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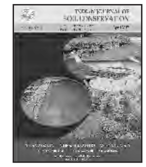

Energy budgeting of different land management practices under common vegetable crops in the Nilgiris of South India

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ABSTRACT

An experiment was conducted at ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Udhagamandalam in Nilgiris, India for evaluating productivity and energy budgeting of land management practices with different conservation measures under common vegetable cropping sequence. Inward slope bench terraces (IBT) (2%) and outward sloped bench terraces (OBT) (5 and 10%) with riser protection, sloping lands (25%) with 1 m strip of vegetative barriers (VB) were practiced using potato (*Solanum tuberosum*)-cabbage (*Brassica oleracea var. capitata*) and carrot (*Daucus carota*)-beans (*Phaseolus vulgaris*) for two rotations. Highest productivity of potato (26.7 t ha^{-1}), cabbage (37.0 t ha^{-1}) and carrot (33.6 t ha^{-1}) were obtained from conservation practice (CP) of VB with geranium in 25% continuous slope. Results revealed that potato required the highest input energy (51,321 MJ ha^{-1}) due to maximum energy (~50%) consumed in seed, whereas energy consumed in chemical fertilizer was maximum in cabbage (~60%), carrot (~58%) and beans (~47%) of the total input energy of the respective crops. Among all crops, potato produced maximum output energy ha^{-1} and among CPs, output energy for all crops were maximum in VB of geranium in 25% continuous slope. Potato was the highest energy producer in spite of higher input energy, resulting in highest energy use efficiency (EUE). Less energy efficiency was found in all the crops under OBT (10%) with grass on the risers under farmers' practice (FP) of nutrient management despite high crop yield. CP of VB in continuous slope is more suitable due to higher productivity, EUE and energy productivity for common vegetable crops in Nilgiris.

1. INTRODUCTION

The agriculture has close relationships with energy, economics and environments which are mutually dependant (Khaledian *et al.*, 2012; Singh *et al.*, 2002). Energy is one of the most important indicators of crop performance. Continuously rising prices, increasing proportion of commercial energy in the total energy input to agriculture and the growing scarcity of commercial energy sources, such as fossil fuels, have necessitated more efficient use of these resources for different crops (Singh *et al.*, 2002; Singh *et al.*, 1999). Agriculture uses large quantities of locally available non-commercial energies, such as seed, manure and animal energy and commercial energies directly and indirectly in the form of diesel, electricity, fertilizer, plant protection, chemicals, irrigation water, machinery, *etc.* The share of agriculture in national energy consumption has been rising consistently over the last three decades. Presently, it accounts for nearly a quarter of the country's electric consumption (Singh *et al.*, 1997). Change in Government's farm input subsidy regime, unpredictable climatic scenario, diminishing agricultural labour force and energy availability pressing farming practice to be more efficient in the use of energy and economic inputs for long term ecological sustainability (Dorward, 2009; Grossman and Dyland, 2011). Therefore, cropping system productivity evaluation using energy budgeting and economic input is useful and very much important (Tuti *et al.*, 2011). The net energy of a cropping system can be quantified for sound planning of sustainable cropping systems (Chaudhary *et al.*, 2006). Yield of different crops can be increased up to 30% by using optimal level of energy input (Chaudhary *et al.*, 2006). Sufficient availability of the right energy and its efficient use are prerequisites for improved agricultural production (Chaudhary *et al.*, 2009; Mohammadi and Omid, 2010). Energy consumption per unit area in agriculture is directly related to the development of farming technology and production level (Azizi and Heidari, 2013).

