rainfed and irrigated conditions. The maximum input during rabi season (second crop season) crop is just 31.2% of maximum inputs of kharif season (first crop season after fallow) under rainfed conditions. Under irrigated conditions the rabi season inputs are about 63% of kharif season inputs. Under rainfed conditions, paddy under sole cropping required maximum inputs (231.31 GJ/ha) as compared to mustard under sole cropping which required minimum inputs (11.79 GJ/ha) (Table 1).

As is evident from Table 1, maximum (247.25 GJ/ha) output is obtained from paddy grown under irrigated conditions and minimum (35.86 GJ/ha) from mustard grown under rainfed conditions. The energy input to paddy mixed with other crops during first crop season after fallow is about 98% of inputs to paddy sole cropping under rainfed conditions. While sole cropping of barnyard millet during this period received about 89.42% of input of paddy sole cropping and sole cropping of foxtail millet received only 40.3% inputs.

The energy inputs to sole cropping of barley is just 49.33% of inputs to wheat mixed with mustard during rabi (second crop season after the fallow) under rainfed conditions. The energy input to finger millet mixed with black gram or a mixture of seven legumes is about 88% of input to sole cropping of finger millet during kharif (third crop season after the fallow) under rainfed conditions. While mixed cropping of seven legumes and sole cropping of black gram received 3.99 and 3.67% of energy inputs to sole cropping of finger millet during this crop season, soybean received only 2.92% inputs. While traditional farmers prefer to go for this fallow during rabi (fourth crop season after the fallow), some innovative farmers started cultivating mustard as sole crop in some land with short fallow before next crop cycle. The energy inputs required for this crop are only 16.33% of rabi season main crop i.e., wheat mixed with mustard.

Energy input though manure accounted for >94% of total energy input for crop cultivation during kharif season (both first and third crop season) except the legume sole or mixed cropping. While energy inputs through seed accounted for about less than 1.5% of total inputs, both animal power and human power accounted for almost equal proportions (Fig. 1) of the rest. However, animal power accounted for about 40–54% of total energy inputs to legume cultivation and rest is almost equally contributed by seed and human power. Inputs through manure accounted for 90–92% of total inputs during rabi (second crop season) and rest of the inputs are contributed together by seeds, animal and human power. Even the sole cropping of mustard during second rabi (fourth crop season) receives about 80.5% energy input through manure. In the latter case, seed and human power accounted for about 5% and animal power contributed rest 10% of inputs. For irrigated crops the relative contributions by manure, human power, animal power and seeds seems to be similar for both kharif and rabi crop seasons.

Except for legumes where manure application is not practiced, human labour allocation to crops is around 52–70% during first crop season after fallow under rainfed conditions (first kharif), 40–48% during third crop season (second kharif) and 32–39% during second crop season (first rabi). The newly practiced sole mustard cropping during fourth crop season accounted for 15% of total human labour demand for manure application. Legumes growing during third crop season (second kharif) and sole cropping of mustard (fourth crop season) have about 15–23% of human labour requirement for ploughing and land preparation. Storing of grain and crop byproducts accounted for major human labour demand for all crops, following demand for land preparation and manuring activities. Weeding, harvesting, threshing and storing have human labour energy investments in decreasing order for most crops.

In irrigated system manure application required about 44–47% of human energy investments. Storing of grain and crop byproducts required 18–20%, ploughing 7–10%, sowing 5–10%, harvesting 7–13%, weeding 4% and threshing 4–7% human energy demand, respectively (Fig. 2). Relative contributions of economic yield and crop byproducts to total energy output are shown in Fig. 3.

Total energy output from the system is maximum (247.25 GJ/ha) in irrigated paddy during kharif and minimum (35.86 GJ/ha) in fourth crop season (second rabi) mustard sole cropping (Table 1). During kharif (both first and third crop seasons after fallow) energy output from the crop system is maximum (186.35 GJ/ha) in paddy mixed with other crops and minimum (87.21 GJ/ha) in sole cropping of foxtail millet. When considered against main crops, finger millets mixed with legumes and sole cropping of legumes except black gram provided more energy output than that of finger millet sole cropping during third crop season after fallow (second rabi). Even black gram energy outputs are 91% of that of finger millet. However, during the first kharif season, paddy mixed with other crops provided 16% more energy output as compared to paddy sole crop. The energy yields from sole cropping of barnyard millet and foxtail millets are just 64.5 and 54.2% of sole cropping of paddy, respectively.

