Research article

Energy and monetary efficiencies at the different altitudinal agroecosystems in central Himalaya, India

Surendra Singh Bargali*, Charu Shahi, Kiran Bargali, Bhawna Negi, Kavita Khatri

Department of Botany, D.S.B. Campus, Kumaun University, Nainital-263001, Uttarakhand, India

HIGHLIGHTS

- Seasonal energy-use pattern differed among agroecosystems.
- Size of agroecosystems had no distinct impact on energy flow.
- High altitude farms were efficient in terms of energy.
- Benefit-cost ratio differed significantly along altitudes.
- Very low altitude farms were efficient in term of money.

ARTICLE INFO

Keywords:
Agroecosystems
Altitudinal gradient
Agroecosystem sizes
Benefit-cost ratio
Energy budget
Energy efficiency

ABSTRACT

Himalayas with diverse topographical and ecological zones sustain diverse agroecosystems. Differences in precipitation regimes, cropping systems, land-use systems and availability of resources significantly affect energy flow within agroecosystems (AGEs) of the region. Thus, the present study was aimed to evaluate the energy use pattern and economic profitability of different sized agroecosystems (small, medium and large) along the altitudinal gradient (very low altitude (VLA), low altitude (LA), mid altitude (MA) and high altitude (HA)) of Central Himalaya, India. The sampling was carried out following random stratified design and total 108 agroecosystems (4 altitudes × 3 sizes × 3 replicates × 3 seasons) were assessed. Data collected on quantities of agricultural inputs and outputs were converted to energy values using standard energetic constants and monetary values on the basis of local market price. Low altitude agroecosystems predominantly support cereal + pulse based cropping systems while, high altitudes favour cash crop cultivation (vegetables). Significant variation (P < 0.05) in total input and output energy was observed seasonally, while differences were insignificant across sizes and altitudes. Irrespective of the sizes and seasons, farmyard manure (organic fertilizer) contributed major share of total energy inputs across all altitudes in the order: HA AGEs (66.7 %) > MA AGEs (66.1 %) > VLA AGEs (62.6 %) > LA AGEs (52.1 %). The share of non-renewable energy inputs (inorganic fertilizers and fuel) declined along altitudinal gradient as: LA (31.1 %) > VLA (26.9 %) > MA (12.5 %) > HA (11.8 %). Seasonally, highest net energy was recorded during rainy season (92286 MJ ha⁻¹ yr⁻¹) followed by summer (68906 MJ ha⁻¹ yr⁻¹) and winter (18686 MJ ha⁻¹ yr⁻¹). The economic yield significantly increased with increasing altitude and was recorded maximum for large sized agroecosystems. Energy use efficiency (EUE) differed distinctly (P < 0.05) across seasons and was recorded maximum during rainy season (8) while, across sizes and altitudes it did not vary significantly. EUE did not reflect any definite pattern along altitudinal gradient [HA AGEs (3.84) > VLA AGEs (3.81) > LA AGEs (3.56) > MA AGEs (3.01)]. Benefit-cost ratios (BCR) differed significantly (P < 0.05) along altitudes and was maximum at VLA AGEs (5.27) however, differences were insignificant across sizes and seasons. From present study, it can be concluded that season and altitude had significant impact on the energetics and economic flow of the agroecosystems while, no marked differences were observed for size classes. High altitude agroecosystems were energetically efficient while, monetary wise very low altitude systems.

* Corresponding author.
E-mail address: surendrkiran@rediffmail.com (S.S. Bargali).

https://doi.org/10.1016/j.heliyon.2022.e11500
Received 11 May 2022; Received in revised form 13 July 2022; Accepted 2 November 2022
2405-8440/© 2022 The Author(s). Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).
1. Introduction

Agricultural operations primarily functions through combined interaction of natural and economic inputs (resources) (Rodríguez-Ortega et al., 2017). These operations require energy as foremost input to production (Schneft, 2004; Singh et al., 2019). In agriculture production two types of energies are involved viz., direct and indirect. Direct energy involves energy coupled with inputs and resources directly used for carrying out different agricultural activities (Abbas et al., 2022), while indirect energy involves energy associated with agriculture production factors for instance, seeds, human labour, organic and chemical fertilizers, pest management chemicals, fossil fuels, machinery and animal production factors (Martinho, 2021). Energy in agriculture holds an important role (Hercher-Pasteur et al., 2020) in identifying energy flows via evaluation of sustainability and energy footprints of the production processes (Méndez Rodríguez et al., 2022). Agricultural energy auditing is one of the most common approaches applied to address and compare energy cost of production, agricultural practices and their resilience and, provide insights into crop productivity related issues (Shahi, 2020).

In recent years, energy intensification in agricultural sector has invariably increased, coupled with population surge, inadequate arable land, varying land-use patterns, technological advancements, and aspirations for higher standard of living (Shahi et al., 2019). These energy-intensive activities at/off farm level are major contributors to greenhouse gas (GHG) emissions, distressing environmental quality, chiefly in developing countries. The agriculture sector in developing countries is responsible for 35% of GHG emissions compared to 12% in developed countries (Yasmeen et al., 2022). Therefore, these energy intensive production systems require acute planning with careful estimation of energy consumption (Kumar et al., 2021), particularly in developing nations. Efficient use of energy resources and the direct use of renewable energies are central for accomplishing true sustainable development (Rodríguez-Ortega et al., 2017; European Environment Agency, 2019; Paramati et al., 2022). The concept of sustainable intensification incorporates goal of strengthening current food production systems from existing farmland and reducing environmental degradation without compromising the future production capacity (Rahn et al., 2018). As a result, researchers, policy makers and concerned stakeholders are pushing and focusing on attaining sustainable intensification which would eventually bring about environmental, social and financial sustainability (Abbas et al., 2022). However, execution of sustainable production systems in developing countries is difficult as rural economy face numerous challenges and constraints owing to limited resources and access options (Uziak and Lorencowicz, 2017). Hence, long lasting and viable solution are required based on the need of farmers (Shahi, 2020).