Energy parameters such as net energy return, energy ratio and energy productivity are meaningful indicators for assessing the efficiency of production systems (Haciseferogullari *et al.*, 2003; Pervanchon *et al.*, 2002). Input and output energy differ widely among crops, production systems and land management practices. The hilly district of Nilgiris in South India covering an area of 2543 km^2 lies in an elevation range of 1117-2595 m above msl. Farmers in the hill are mainly dependent on agriculture, particularly intensive vegetable cultivation throughout the year due to congenial climatic conditions. However, small and fragmented land holdings with steep slopes restrict the farm mechanization and farmers cultivate manually with insufficient draught power and lack of resources leading to high cost of cultivation and low crop productivity. Therefore, productivity-energy-agriculture relationship is more important for the intensive cropping systems practiced under adverse farming situations. Energy budgeting, therefore, is necessary for efficient management of scarce resources for improved agricultural production and identifies the economical and effective production practices. Therefore, the study was undertaken to identify energy efficient land management systems for satisfactory energy output and net return.

2. MATERIALS AND METHODS

Study Area

The field experiments were carried out at research farm of ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Udhagamandalam, Nilgiris, South India during 2003-06. The site was located at 11°24′ N latitude and 70°41′ E longitude at an elevation of 2217 m above msl. The long term mean annual rainfall is 1276 mm with 80% rain received during South-West and North-East monsoon (June to December). The climate is temperate to sub-tropical (Fig.1). The soil is very deep, silty clay loam with acidic (pH 4.7) in reaction, EC of 0.1 dS m^{-1} and organic C of 1.9%.

Experiment Details

The experiment was conducted in randomized block design replicated thrice on an original slope of 25% converted to outward and inward bench terraces with grasses and medicinal plants on the risers. Experimental plots of sizes 120 m^2 each were laid out consisting of 3 bench terraces (10 m length x 4 m width) in series for all CPs (Table 1).

Crop and Agronomic Practices

Two crop rotations of potato-cabbage and carrot-beans in first and second year, respectively were followed with recommended nutrient management in all treatments except FP (T_1) where fertilizer mixtures of 2000 kg ha^{-1} (6N: 12P: 6K) for potato and 1500 kg ha^{-1} (9N: 9P: 9K) for cabbage, carrot and beans were applied. Three to six months old seedlings of the medicinal plants were planted on the risers and well maintained. In the sloping field (T_{10}), one m strip of geranium was established as VB across the slope at every 10 m interval.

Energy Budget

Energy input and output in the vegetable cultivation under different CPs were estimated based on the information on energy inputs (fertilizers, seeds, plant protection chemicals, fuel requirement, human labor, power tools and farm machinery) of various operations from primary tillage up to harvest of vegetable crops and outputs energy from main and by-products. The energy value of each cropping system was determined based on the energy input and energy production from the individual crops in the system. The output energy

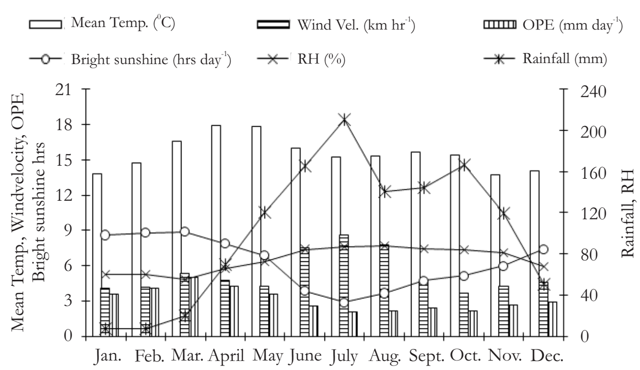

Fig. 1. Mean climatic parameters at the experimental site

Table: 1
Treatments with conservation practices

Treatments	Details
T_1	OBT (10%) + grass on the risers with FP of nutrient management
T_2	OBT (10%) + grass on riser
T_3	IBT (2%) + grass on riser
T_4	OBT (5%) + Rosemary (*Rosemarinus officinalis*) on riser
T_5	OBT (5%) + Geranium (*Pelargonium graveolens*) on rise
T_6	OBT (5%) + Cineraria (*Cineraria martima*) on riser
T_7	OBT (10%) + Rosemary (*R. officinalis*) on riser
T_8	OBT (10%) + Geranium (*P. graveolens*) on riser
T_9	OBT (10%) + Cineraria (*C. martima*) on riser
T_{10}	VB of Geranium (*P. graveolens*) across 25% slope at 2.5 m vertical interval