The energy yield of sole paddy under rainfed conditions is 65% of that under irrigated conditions. Similarly wheat mixed with mustard under rainfed conditions had 66.77% of energy outputs of the crop under irrigated conditions. The maximum energy outputs from the system during rabi is about 44.75% of kharif under rainfed conditions and about 50.2% under irrigated conditions.

Mixing legumes seems to improve crop outputs significantly. The yield improvements resulted in total energy output from systems during third crop season almost equalled with maximum energy outputs of first crop season, where the sole cropping of finger millet produce only 66.7% of that from paddy sole crop. Even sole cropping of legumes seems to produce similar amounts of energy. Relative contribution of energy output to total energy output through grain yield is maximum (45.58%) in soybean under rainfed conditions followed by wheat mixed with mustard (42%) under irrigated conditions, legumes mixed (38.62%) under rainfed conditions and paddy (37.3%) under irrigated conditions. It is lowest (10.32%) for foxtail millet. While the cereal and millet crop byproducts are the major source of fodder and their contribution (>55%) is equally important to the farmer, the byproduct energy outputs from other crops is not of much use.

The energy output–input ratio is highest for soybean (16.46) followed by legumes mixed (9.61), black gram (8.01) and mustard (0.88) when only grain yields are considered (Table 1). The trends were similar for total energy outputs from the system. The output–input ratio is significantly higher under irrigated conditions as compared to rainfed conditions for

Table 1 – Energy input (mean ± standard deviation, $n = 3$) (MJ/ha) for traditional crops grown during rabi and kharif season.

Land use	Crop systems	Input				Output				Energy output/input ratio	
		Manure (I, R)	Economic yield (R)	Crop byproduct (R)	Total	Seed (I, R)	Bullock labour (D, R)	Human labour (D, R)	Total	Based on grain	Based on biological yield
Rainfed											
First crop season (first kharif)	Paddy	223867 ± 4215	42671 ± 5552	118300 ± 11084	160971 ± 11077	497 ± 49	2610 ± 141	4335 ± 53	231308 ± 4145	0.18	0.70
	Paddy + others	219000 ± 7300	51806 ± 8886	134540 ± 2368	186346 ± 10156	729 ± 50	2640 ± 141	4839 ± 58	227208 ± 7292	0.23	0.82
	Barnyard millet	202210 ± 1931	21726 ± 2409	81928 ± 4155	103654 ± 5497	251 ± 36	1075 ± 141	3304 ± 60	206840 ± 2051	0.11	0.50
	Foxtail millet	90033 ± 2107	9003 ± 1620	78204 ± 5075	87207 ± 5210	327 ± 38	921 ± 92	1945 ± 81	93226 ± 2305	0.10	0.94
Second crop season (first rabi)	Wheat + Mustard	66917 ± 5575	21976 ± 3537	60900 ± 9652	82876 ± 10869	1161 ± 98	2118 ± 92	1983 ± 85	72179 ± 5662	0.30	1.15
	Barley	32120 ± 1264	14711 ± 2988	46508 ± 4328	61219 ± 6157	1041 ± 41	1289 ± 92	1153 ± 50	35604 ± 1433	0.41	1.72
Third crop season (second kharif)	Finger millet	105120 ± 1264	32717 ± 9615	74648 ± 4199	107365 ± 11070	630 ± 57	2303 ± 92	2520 ± 37	110572 ± 1430	0.30	0.97
	Finger millet + Black gram	90763 ± 843	37854 ± 8306	127176 ± 3624	165030 ± 8435	1143 ± 30	2333 ± 53	2523 ± 48	96762 ± 946	0.39	1.71
	Finger millet + Legumes (mixed)	91250 ± 730	38560 ± 6358	129724 ± 2828	168284 ± 6412	1399 ± 30	2395 ± 92	2635 ± 98	97678 ± 814	0.39	1.72
	Legumes (mixed)	0	41827 ± 7448	67480 ± 5443	109307 ± 10802	1083 ± 49	2149 ± 106	1120 ± 32	4352 ± 181	9.61	25.12
	Black gram	0	32490 ± 2499	65240 ± 4070	97730 ± 5158	832 ± 55	2180 ± 141	1045 ± 52	4057 ± 242	8.01	24.09
	Soybean	0	53078 ± 4813	62608 ± 4566	115686 ± 6212	941 ± 86	1289 ± 92	996 ± 84	3226 ± 258	16.46	35.87
Fourth crop season (second rabi)	Mustard	9490 ± 1264	10351 ± 2071	25508 ± 4485	35859 ± 4578	598 ± 73	1105 ± 92	595 ± 25	11788 ± 1323	0.88	3.04
Irrigated											
Kharif season	Paddy + Black gram[a]	175200 ± 19314	102240 ± 11269	145012 ± 10411	247252 ± 14618	712 ± 57	2640 ± 106	4222 ± 214	182774 ± 19561	0.55	1.35
Rabi season	Wheat + Mustard	109500 ± 7300	52157 ± 4702	71960 ± 3176	124117 ± 6034	897 ± 98	2272 ± 141	2597 ± 104	115265 ± 7358	0.45	1.08