In addition, different land use systems that foremost increases livelihood security and reduce vulnerability to climate and environmental change are also necessary (Nautiyal et al., 1998). Himalayas with diverse topographical and ecological zones sustain diverse agroecosystems (Maikhuri et al., 2001). The Himalayan agroecosystems represent one of the diversified, heterogeneous and complex unit of nature which are the important source of subsistence (Rastogi et al., 2018; Bargali et al., 2019; Padalia et al., 2022). Here farmers extensively perform agricultural operations with various labour input and provide output in the form of agronomic yield and associated by-products (Kumar, 2011). Land holdings in these regions are small and fragmented on small terraces of steep slopes with limited irrigation facilities, particularly in hilly regions (Negi et al., 2018). Inconsistency associated with precipitation regimes, availability of resources, accessibility to agricultural fields, different cropping systems and land use patterns significantly affects energy flow of agroecosystems across the regions. The differences in management cultures, climatic and soil conditions and socioeconomic conditions are responsible for variations in structure and function of agroecosystems. Further, small landholdings and poor natural resource management are amongst major issues for lower crop productivity in South Asian countries (Kumar et al., 2021). These inconsistencies along altitudes may provide vital insights into energy and economic flow in the face of current scenario of agricultural production system. For developing eco-efficient and sustainable production system, energetic constancy must be assessed for diverse cropping systems along the altitudinal gradient. On a broad range of issues, information about agricultural resource uses, production practices, inputs, farm costs and returns can be utilized for the well-being of farm households. Therefore, the present study was aimed to assess and compare energetic and economic profitability of agroecosystems on the basis of different sized landholdings, seasons and altitudes.

2. Materials and methods

2.1. Description of study area

This study was carried out within the administrative boundary of District Nainsital of Kumaun Central Himalaya along an altitudinal gradient ranging from 450 m to 2200 m asl. Study area was further categorized into four altitudes viz. very low altitude (VLA), low altitude (LA), mid altitude (MA), and high altitude (HA) (Figure 1). Detailed geographic locations of the study sites are given in Table 1. After intensive reconnaissance surveys, three types of agroecosystems (AGEs) were selected on the basis of their sizes i.e. small, medium and large in triplicates across each altitudes. The study was carried out following random stratified sampling design. The size class differentiation of agroecosystems was site specific (Table 1). Data were collected during rainy, summer and winter season for the crop year July 2017 to June 2018. Therefore, total 108 AGEs (4 altitudes × 3 sizes × 3 replicates × 3 seasons) were assessed in the present study. The AGEs at VLA were supported by sub-tropical broad leaved sal (Shorea robusta) forest, LA by sal-mixed broad-leaved forests, MA by needle leaved chir-pine (Pinus roxburghii) forest and HA by broad leaved banj oak (Quercus lescotrichophora) forest.

2.2. Climate

The climate of the study area is mainly governed by the monsoon, which generally starts during mid-June and continues till mid-September. During the study period, maximum rainfall was recorded during the month of July while, the mean temperature was highest during the month of May (Figure 2).

2.3. Geology

Geologically, the study sites are located in the lesser Himalayan zone. In this zone the rocks are complex mixture of sedimentary, low grade metamorphosed and igneous rocks and belong to Krol series. The Krol formation consists predominantly of carbonates, limestones, marl and slates in the lower part and dolomites on the upper part (Valdiya, 1980).

2.4. Soil

Soil samples randomly collected from surface layer (0–15 cm) revealed variation in soil texture which ranged from clay type, clay loam to loam. Along altitudes, highest sand and silt content were recorded from MAAGEs while, clay content from HAAGEs. Bulk density significantly declined with increasing altitudes. Along altitudes, highest soil organic matter was recorded from HAAGEs (4.88 %) and lowest from VLAAGEs (3.17 %) (Figure 3). C:N ratio along altitudes was maximum across HAAGEs (9.87) and minimum along LAAGEs (8.35) whereas, seasonally it was maximum during rainy (10.47) and minimum during summer (7.07) season (Shahi, 2020).
2.5. Energy and monetary budget estimation

Information on all aspects of agroecosystems was collected using semi-structured interview held during each cropping season with adult members of the family. All the information was collected by repeated field visits and a complete inventory was made at household levels for each agroecosystem. The energy budget was calculated seasonally for each selected site by converting quantities of agricultural inputs and outputs into their calorific values using standard values (Table 2) and published research work (Gopalan et al., 1978; Mitchell, 1979; Mobtaker et al., 2010; Singh, 2006). The input was calculated in terms of labour in human and bullock labour per day and material such as quantities of seeds, manure, chemical fertilizers. The output was calculated as crop yield and yields of by-products. Human labour was estimated as hours spent on various agricultural activities such as leveling, sowing, weeding, harvesting and threshing by male and female farmers. Bullock labour was
calculated as time taken (in hours) to level and plough a field and for threshing grains. The quantities of inputs and outputs for all crops were evaluated through repeated field visits during various agricultural activities from the period of field preparation till harvesting.