OBT: Outward bench terraces; IBT: Inward bench terraces calculated considering the actual yield of crop and equivalent yield (EY) of the crop from the respective yield of medicinal/aromatic plants from the riser. Inputs and outputs were converted from physical to energy unit through published conversion coefficients (Singh *et al.*, 2008; Heidari *et al.*, 2011; Devasenapathy *et al.*, 2009). The energy calculations like net energy, EUE, energy productivity and energy profitability were worked out using the following formula (Hatirli *et al.*, 2006; Canakci *et al.*, 2005).

$$\text{Net energy} = \text{Output energy (MJ ha}^{-1}\text{)} - \text{Input energy (MJ ha}^{-1}\text{)} \quad ...(1)$$

$$\text{EUE} = \frac{\text{Total Energy Output (MJ ha}^{-1}\text{)}}{\text{Total Energy Input (MJ ha}^{-1}\text{)}} \quad ...(2)$$

$$\underset{\text{(kg MJ}^{-1}\text{)}}{\text{Energy Productivity}} = \frac{\text{Crop Yield (kg ha}^{-1}\text{)}}{\text{Total Energy Input (MJ ha}^{-1}\text{)}} \quad ...(3)$$

$$\text{Energy Profitability} = \frac{\text{Net energy return (MJ ha}^{-1}\text{)}}{\text{Total Input Energy (MJ ha}^{-1}\text{)}} \quad ...(4)$$

Energy equivalents for all inputs were summed to provide an estimate for total energy input for individual crops. Energy output from the product was calculated by multiplying the amount of production and its corresponding energy equivalent. Energy output from the by-product (leaves/stalk/ vine) was estimated by multiplying the amount of by-product and its corresponding equivalent.

3. RESULTS AND DISCUSSION

Productivity

The high organic C in the first year resulted in very good potato yield and found statistically insignificant among treatments whereas significantly different cabbage yield was found with maximum (21.3 t ha^{-1}) in VB of geranium across 25% slope. In second year, carrot yield was significantly higher (38.9 t ha^{-1}) in comparison to remaining treatments again in the treatment with VB of geranium across the slope whereas the yield in the remaining treatments were nearly at par. However, the yield of beans in second year was maximum in 10% outward slope + grass on the risers under FP nutrient management due to higher dose of fertilizer mixtures applied as already reported by Sahoo *et al.*, 2010. The trend was clear in the second crop rotation, where significantly higher yield from all crops was obtained in the sloping plot with VB of geranium.

Mean productivity of vegetables from all the CPs during the experimental period are given in Table 2. The highest mean potato yield of 26.7 t ha^{-1} was obtained from VB of geranium in 25% slope followed by OBT (5%) with Cineraria on riser (23.0 t ha^{-1}) and OBT (10%) with geranium on riser (22.3 t ha^{-1}). Similarly, the highest yield of cabbage (37.0 t ha^{-1}) was obtained from practice of VB with geranium in slope 25% followed by OBT (10%) with grass on riser with FP nutrient management (32.2 t ha^{-1}) and OBT (5%) + cineraria on riser (28.8 t ha^{-1}). However, the difference in the yield of potato and cabbage among treatments was statistically insignificant. In case of carrot, yield was significantly higher in the treatment of VB of geranium on 25% slope followed by OBT (10%) + grass on the risers with FP of nutrient management. In the FP of nutrient management, higher yield of cabbage and carrot, at par yield of potato and the highest yield of beans due to direct effect of higher dose of fertilizer mixture. The highest yield and productivity in practice with VB of geranium on continuous slope of 25% due to higher available soil moisture in the crop root zone resulting from intercepted runoff by VB of geranium. A similar trend was obtained in both the crop rotations. The higher yield in VB on 25% slope clearly illustrates the reason for FP on outward sloping terraces under normal annual rainfall.