D = Direct, I = Indirect, R = Renewable.

a Grown only on bunds of paddy crop fields.

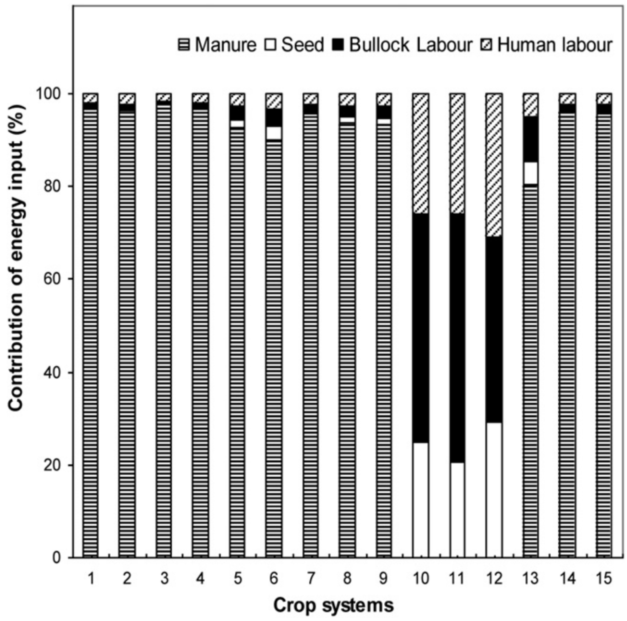

Fig. 1 – Relative contribution of energy input in crop cultivation. The details of crop systems are (1) Paddy, (2) Paddy + Barnyard millet + Pigeon pea + Sesame + Foxtail millet, (3) Barnyard millet, (4) Foxtail millet, (5) Wheat + Mustard, (6) Barley, (7) Finger millet, (8) Finger millet + Black gram, (9) Finger millet + Legumes (Mixed), (10) Legumes (Mixed), (11) Black gram, (12) Soybean, (13) Mustard, (14) Paddy + Black gram, (15) Wheat + Mustard.