For monetary budget evaluation, the quantities of input and output were converted into money value in US dollar ($) using local market prices. Costs of input energy by human/machinery was evaluated for land preparations, weeding, harvesting threshing and fertilizer. The human labour cost was estimated by multiplying prevailing daily wage rate with man-day ha⁻¹.

Based on input output energy profile, energy use efficiency (energy ratio), energy productivity, specific energy (Khan and Singh, 1996; Mandal et al., 2002; Yilmaz et al., 2005) and net energy were calculated using equations below (Mani et al., 2007; Mohammadi and Omid, 2010; Shrestha, 1998; Singh et al., 1997).

\[
\text{Energy efficiency} = \frac{\text{Total energy output (MJ ha}^{-1})}{\text{Total energy input (MJ ha}^{-1})}
\]

\[
\text{Specific energy} = \frac{\text{Total energy input (MJ ha}^{-1})}{\text{Grain yield (kg ha}^{-1})}
\]

\[
\text{Net energy} = \text{Energy output (MJ ha}^{-1}) - \text{Energy input (MJ ha}^{-1})
\]

### Table 1. Geographical description of the study area.

| Altitude range (m) | Latitude/Longitude | Size class | Available size range of AGEs (ha) |
|--------------------|--------------------|------------|---------------------------------|
| Very low (<450)    | -29°12’47.91N, 79°29’19.20E | Small | 0.09–0.54 |
|                    |                     | Medium    | 0.48–1.08 |
|                    |                     | Large     | 0.60–1.80 |
| Low (450–900)      | -29°19’7.94N, 79°31’30.92E | Small | 0.06–0.12 |
|                    |                     | Medium    | 0.16–0.18 |
|                    |                     | Large     | 0.24–0.80 |
| Mid (900–1500)     | -29°21’27.55N, 79°36’24.08E | Small | 0.12–0.50 |
|                    |                     | Medium    | 0.20–0.60 |
|                    |                     | Large     | 0.40–1.20 |
| High (1500–2200)   | -29°23’39.31N, 79°39’48.02E | Small | 0.10–0.26 |
|                    |                     | Medium    | 0.16–0.30 |
|                    |                     | Large     | 0.20–0.40 |

Where, AGEs- agroecosystems.

2.6. Statistical analysis

The variability among the inputs, outputs and related ratios across agroecosystem sizes, seasons and altitudes were assessed using Kruskal-Wallis H-test as the data were not distributed normally using IBM SPSS software (version 16). Differences between means were considered significant at 5% level (P < 0.05). Pearson’s correlation coefficient (r) was evaluated for measured parameters using PAST software. Association between assessed variables was further explored through regression analysis. Linear regression model was best fitted to assess the significance level shown by H-test and Pearson’s correlation coefficient (r) using SPSS.

3. Results

The cropping pattern differed considerably along altitudinal gradient. VLAAGEs were characterized by two cropping patterns; grain based and pulse + grain based. LAAGEs were documented with three types of pattern i.e. grain based, pulse + grain based and pulse + vegetable based. MA AGES with three types of systems i.e. vegetable based, vegetable + millet based and grain + vegetable based. HA AGES were reported with three types of patterns i.e. vegetable based, grain based and vegetable + grain based (Table 3 and Appendix I).

3.1. Seasonal variation in energy inputs and output within AGEs

Quantity of different inputs and outputs during rainy, winter and summer cropping on the basis of per ha cultivated land are presented in Tables 4, 5, and 6.

3.1.1. Rainy season

Total energy input (TEI) differed significantly (P < 0.05) across altitudes while, no significant difference was observed across sizes. Total energy output (TEO) showed no significant differences across sizes as well as altitudes. At VLAAGEs, maximum energy input (EI) was recorded for chemical fertilizers (5899 M J ha⁻¹) and minimum for human labour (53 M J ha⁻¹ in the medium sized AGEs) whereas, highest energy output (EO) was detected for food grains (93312 M J ha⁻¹) and lowest for crop by-products (3208 M J ha⁻¹ in large sized AGEs). At LAAGEs, highest EI was documented for cow dung (12923 M J ha⁻¹) and lowest for crop by-products (9972 M J ha⁻¹ in small sized AGEs) whereas, the maximum EO was observed for food grains...
(76327 M J ha\(^{-1}\) in the large sized AGEs) and minimum for pulses (4250 M J ha\(^{-1}\) in the small sized AGEs). Across MAAGEs, maximum EI was recorded for farmyard manure (24938 M J ha\(^{-1}\) in small sized AGEs) and minimum for human labour (146 M J ha\(^{-1}\) in large sized AGEs) while, highest EO was observed for green leafy vegetables (98750 M J ha\(^{-1}\) in small and large sized AGEs) and least for by-products (389 M J ha\(^{-1}\) in small sized AGEs). Across MAAGEs, maximum EI was recorded for farmyard manure (24938 M J ha\(^{-1}\) in small sized AGEs) and minimum for human labour (146 M J ha\(^{-1}\) in large sized AGEs) while, highest EO was observed for green leafy vegetables (98750 M J ha\(^{-1}\) in small and large sized AGEs) and least for by-products (389 M J ha\(^{-1}\) in small sized AGEs).