Energy Budgeting

Among the crops, potato requires maximum input energy of 51,321.4 MJ ha^{-1} followed by carrot (26,936.5 MJ ha^{-1}) and cabbage (25,775.8 MJ ha^{-1}) (Table 3). Energy consumption for seed in potato crop (25,500 MJ ha^{-1}, ~50% of the total energy requirement) was the prime factor in its higher energy consumption followed by chemical fertilizer (15,840 MJ ha^{-1}) and manures (4,500 MJ ha^{-1}). Energy consumed in chemical fertilizer was maximum in cabbage (~60%), carrot (~58%) and beans (~47%) of the total input energy for the respective crops followed by manures in comparison to human and mechanical energy requirement (Table 4). Higher energy consumption in all the crops in the form of chemical

Table: 2
Mean yield of vegetable crops (t ha^{-1}) under different land management practices

Treatment	Potato	Cabbage	Carrot	Beans
OBT (10%)+grass on the risers with farmers practice nutrient management	22.0	32.2	21.3	3.7
OBT (10%)+grass on riser	18.8	20.9	14.0	2.8
IBT (2%) + grass on riser	19.4	24.8	15.8	3.1
OBT (5%) + Rosemary on riser	18.7	21.9	11.4	1.9
OBT (5%) + Geranium on riser	20.2	22.6	15.2	2.8
OBT (5%) + Cineraria on riser	23.0	28.8	18.5	3.3
OBT (10%) + Rosemary on riser	20.9	23.5	19.0	3.0
OBT (10%) + Geranium on riser	22.3	25.4	18.3	2.4
OBT (10%) + Cineraria on riser	20.1	26.2	13.7	2.6
VB of Geranium across 25% slope	26.7	37.0	33.6	3.3
Mean	21.2	26.3	18.1	2.89
SEm$\pm$	0.767	1.59	1.96	0.16
CV	11.4	19.1	34.3	17.7

OBT: Outward bench terraces; IBT: Inward bench terraces

Table: 3
Energy input and output of crops in sequence under different land management practices

Treatments	Energy input (MJ ha^{-1})					Energy Output (MJ ha^{-1})				
	Potato	Cabbage	Carrot	Beans	Total	Potato	Cabbage	Carrot	Beans	Total
T_1-OBT (10%) + grass on the riser (farmers practice)	57581.1	28397.1	28057.8	17687.4	131723.4	84507.5	44310.0	41437.5	22795.0	193050.0
T_2-OBT (10%) + grass on riser	52303.9	26758.3	27919.0	16740.1	123721.3	72380.0	32445.0	27300.0	18187.5	150312.5
T_3-IBT (2%) + grass on the riser	52827.8	27282.3	28442.9	17264.0	125817.0	74690.0	36540.0	30712.5	19642.5	161585.0
T_4- OBT (5%) + Rosemary on riser	52668.4	27122.8	28283.5	17104.6	125179.3	73745.9	34662.3	24389.4	14722.3	147519.9
T_5- OBT (5%) + Geranium on the riser	52668.4	27122.8	28283.5	17104.6	125179.3	86353.9	40080.9	40366.7	22940.1	189741.6
T_6- OBT (5%) + Cineraria on riser	52668.4	27122.8	28283.5	17104.6	125179.3	100350.0	48606.7	50628.3	24676.4	224261.4
T_7- OBT (10%) + Rosemary on the riser	52340.9	26795.3	27956.0	16777.1	123869.3	82215.9	36289.8	39111.9	20299.8	177917.4
T_8- OBT (10%) + Geranium on the riser	52340.9	26795.3	27956.0	16777.1	123869.3	94438.9	42968.4	46509.2	21000.1	204916.6
T_9- OBT (10%) + Cineraria on riser	52340.9	26795.3	27956.0	16777.1	123869.3	88992.5	45876.7	41268.3	23281.4	199418.9
T_{10}- VB (Geranium) across 25% slope	51358.5	25812.9	26973.6	15794.7	119939.7	111295.5	55145.3	76241.4	25322.2	268004.4
Mean	52909.9	27000.5	28011.2	16913.1	124834.7	86897.0	41692.5	41796.5	21286.7	191672.8
Sem±	534.8	201.9	129.3	155.3	923.6	3941.5	2231.2	4633.6	1017.7	11491.1
CV	3.2	2.4	1.5	2.9	2.3	14.3	16.92	35.1	15.1	18.9