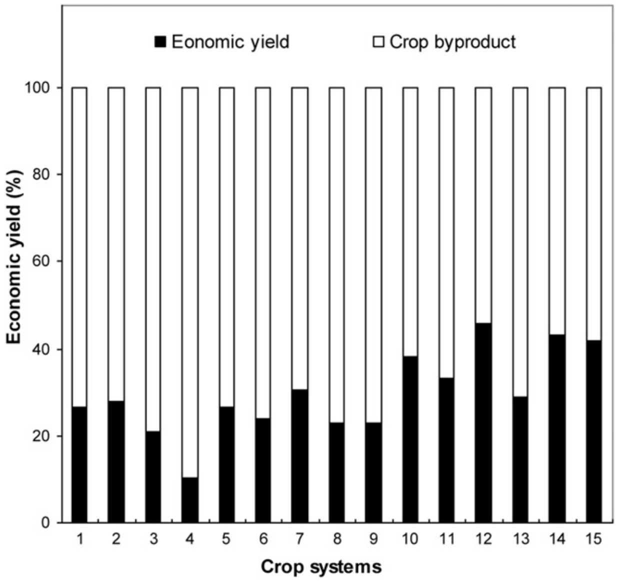

Fig. 3 – Relative contributions of economic yield crop byproducts to total energy output. The details of crop systems are (1) Paddy, (2) Paddy + Barnyard millet + Pigeon pea + Sesame + Foxtail millet, (3) Barnyard millet, (4) Foxtail millet, (5) Wheat + Mustard, (6) Barley, (7) Finger millet, (8) Finger millet + Black gram, (9) Finger millet + Legumes (Mixed), (10) Legumes (Mixed), (11) Black gram, (12) Soybean, (13) Mustard, (14) Paddy + Black gram, (15) Wheat + Mustard.

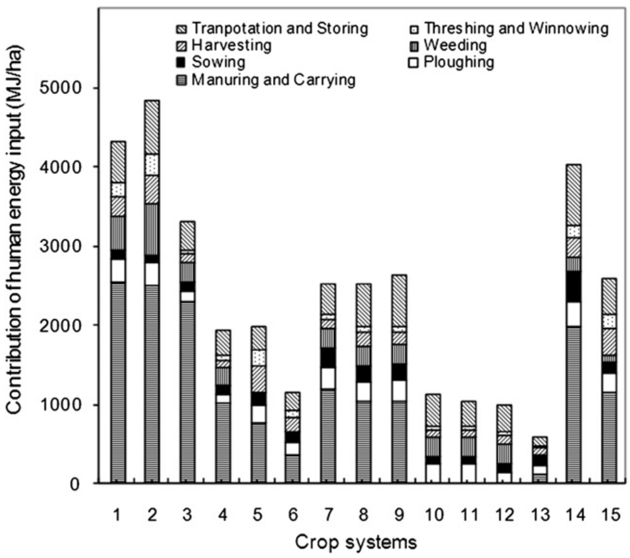

Fig. 2 – Contribution of human energy input for traditional crop cultivation in Langasu-Uttaron village. The details of crop systems are (1) Paddy, (2) Paddy + Barnyard millet + Pigeon pea + Sesame + Foxtail millet, (3) Barnyard millet, (4) Foxtail millet, (5) Wheat + Mustard, (6) Barley, (7) Finger millet, (8) Finger millet + Black gram, (9) Finger millet + Legumes (Mixed), (10) Legumes (Mixed), (11) Black gram, (12) Soybean, (13) Mustard, (14) Paddy + Black gram, (15) Wheat + Mustard.

paddy under sole cropping. Under rainfed conditions paddy mixed cropping have better ratio than sole cropping. Amazingly, black gram grown on bunds of irrigated paddy showed an output–input ratio of 35.37 for only grains and 119.64 for total outputs which is an exception.

Energy productivity of the traditional crops/crop systems is given in Table 2. Based on grains (the main economic yield), the energy productivity of crop/crop combinations is maximum (960.99 kg/GJ/ha) for soybean sole cropping and lowest (6.68 kg/GJ/ha) for foxtail millet sole cropping under rainfed conditions. Under irrigated condition both kharif and rabi crops shows an energy productivity of about 27 kg/GJ/ha. When stover, an important fodder resource and economically important crop byproduct is added to grain yields the energy productivity is maximum (2345.5 kg/GJ/ha) for soybean sole cropping system and minimum (35.66 kg/GJ/ha) for barnyard millet sole cropping under rainfed conditions. These values are 69 and 72 kg/GJ/ha for irrigated system for kharif and rabi, respectively. Sole mustard during fourth crop season which is a recent introduction showed 38.68 kg/GJ/ha energy productivity for grains only and 193.32 kg/GJ/ha energy efficiency for grain with stover.