At HAAGEs, highest EI was reported for cow dung (35000 M J ha\(^{-1}\) in small sized AGEs) and lowest for human labour (20 M J ha\(^{-1}\) in the large sized AGEs) while, EO was noted maximum for food grains (45262 M J ha\(^{-1}\) in large sized AGEs) and minimum for crop by-products (24872 M J ha\(^{-1}\) in small AGEs). Similarly at LAAGEs, maximum EI was noted for cow dung (18599 M J ha\(^{-1}\) in large sized AGEs) and minimum for human labour (86 M J ha\(^{-1}\) in the large sized AGEs) while, highest EO was documented for food grains (37283 M J ha\(^{-1}\) in large sized AGEs) and least for crop by-products (17312 M J ha\(^{-1}\) in the medium sized AGEs). At MAAGEs, maximum EI was observed for farmyard manure (26361 M J ha\(^{-1}\) in the large sized AGEs) and minimum for human labour (114 M J ha\(^{-1}\) in large sized AGEs) whereas, highest EO was noted for crop by-products (29750 M J ha\(^{-1}\) in large sized AGEs) and least for food grains (7077 M J ha\(^{-1}\) in the medium sized AGEs). At HAAGEs, maximum EI was estimated for farmyard manure (29055 M J ha\(^{-1}\) in the medium sized AGEs) and minimum for human labour (85 M J ha\(^{-1}\) in the large sized AGEs) while, highest EO was documented for food grains (20061 M J ha\(^{-1}\) in the large sized AGEs) and lowest for fruits (1593 M J ha\(^{-1}\) in the small sized AGEs). EUE differed distinctly (P < 0.05) across altitudes however, no significant effect was observed for sizes. Large sized

3.1.2. Winter season

TEI showed no distinct separation across sizes and altitudes while, TEO differed significantly (P < 0.05) across altitudes while, no significant difference was observed across sizes. At VLAAGEs, highest EI was reported for cow dung (35000 M J ha\(^{-1}\) in small sized AGEs) and least for human labour (20 M J ha\(^{-1}\) in the large sized AGEs) while, EO was noted maximum for food grains (45262 M J ha\(^{-1}\) in large sized AGEs) and minimum for crop by-products (24872 M J ha\(^{-1}\) in small AGEs). Similarly at LAAGEs, maximum EI was reported for cow dung (18599 M J ha\(^{-1}\) in large sized AGEs) and minimum for human labour (86 M J ha\(^{-1}\) in the large sized AGEs) while, highest EO was documented for food grains (37283 M J ha\(^{-1}\) in large sized AGEs) and least for crop by-products (17312 M J ha\(^{-1}\) in the medium sized AGEs). At MAAGEs, maximum EI was observed for farmyard manure (26361 M J ha\(^{-1}\) in the large sized AGEs) and minimum for human labour (114 M J ha\(^{-1}\) in large sized AGEs) whereas, highest EO was noted for crop by-products (29750 M J ha\(^{-1}\) in large sized AGEs) and least for food grains (7077 M J ha\(^{-1}\) in the medium sized AGEs). At HAAGEs, maximum EI was estimated for farmyard manure (29055 M J ha\(^{-1}\) in the medium sized AGEs) and minimum for human labour (85 M J ha\(^{-1}\) in the large sized AGEs) while, highest EO was documented for food grains (20061 M J ha\(^{-1}\) in the large sized AGEs) and lowest for fruits (1593 M J ha\(^{-1}\) in the small sized AGEs). EUE differed distinctly (P < 0.05) across altitudes however, no significant effect was observed for sizes. Large sized

Figure 3. Diagramatic representation of the study area (where, VLA = very low altitude; LA = low altitude; MA = mid altitude; HA = high altitude; SOM = soil organic matter; C:N = carbon: nitrogen).
Table 2. Energy equivalents of inputs and outputs in the agroecosystems.

| Category                   | Energy (MJ/kg) |
|----------------------------|----------------|
| Fruits(a)                  | 9.1            |
| Grains(a)                  | 16.2           |
| Green fodder(a)            | 15.8           |
| Hay(b)                     | 16.4           |
| Leafy vegetables(a)        | 15.8           |
| Maize output(a)            | 14.7           |
| Maize seed(c)              | 15.7           |
| Other vegetables(a)        | 2.4            |
| Pulses(a)                  | 17.1           |
| Roots and Tubers(a)        | 15.3           |
| Straw(a)                   | 14             |
| Wheat output(c)            | 14.7           |
| Wheat seed(c)              | 15.7           |
| Wheat straw(d)             | 9.25           |
| Human labour category      | Energy (MJ/h)  |
| Male(c)                    | 56.31 (MJ J/l) |
| Sedentary work             | 0.418          |
| Moderate work              | 0.488          |
| Heavy work                 | 0.679          |
| Female(b)                  | 0.331          |
| Sedentary work             | 0.383          |
| Heavy work                 | 0.523          |
| One bullock day(b)         | 72.2 M J/day   |
| Manure(b)                  | Energy (MJ/kg) |
| Cow dung                   | 2.1            |
| Farmyard manure            | 7.3            |
| Fertilizer(c)              | Energy (MJ/kg) |
| Nitrogen                   | 60.6           |
| Phosphorous                | 11.1           |
| Potassium                  | 6.7            |
| Diesel(d)                  | 56.31 (MJ J/l) |

(a)- Mitchell (1979), (b)- Gopalan et al., (1978), (c)- Singh (2006), Mani et al., (2007), Shrestha (1998), (d)- Mobtaker et al., (2010).