fertilizer (non renewable source of energy) may be supplemented through renewable source of energy like farm yield manures for sustainable crop production. Due to small land holding with steep slopes in the hill terrain, farm mechanization is restricted, therefore, human energy consumption is more in potato and beans, whereas it is close to mechanical energy consumption in cabbage and carrot.

The total input energy for all the crops in the cropping sequence of two years among all the land management practices ranged from 1,19,939.7 MJ ha^{-1} under VB of geranium in 25% of continuous slope to 1,31,723.4 MJ ha^{-1} under OBT (10%) with grass on riser and FP of nutrient management with intermediate values for the remaining treatments. Maximum energy input under OBT (10%) with grass on riser and FP of nutrient management is due to high dose of chemical fertilizer applied through fertilizer mixture and minimum under VB of geranium in 25% continuous slope.

Among all crops, potato produced maximum output energy ha^{-1} in all the land management practices. The total output energy for potato including that obtained from the medicinal/aromatic plants on the riser ranged from maximum of 1,11,295.5 MJ ha^{-1} under VB of geranium in 25% of continuous slope to minimum of 73,745.9 MJ ha^{-1} under IBT (5%) with rosemary on riser. The highest value of energy output is attributed to the maximum yield of potato under VB of geranium in 25% of continuous slope as explained earlier. Similarly, maximum output energy was obtained under VB of geranium in 25% of continuous slope in cabbage (55,145.3 MJ ha^{-1}), carrot (76,241.4 MJ ha^{-1}) and beans (25322.2 MJ ha^{-1}) due to their high yields. The land management practice with VB produced total maximum output energy from all the crops (2,68,004.4 MJ ha^{-1}) in sequence of two years followed by OBT (5%) with cineraria on riser (2,26,261.4 MJ ha^{-1}) and OBT (10%) with geranium on the riser (2,04,917 MJ ha^{-1}).

Energy Efficiency (EUE)

EUE, energy productivity and energy profitability are estimated for different crops under all the land management practices (Table 5). Among the crops, potato was the highest energy producers in spite of higher input energy, resulting in

Table: 4
Total input requirements of the individual crops

Input (MJ)	Potato	Cabbage	Carrot	Beans
Human energy	2627.2	2286.9	2147.0	2155.0
Mechanical energy	2224.2	2674.7	2674.7	1830.1
Seed	25500.0	0.2	0.8	51.0
FYM	4500.0	4500.0	6000.0	3750.0
Chemical Fertilizer	15840.0	15684.0	15584.0	7341.5
Plant protection chemicals	630.0	630.0	530.0	630.0
Total	51321.4	25775.8	26936.5	15757.6

Table: 5
Energy input-output relationship of different crops under different treatments