The crop cultivation in the region receives only renewable energy and no non-renewable energy inputs are recorded. The contribution of energy for crop production from indirect energy source is 86–98% of total energy for all crops except legumes which have about 71–80% from direct sources (Table 3). Mixed cropping systems have slightly higher inputs from direct sources as compared to sole cropping system of paddy and

Table 2 – Energy production (Kg/GJ/ha) for traditional crops grown during rabi and kharif season.

Land use	Crop systems	Grains	Grains + Stover
Rainfed			
First crop season (First kharif)	Paddy	11.33	47.86
	Paddy + others	14.30	56.59
	Barnyard millet	7.37	35.66
	Foxtail millet	6.68	66.60
Second crop season (First rabi)	Wheat + Mustard	18.09	78.36
	Barley	29.10	122.42
Third crop season (Second kharif)	Finger millet	21.20	69.42
	Finger millet + Black gram	25.13	119.02
	Finger millet + Legumes (Mixed)	24.67	119.53
	Legumes (Mixed)	562.30	1670.35
	Black gram	467.98	1615.76
	Soybean	960.98	2345.51
Fourth crop season (Second rabi)	Mustard	38.68	193.22
Irrigated			
Kharif season	Paddy + Black gram	27.06	68.99
Rabi season	Wheat + Mustard	26.89	71.48

finger millet. Similarly rabi season crops have slightly higher inputs from direct sources as compared to kharif season crops.

Average energy inputs and outputs for crop production are shown in Table 4. The total energy inputs and outputs are higher for irrigated agriculture as compared to rainfed system, the difference of input is about 5 folds and output is about 2 folds. The output–input ratio for the rainfed and irrigated systems showed that irrigated systems have higher values as compared to rainfed systems. When only energy output through grain yield is considered, irrigated paddy showed a maximum value of 0.52 and the value for total annual production is 0.49. When grain yield and stover is taken together, rabi cropping under rainfed conditions and kharif cropping under irrigated conditions have output–input ratios of 1.37 and 1.21, respectively. In other cases it is just above one. However, when annual gross inputs and outputs are considered both irrigated and rainfed systems have an identical output–input ratio (1.15) which indicates that both systems are equally efficient in total energy output per unit energy inputs.

Gross energy input and output for crop cultivation for agricultural land in the village is shown in Fig. 4a–d. The gross energy input for crop cultivation is 3022.36 GJ/yr for the entire cultivated land of the village of which about 2/3rd is used for rainfed agriculture area and rest 1/3rd for irrigated agriculture. However, the energy output from the village in terms of grains is only 1147.61 GJ/yr as compared to 2286.89 GJ/yr from stover. The energy output from grain yield is about 53% of total from rainfed agriculture and remaining 47% from irrigated agriculture. However, stover from rainfed agriculture contributed 68% of annual production of the village.

4. Discussion

Energy and monetary input–output budgeting is a common approach for assessment of the production efficiency of different land use systems. Boundaries of the production systems need to be clearly defined in space and time for making meaningful comparisons [15]. Efficacy in understanding the ecological and economic efficiency of various crops and cropping systems was indicated by several workers [7,16–22]. The energy inputs for crop cultivation were chiefly derived from manure which was extracted from forest floor litter. Thus, the agroecosystem productivity was sustained by the energy extracted from forests. Studies in the region indicate that manure derived from about 5 to 18 units of forest ecosystem was required to sustain one unit agricultural land [1,3,17].

The farmer's decision on choice of crops is guided by food requirements, productivity and their ability to generate

Table 3 – Contribution of direct and indirect energy inputs for crop husbandry.

Land use	Crop systems	Indirect	Direct	Total (GJ/ha)
Rainfed				
First crop season (First kharif)	Paddy	97.00	3.00	231.31
	Paddy + others	95.00	5.00	227.21
	Barnyard millet	97.88	2.12	206.84
	Foxtail millet	96.93	3.07	93.23
Second crop season (First rabi)	Wheat + Mustard	94.32	5.68	72.18
	Barley	93.14	6.86	35.60
Third crop season (Second kharif)	Finger millet	95.64	4.36	110.57
	Finger millet + Black gram	94.98	5.02	96.76
	Finger millet + Legumes (Mixed)	94.85	5.15	97.68
	Legumes (Mixed)	24.89	75.11	4.35
	Black gram	20.51	79.49	4.06
	Soybean	29.17	70.83	3.23
Fourth crop season (Second rabi)	Mustard	85.58	14.22	11.79
Irrigated				
Kharif season	Paddy + Black gram	96.25	3.75	182.77
Rabi season	Wheat + Mustard	95.61	4.39	115.27

Table 4 – Average energy input (MJ/ha) for rabi and kharif crop seasons.