Table 3. Types of agroecosystems prevailing in study area.

| Altitude       | Types of Agroecosystems       | Rainy  | Winter | Summer |
|----------------|--------------------------------|--------|--------|--------|
| Very low       | Grain based                    | Rice/ | Maize-Wheat-Forage | |
|                | Pulse + Grain based            | Soybea | -Wheat- | Forage |
| Low            | Grain based                    | Rice-Wheat-Maize/Forage | |
|                | Pulse + Grain based            | Black | gram/Bhatt-Wheat-Maize | |
|                | Pulse + Vegetable based        | Soybean-Wheat-Okr | |
| Mid            | Vegetable based                | Beans/ | Cabbage-Pea-Potato | |
|                | Vegetable + Millet based       | Beans-Pea-Finger millet | |
|                | Grain + Vegetable based        | Rice-Pea-Tomato | |
| High           | Vegetable based                | Potato-Pea-Pea-Cabbage | |
|                | Grain/millet based             | Potato-Wheat-Maize | |
|                | Vegetable + Grain based        | Potato-Cabbage-Wheat-Pea | |

Please refer Appendix I for the reported plant species with their common names, families and respective uses among all the sites.

AGEs demonstrated highest economic yield across all altitudes except at MA. Similarly, medium sized AGEs showed minimum yield along altitudinal gradient except at VLA (Table 5).

3.1.3. Summer season

TEI differed significantly (P < 0.05) across altitudes while, no significant difference was observed across sizes. TEO did not differed distinctly across sizes and altitudes. Across VLAAGEs, highest EI was observed for bullock power (1622 M J ha⁻¹) and lowest for human labour (20 M J ha⁻¹) in both large sized AGEs whereas, maximum EO was reported for forages (18096 M J ha⁻¹ in large sized AGEs) and minimum for fruits (1820 M J ha⁻¹ in small sized AGEs). At LAAGEs, highest EI was recorded for seeds (2360 M J ha⁻¹ in the small sized AGEs) and lowest for human labour (77 M J ha⁻¹ in the large sized AGEs) while, EO was highest for forages (22750 M J ha⁻¹ in the large sized AGEs) and lowest for fruits (4550 M J ha⁻¹ in small sized AGEs). At MAAGEs, highest EI was evaluated for seeds (1222 M J ha⁻¹ in the large sized AGEs) and lowest for human labour (222 M J ha⁻¹ in small sized AGEs) while, maximum EO was recorded for tubers (38443 M J ha⁻¹ in the large sized AGEs) and minimum for tomato crop (6400 M J ha⁻¹ in the small sized AGEs). Across HAAGEs, highest EI was estimated for seeds (11563 M J ha⁻¹ in the small sized AGEs) and least for human labour (163 M J ha⁻¹ in the medium sized AGEs) whereas, maximum EO was recorded for green leafy vegetables (193111 M J ha⁻¹ in the large sized AGEs) and minimum for tuber crop (37556 M J ha⁻¹ in the medium sized AGEs). EUE in summer season differed distinctly (P < 0.05) across altitudes however, no significant effect was observed for sizes.

Highest economic yield was evaluated across large sized AGEs while, lowest across small sized AGEs along all the altitudes (Table 6). AGEs size classes positively affected the yield (R² = 0.847) which escalated with surge in landholdings as: large (9169 kg ha⁻¹ yr⁻¹) > medium (7635 kg ha⁻¹ yr⁻¹) > small (7400 kg ha⁻¹ yr⁻¹). Seasons had positive but insignificant effect on yield (Figure 4). The effect of seasons (R² = 0.014) and size classes (R² = 0.211) were insignificant on input and output (Figure 5). Net energy was recorded maximum for large (213476 M J ha⁻¹ yr⁻¹) and minimum for small (155816 M J ha⁻¹ yr⁻¹) sized AGEs. Across seasons, highest net energy was observed during rainy season (92286 M J ha⁻¹ yr⁻¹) followed by summer (68906 M J ha⁻¹ yr⁻¹) and winter (18686 M J ha⁻¹ yr⁻¹) season. EUE increased with increasing size of the AGEs while, across seasons, EUE was recorded highest in summer season and lowest in winter season (Figure 6).

3.2. Altitudinal variation in energy inputs and output within AGEs

TEI and TEO did not vary significantly along altitudes. The energy input significantly (P < 0.05) increased with increasing altitudes for human and bullock labour, seed and manure applied whereas, imported energy inputs did not depict any definite pattern along altitudes (Figure 5A). Food grains (wheat, rice, maize and millets) cultivation significantly declined (R² = 0.949) towards higher altitudes and was recorded highest across VLAAGEs (65.5 %) and LAAGEs (63.8 %) (Figure 5B). While, high altitudes AGE supported vegetables crops (green leafy + tubers + other vegetables) and was recorded maximum across HAAGEs (88.1 %) and MAAGEs (58.3 %) AGES. Highest total EI was recorded at HA (107608.25 M J ha⁻¹ yr⁻¹) followed by MA (65654.67 M J ha⁻¹ yr⁻¹) whereas, maximum total EO was recorded at HA (412859.14 M J ha⁻¹ yr⁻¹) followed by VLA (205053.67 M J ha⁻¹ yr⁻¹). The relation between energy input and output were significant (R² = 0.949) with altitude (Figure 5). The annual mean EUE did not differed across altitudes and showed pattern in the order; HA (3.84) > VLA (3.81) > LA (3.56) > MA (3.01).