Treatments	Energy use efficiency				Energy productivity (kg MJ^{-1})				Energy profitability			
	Potato	Cabbage	Carrot	Beans	Potato	Cabbage	Carrot	Beans	Potato	Cabbage	Carrot	Beans
T_1-OBT (10%) + grass on the riser (farmers practice)	1.47	1.56	1.48	1.29	0.38	1.49	0.76	0.27	0.47	0.56	0.48	0.29
T_2-OBT (10%) + grass on riser	1.38	1.21	0.98	1.09	0.36	1.15	0.50	0.22	0.38	0.21	-0.02	0.09
T_3-IBT (2%) + grass on the riser	1.41	1.34	1.08	1.14	0.37	1.28	0.55	0.23	0.41	0.34	0.08	0.14
T_4-OBT (5%) + Rosemary on riser	1.40	1.28	0.86	0.86	0.36	1.18	0.40	0.17	0.40	0.28	-0.14	-0.14
T_5-OBT (5%) + Geranium on the riser	1.64	1.48	1.43	1.34	0.38	1.20	0.54	0.22	0.64	0.48	0.43	0.34
T_6-OBT (5%) + Cineraria on riser	1.91	1.79	1.79	1.44	0.44	1.43	0.65	0.25	0.91	0.79	0.79	0.44
T_7-OBT (10%) + Rosemary on the riser	1.57	1.35	1.40	1.21	0.40	1.25	0.68	0.24	0.57	0.35	0.40	0.21
T_8-OBT (10%) + Geranium on the riser	1.80	1.60	1.66	1.25	0.43	1.32	0.65	0.20	0.80	0.60	0.66	0.25
T_9-OBT (10%) + Cineraria on riser	1.70	1.71	1.48	1.39	0.38	1.35	0.49	0.21	0.70	0.71	0.48	0.39
T_{10}-VB (Geranium) across 25% slope	2.17	2.14	2.83	1.60	0.52	1.82	1.25	0.27	1.17	1.14	1.83	0.60
Mean	1.65	1.55	1.50	1.27	0.40	1.35	0.65	0.23	0.65	0.55	0.50	0.27

the highest EUE (energy ratio) under the practice of VB in 25% continuous slope (2.17) followed by OBT (5%) with Cineraria on riser (1.91) and OBT (10%) with geranium on the riser (1.8). Despite giving a reasonably high yield of potato from OBT (10%) with grass on the risers under FP of nutrient management, its EUE is considerably less (1.47) due to more consumption of input energy. Similar trend in EUE was also obtained for cabbage, carrot and beans with maximum under the VP of geranium in 25% of continuous slope. Less energy efficiency was found in all the crops under OBT (10%) with grass on the risers under FP of nutrient management despite good crop yield due to higher input energy. The highest energy productivity was found for cabbage (1.35 kg MJ^{-1}) under all the management practices because of the highest total biomass production with less input energy followed by carrot (0.65 kg MJ^{-1}) and potato (0.40 kg MJ^{-1}). However, similar trend in energy productivity was also found to that of EUE (energy ratio) among the CPs with maximum of 1.82, 1.25, 0.52 under VB of geranium in 25% slope for cabbage, carrot and potato, respectively. Further, the highest mean energy profitability among crops was found in potato (0.65) followed by cabbage (0.55), carrot (0.5) and beans (0.27).

4. CONCLUSIONS

Results from the study revealed that VB with geranium in 25% slope enhances productivity of potato (26.7 t ha^{-1}), cabbage (37.0 t ha^{-1}) and carrot (33.6 t ha^{-1}) and close to highest in beans (3.3 t ha^{-1}) among different CPs. The increase in yield is due to infiltrated runoff by VB contributing to higher soil moisture in the crop root zone. Potato required the highest input energy among the crops followed by carrot, cabbage and beans. Potato is the highest energy producers in spite of highest input energy, resulting in the highest EUE (energy ratio). Output energy for all crops was maximum in VB of geranium in 25% slope and therefore, more suitable due to higher productivity, EUE and energy productivity for common vegetable crops in Nilgiris.

REFERENCES

Azizi, A. and Heidari, S. 2013. A comparative study on energy balance and economical indices in irrigated and dry land barley production systems. *Int. J. Environ. Sci. Technol.*, 10: 1019-1028.