Season	Output			Input					Output input ratio	
	Economic yield	Byproducts	Total	Manure	Seed	Bullock labour	Human labour	Total	Based on economic yield	Based on biological yield
A. Kharif										
Rainfed	42185	105141	147327	131736	799	2252	3171	137957	0.31	1.07
Irrigated	80385	107506	187891	149308	543	2250	3471	155572	0.52	1.21
B. Rabi										
Rainfed	17127	47584	64710	43164	970	1659	1411	47204	0.36	1.37
Irrigated	52157	71960	124117	109500	897	2272	2597	115265	0.45	1.08
C. Annual										
Rainfed	59312	152725	212037	174901	1769	3911	4582	185161	0.32	1.15
Irrigated	132542	179466	312008	258808	1439	4522	6068	270837	0.49	1.15

resources required for sustaining production systems. Markets do show influence in terms of intensification of land use and emphasizes on certain high economic crops. Research confirmed that traditional field crop cultivation result in low levels of soil loss/erosion, require less manure as compared to High Yielding Varieties (HYVs) and have comparative advantages in terms of stable yields [3]. While the productivity of major crops seems to be similar to the national averages reported but the energy used to get such yield is very large as compared to national averages. The better performance of mixed cropping as compared to sole cropping confirmed the farmer's understanding about the advantages of yield stability achieved by such mixtures. Other workers too reported better performance of crops under mixed cropping [22,23]. Legumes provide multiple benefits to crop systems and such knowledge seems to exist with local farmers as the farmers prefer mixing legumes with millets. This showed improved gross productivity and energy yield using sole or mixed legumes as part of cropping systems to reduce total input loads as legumes do not receive any manure input (which accounted for more than 90% of energy inputs for other crops/crop combinations). In addition, population viability of the beneficial microorganism requires legumes to be cropped once during the course of cropping sequence. Synergistic relationships of one crop on following crop attracted interest of researchers [24,25] but the ecological and economic benefits of using legumes as