3.3. Seasonal variation in monetary input and output within AGEs

3.3.1. Rainy season

Total monetary input (TMI) differed significantly (P < 0.05) across altitudes while, no significant difference was recorded across sizes. However, total monetary output (TMO) showed no marked differences across sizes and altitudes. Across VLAAGEs, maximum monetary input (MI) was recorded for human labour and minimum for cow dung (201 $ ha⁻¹ and 13 $ ha⁻¹, respectively in small sized AGEs) whereas, the maximum monetary output (MO) was observed for food grains (1153 $ ha⁻¹ in medium AGEs) and minimum for crop by-products (20 $
Table 4. Energy input, output, energy use efficiencies and their monetary equivalents (in $ ha\(^{-1}\) within parentheses) of the agroecosystems during rainy season.

| AGIs size | Very low altitude | Low altitude | Mid altitude | High altitude |
|-----------|-------------------|--------------|--------------|---------------|
|           | Small | Medium | Large | Small | Medium | Large | Small | Medium | Large | Small | Medium | Large | Small | Medium | Large |
| Bullock   | 471 (13) | 4917 (16) | 5670 (18) | 12923 (41) | 7560 (24) | 10247 (18) | 24938 (79) | 24150 (76) | 17864 (56) | 48900 (71) | 45342 (68) | 46076 (67) |
| Compost   | 5161 (77) | 5899 (41) | 2161 (33) | 6494 (47) | 7744 (41) | 4484 (24) | 601 (7) | 526 (6) | 627 (6) | 4927 (60) | 4668 (56) | 6601 (82) |
| Fuel      | 1803 (25) | 1494 (21) | 1619 (23) | 650 (9) | 507 (7) | 582 (8) | 1689 (24) | 1971 (28) | 2301 (32) | 516 (7) | 482 (7) | 398 (6) |
| Human labour | 95 (201) | 53 (182) | 54 (189) | 375 (290) | 426 (229) | 109 (314) | 204 (159) | 215 (169) | 146 (118) | 480 (374) | 489 (383) | 490 (360) |
| Seed      | 1061 (58) | 571 (33) | 411 (19) | 223 (27) | 455 (43) | 374 (50) | 653 (110) | 656 (95) | 390 (74) | 6585 (880) | 5775 (790) | 6127 (832) |
| Total Input | 11846 (375) | 12935 (293) | 9915 (282) | 21554 (578) | 17701 (630) | 16451 (535) | 28762 (504) | 28168 (494) | 21863 (385) | 62070 (1514) | 57467 (1435) | 60397 (1477) |
| Food grain | 63622 (728) | 93312 (1153) | 75404 (863) | 68850 (788) | 73853 (845) | 76327 (874) | 6900 (232) | 67500 (662) | 64800 (636) | 23100 (470) | 15390 (252) |
| Green vegetables | - | - | - | - | - | - | 98750 (1490) | 98750 (1241) | 96255 (1333) | 73733 (1422) | 79000 (1523) |
| Other vegetables | - | - | - | - | - | - | 7345 (770) | 7852 (832) | 10320 (1139) | - | - |
| Pulses | 15251 (770) | 7444 (261) | 24963 (544) | 4250 (298) | 10838 (752) | 6375 (232) | - | - | - | - | - |
| Tubers | 5922 (36) | 3824 (23) | 3208 (20) | 16154 (99) | 14467 (89) | 16061 (98) | 389 (7) | 5600 (26) | 5922 (36) | 1768 (11) | 0 (0) | 653 (4) |
| Total Output | 84795 (1535) | 104581 (1437) | 103575 (1427) | 89254 (1185) | 99157 (1068) | 98763 (1204) | 113384 (2499) | 80952 (1520) | 179792 (3053) | 157254 (3080) | 158976 (2950) | 187236 (3215) |
| O/I Ratio | 3.88 (4.09) | 8.09 (4.91) | 10.45 (5.07) | 4.14 (2.05) | 5.6 (2.68) | 6 (2.25) | 3.94 (4.96) | 2.87 (3.08) | 8.25 (7.93) | 2.82 (2.03) | 2.77 (1.92) | 3.1 (2.18) |
| Total Economic yield (kg ha\(^{-1}\)) | 4824 | 6198 | 6170 | 4500 | 5197 | 5087 | 9811 | 7307 | 14665 | 11188 | 10238 | 11406 |
3.3. Winter season

TMI and TMO differed distinctly across altitudes (P < 0.05) while, non-significant across sizes. Total monetary output (TMO) showed no marked differences across sizes and altitudes. At VLAAGEs, maximum MI was recorded for cow dung (80 $ ha⁻¹) and minimum for human labour (16 $ ha⁻¹) in large sized AGES while, MO was highest for food grains (816 $ ha⁻¹) in large sized AGES and least for crop by-products (178 $ ha⁻¹) in small sized AGES. At LAAGEs, highest MI was recorded for bullock power (258 $ ha⁻¹) and lowest for fossil fuel (7 $ ha⁻¹) in small sized AGES while, maximum MO was evaluated for food grains (672 $ ha⁻¹) in large sized AGES and minimum for crop by-products (123 $ ha⁻¹) in medium sized AGES. At MAAGEs, MI was reported highest for bullock power (222 $ ha⁻¹) in large sized AGEs and minimum for fertilizers (4 $ ha⁻¹) in small sized AGES while, MO was maximum for food grains (1299 $ ha⁻¹) in small sized AGES and minimum for crop by-products (16 $ ha⁻¹) in medium sized AGES. At HAAGEs, MI was noted highest for bullock power (258 $ ha⁻¹) in small sized AGES and minimum for fertilizers (5 $ ha⁻¹) in large sized AGES while, the MO was maximum for fruits (393 $ ha⁻¹) in large sized AGES and minimum for crop by-products (69 $ ha⁻¹) in large sized AGES (Table 5). BCR differed distinctly (P < 0.05) across altitudes however, there was no significant effect observed for sizes.