Canakci, M., Topakci, M., Akinci, I. and Ozmerzi, A. 2005. Energy use pattern of some field crops and vegetable production, case study for Antalya Region, Turkey. *Energy Cons. Manage.*, 46: 655-666.

Chaudhary, V.P., Gangwar, B. and Pandey, D.K. 2006. Auditing of energy use and output of different cropping systems in India. *Agril. Engg. Int. CIGR E-journal*, VIII: 1-13.

Chaudhary, V.P., Gangwar, B., Pandey, D.K. and Gangwar, K.S. 2009. Energy auditing of diversified rice-wheat cropping systems in Indo-Gangetic plains. *Energy,* 34: 1091-1096.

Devasenapathy, P., Senthilkumar, G. and Shanmugam, P.M. 2009. Energy management in crop production. *Ind. J. Agron.*, 54: 80-90.

Dorward, A. 2009. Rethinking agricultural input subsidy programmes in a changing world. *School of Oriental and African Studies,* University of London, UK, 48 p.

Grossman, N. and Dyland, C. 2011. Agriculture policy in India: The role of input subsidies. In: USITC Executive Briefings on Trade. http://usitc.gov/publications/332/executive_briefings/EBOT_IndiaAg Subsidies.pdf.

Haciseferogullari, H., Acaroglu, M. and Gezer, I. 2003. Determination of the energy balance of the sugar beet plant. *Energy Source Part A.,* 25: 15-22.

Hatirli, S.A., Ozkan, B. and Fert, C. 2006. Energy inputs and crop yield relationship in greenhouse tomato production. *Renewable Energy*, 31: 427-438.

Heidari, M.D. and Omid, M. 2011. Energy use patterns and econometric models of major greenhouse vegetable productions in Iran. *Energy*, 36: 220-225.

Khaledian, M.R., Mailhol, J.C. and Ruelle, P. 2012. Impacts of direct seeding into mulch on the CO_2 mitigation. *Agron. Res.,* 10: 303-310.

Mohammadi, A. and Omid, M. 2010. Economical analysis and relation between energy inputs and yield of greenhouse cucumber production in Iran. *Appl. Energy*, 87: 191-196.

Pervanchon, F., Bockstaller, C. and Girardin, P. 2002. Assessment of energy use in arable farming systems by means of an agroecological indicator: the energy indicator. *Agr. System,* 72:149-72.

Sahoo, D.C., Muralidharan, P., Madhu M. and Sundarambal, P. 2010. Influence of land management practices on rainwater productivity of major crops in the Nilgiris. *Ind. J. Agr. Sci.,* 80: 872-877.

Singh, S., Verma, S.R. and Mittal, J.P. 1997. Energy requirement for production of major crops in India. *Agr. Mechanization in Asia, Africa Latin Am.*, 28:13-17.

Singh, S.A., Singh, S.U., Pannu, C.J.S. and Singh, J. 1999. Energy input and yield relations for wheat in different agro-climatic zones of the Punjab. *Appl. Energy*, 63: 287-298.

Singh, H., Mishra, D. and Nahar, N.M. 2002. Energy use pattern in production agriculture of a typical village in arid zone, India-part I. *Energy Cons. Manage.,* 43: 2275-2286.

Singh, K.P., Prakash, V., Srinivas, K. and Srivastava, A.K. 2008. Effect of tillage management on energy-use efficiency and economics of soybean (*Glycine max*) based cropping systems under the rainfed conditions in North-West Himalayan region. *Soil Till. Res.*, 100: 78-82.

Tuti, M.D., Pandey, B.M., Bhattacharya, R., Bisht, J.K. and Bhatt, J.C. 2011. Integrated assessment of vegetable-based relay intercropping systems in the north-western Himalaya. In: *Abstracts and Souvenir, 6th Uttarakhand State Sci. and Tech. Congress,* 17 p.