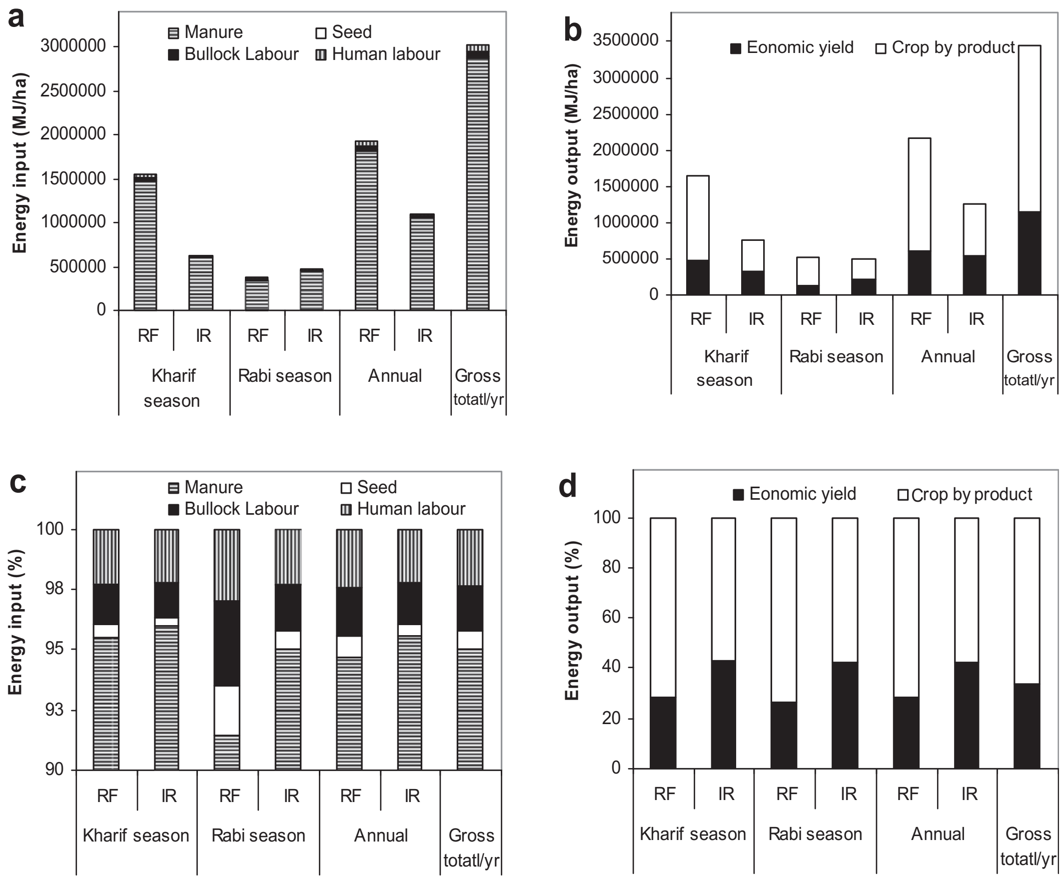

Fig. 4 – Absolute and relative gross energy inputs and outputs for crop cultivation in Langasu-Uttaron village.

comparison crops or sequence crops received much higher attention as the ecological and economic benefits seems to be more [8,19,22,23,26,27]. While most workers reported that millets are not good for grain production, the present study indicates that grain yield of finger millet based system which occupies largest extent of rainfed area have only marginally lower grain yield and in terms of energy efficiency they are far better than paddy based systems. Similar results were also reported by other workers [22,28,29].

Though farmers know that certain crops do not provide sufficient grains, but, still allocate land to these crops as it seems to fulfil their requirements such as fodder with low level of inputs which may be available with farmer's families such as manure and human labour [30–32]. The socio economic pressures, technological change do influence the crop cultivation [33,34] but the production potential of traditional cropping sequences are seldom understood by the researchers. The present study highlighted the significance of crop sequences on the basis of inputs and outputs. Present study also indicated that increasing returns are obtained on increase in input costs. It is realized that the use of specific low output crops in the sequence could only be explained based on the realization of crop genetic diversity requirements by local people for risk aversion as they believe that such low yielding crops will provide higher returns in the years of climatic uncertainty. Similar views were also expressed by Zoebl [15]. All the crops growing in the region are totally dependent on renewable energy sources and this could be one reason for their higher efficiencies than those reported by others where non-renewable energy sources are also used for paddy–wheat system [34–36]. Legume based crop systems used more direct energy. Farmers seem to be happy to allocate such energy i.e. human and animal labour as they provide far superior economic returns. The present study indicates that females contribute more than 90% human labour required for agricultural activities, such gender based segregation was not apparent in most other studies.

In terms of annual energy efficiencies, both rainfed and irrigated systems have similar rates (1.73–1.79). However, overall bioproductivity efficiency is superior in rainfed systems. This may be due to the use of only animal draught power and organic manure in the study area as compared to chemical inputs and mechanized power for land preparation in intensive agricultural systems. Management of productivity in rice–wheat rotations seems to be most important aspect for Indo-Gangetic plains and elsewhere [7,37]. In the Himalayan region integrated resource management is most important [3,38]. Maintenance of traditional cropping systems and diversification without endangering the food security seems to be the prime motive of local farmers as could be seen from low acreage of soybean and growing mustard during fourth crop season in rainfed conditions with low inputs. Such interventions confirm that farmers in Himalaya (Present study) or elsewhere prefer to have high rates of returns to their dwindling resources and keep the labour and land productivity high [21,39,40].

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Annexure 1. Energy coefficients [6,14].

Category	MJ/kg	MJ/h
Grain	16.2	
Millets	13.8	
Pulses (various beans)	17.1	
Mustard	22.7	
Straw	14	
Farm yard manure	7.3	
Man labour		2.09
Bullock labour		9.21

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