3.3.3. Summer season

TMI and TMO differed markedly across altitudes (P < 0.05) while, insignificant across sizes. At VLAAGEs, highest MI was recorded for bullock power (82 $ ha⁻¹) and least for fertilizers (5 $ ha⁻¹) in large AGES whereas, MO was highest for maize (742 $ ha⁻¹) in large sized AGES and lowest for fruits (32 $ ha⁻¹) in small sized AGES. At LAAGEs, maximum MI was evaluated for human labour (86 $ ha⁻¹) in small sized AGES and minimum for fertilizers (6 $ ha⁻¹) in large sized AGES whereas, MO was highest for maize (353 $ ha⁻¹) in small sized AGES and least for fruits (3 $ ha⁻¹) in small sized AGES. At MAAGEs, MI was maximum for seeds (2021 $ ha⁻¹) and minimum for fertilizers (6 $ ha⁻¹) across large AGES whereas, highest MO was noted for tomato (3200 $ ha⁻¹) in large sized AGES and lowest for tubers (1157 $ ha⁻¹) in small sized AGES. At HAAGEs, highest MI was recorded for seeds (1841 $ ha⁻¹) small sized AGES and lowest for fertilizer (12 $ ha⁻¹) in large sized AGES while, both highest and lowest MO values were recorded for green leafy vegetables (1619 $ ha⁻¹) in large sized AGES and 1144 $ ha⁻¹ in small sized AGES, respectively (Table 6). BCR differed markedly (P < 0.05) across altitudes however, insignificant for sizes.

Across seasons (R² = 0.777) and among AGES size classes (R² = 0.681), the relations between total monetary input (TMI) and total monetary output (TMO) were significant (P < 0.05), which shows that monetary output positively improves with increasing monetary inputs in AGES (Figure 7). The relation between net benefit (NB) and BCR did not show any regular pattern across seasons and were insignificant while, among AGES sizes (R² = 0.998) the relations were highly significant (P < 0.05) (Figure 7).
3.4. Altitudinal variation in monetary input and output within AGEs

Maximum MI at VLA\textsubscript{AG} was accounted for human labour (28.1 \%) followed by bullock power (25.8 \%) and seed inputs (14.1 \%) and similar pattern was recorded at LA\textsubscript{AG}. Highest MI for seed were recorded at both HA\textsubscript{AG} (65.1 \%) and MA\textsubscript{AG} (63.3 \%) followed by human labour at both HA\textsubscript{AG} (14.6 \%) and MA\textsubscript{AG} (13.7 \%) (Figure 8A). At VLA\textsubscript{AG}, highest contribution in terms of MO was made by food grains (46 \%) followed by forage production (31.3 \%), forage production (10.5 \%) and similar contribution patterns were observed for LA\textsubscript{AG}. At MA\textsubscript{AG}, highest MO was contributed by other vegetables (35.6 \%) followed by green vegetables (25 \%) and tuber crop (23.1 \%) while, at HA the contribution patterns were

| Table 6. Energy input, output, energy use efficiencies and monetary equivalents (in $ ha\textsuperscript{-1} within parentheses) of the agroecosystems during summer season. |
|---|---|---|---|---|---|---|---|---|---|
| AG\textsubscript{E} size | Very low altitude | Low altitude | Mid altitude | High altitude |
| Input (M J ha\textsuperscript{-1}) | Summer | | | |
| Bullock | 1051 (56) | 1351 (71) | 1622 (82) | 1203 (27) |
| Fertilizers | 1338 (6) | 1264 (5) | 1115 (5) | 1742 (7) |
| Fuel | 1351 (19) | 1051 (15) | 946 (13) | - |
| Human labour | 27 (22) | 24 (19) | 20 (18) | 121 (86) |
| Seed | 504 (11) | 441 (9) | 512 (11) | 2360 (50) |
| Total Input | 4271 (113) | 4131 (120) | 4215 (128) | 5426 (171) |
| Output (M J ha\textsuperscript{-1}) | | | | |
| Forage | 16640 (169) | 17160 (175) | 18096 (184) | 13650 (139) |
| Fruits | 1820 (32) | 9100 (132) | 8190 (119) | 4550 (53) |
| Green vegetables | - | - | - | 136455 (1144) |
| Maize | 12480 (424) | 14040 (715) | 14560 (741) | 10400 (353) |
| Tomato | - | - | - | 6400 (2649) |
| Tubers | - | - | - | 30971 (1157) |
| Total Output | 30940 (625) | 40300 (1022) | 40846 (1045) | 28600 (545) |
| O/I Ratio | 7.24 (5.54) | 9.76 (8.49) | 9.69 (8.15) | 5.27 (3.19) |
| Total Economic yield (kg ha\textsuperscript{-1}) | 7667 | 9000 | 9273 | 6667 |

Figure 4. Effect of altitude, size and seasonal variation on economic yield of agroecosystems (where, VLA = very low altitude; LA = low altitude; MA = mid altitude; HA = high altitude).

Figure 8A. At VLA\textsubscript{AG}, highest contribution in terms of MO was made by food grains (46 \%) followed by pulses (31.3 \%), forage production (10.5 \%) and similar contribution patterns were observed for LA\textsubscript{AG}. At MA\textsubscript{AG}, highest MO was contributed by other vegetables (35.6 \%) followed by green vegetables (25 \%) and tuber crop (23.1 \%) while, at HA the contribution patterns were
observed as – other vegetable (33.8 %) > tuber (33.4 %) > green vegetable (17.1 %) > food grain (8.1 %) > fruit (6.4 %) (Figure 8B).

TMI and TMO differed significantly (P < 0.05) across altitudes where, TMI increased with increasing altitudes but TMO showed no definite pattern (MA (7841 $ ha^{-1} yr^{-1}) > HA (6478 $ ha^{-1} yr^{-1}) > VLA (3333 $ ha^{-1} yr^{-1}) > LA (2685 $ ha^{-1} yr^{-1})). BCR differed significantly (P < 0.05) across altitudes. Along altitudes (R² = 0.727), the relations between TMI and TMO were significant (P < 0.05) (Figure 6). Along altitudes, highest NB was accounted for MA (4879 $ ha^{-1} yr^{-1}) followed by VLA (2701 $ ha^{-1} yr^{-1}) and HA (2618 $ ha^{-1} yr^{-1}) while, BCR was highest at VLA (5.27) followed by MA (2.65). Along altitudes, insignifi-

3.5. Specific energy (SE) of crop yield

Specific energy (SE) at VLA ranged between 13 M J kg⁻¹ (in the large sized AGEs) and 23 M J kg⁻¹ (in the small sized AGEs). At LA, the SE ranged between 19 M J kg⁻¹ (in the medium sized AGEs) to 40 M J kg⁻¹ (in the small sized AGEs). MA showed the range of SE from 8 M J kg⁻¹ (in medium sized AGEs) to 27 M J kg⁻¹ (in small sized AGEs) while, high altitude depicted the maximum SE (81 M J kg⁻¹) for small
sized AGEs while, minimum SE (35 MJ kg$^{-1}$) for medium sized AGEs. Specific energies were reported higher at HA whereas, comparatively lower at VLA (Figure 9).

3.6. Pearson's correlation matrix

3.6.1. In terms of energy budget

Correlation analysis revealed that altitude showed significant relation with TEI ($r = 0.449$), EO ($r = 0.414$) and SE of crops ($r = 0.340$) (Figure 10). The EI ($r = -0.544$) and SE ($r = -0.435$) of crops showed significant negative correlation with seasons while, seasons and energy productivity of crops showed positive correlation ($r = 0.642$) at $P < 0.01$. Most of the parameters were positively correlated with AGE sizes, though the relations were non-significant. EO ($r = 0.374$) and SE ($r = 0.474$) significantly increased with increasing EI whereas, EUE ($r = -0.549$) and energy productivity ($r = -0.692$) significantly decreased. EUE ($r = 0.486$) and NE ($r = 0.970$) showed positive correlation with EO at $P < 0.01$ (Figure 6).

3.6.2. In terms of monetary budget

Altitude showed distinct positive relationship with MI ($r = 0.647$) and MO ($r = 0.482$) whereas negative with BCR ($r = -0.638$) at $P < 0.01$.
Figure 7. Monetary input and output ($ ha\(^{-1}\) yr\(^{-1}\)) as affected by altitudes, seasons and agroecosystems sizes.

(Figure 11). AGE sizes and seasons had no significant impact on monetary budget though the relations were positive with MI, MO and BCR. MO (r = 0.868) and NB (r = 0.501) significantly increased with increasing MI however, BCR (r = -0.546) showed inverse relationship (at P < 0.01). NB and MO were positively related (r = 0.865) with each other (at P < 0.01).

4. Discussion

4.1. Input energy

Agriculture is both a manufacturer and devourer of energy as it consumes large quantities of region-specific non-commercial energy, such as seed, manure and human energy, as well as direct and indirect commercial energies. Input and output energy differ along altitudes due to various factors such as region-specific resource availability and accessibility to agricultural field (Kumar, 2011). Compared to low altitude agroecosystems, total input energy in the present study was recorded maximum across high altitude agroecosystems. Irrespective of size classes, seasons and altitudes, fertilizers (organic/inorganic) and seed input together shared >50% of the total input energy. According to Negi et al. (2018), the major energy inputs in the Himalayan agroecosystem are related to human and bullock labour and application of farm yard manure (FYM). Due to inaccessibility to agriculture fields the high altitude agroecosystems are relatively more labour intensive (Shahi, 2020). It is evident from the study that high altitude agroecosystems were actively involved in cash crop cultivation. Cash crops systems are more energy-intensive and requires high energy inputs in terms of forest biomass compared to cereal – pulse-based cropping systems. This clearly shows that high altitude agroecosystems are primarily sustained by the energy derived from forests. The total input energy recorded in present study were in line with the reported range from 556000-920000 MJ ha\(^{-1}\) yr\(^{-1}\) by Bagwari and Todaria (2011) to 1921000–3433000 MJ ha\(^{-1}\) by Kumar (2011) along the altitudinal gradient of Central Himalaya. The energy input values were also comparable to input values reported by similar studies on different land use systems of the region (Bisht et al., 2021; Padalia et al., 2018; Parihaar et al., 2015).

The energy input values used in crop production were calculated for human and bullock labor on the basis of man- and bullock-days and quantities of seed, manure, fertilizers and pesticides etc. used. Consumption of human and bullock labor in present study were comparable to energetic values reported by several workers for different agroecosystems of the region (Bisht et al., 2021; Padalia et al., 2018). The quantities of seed inputs recorded in our study were relatively highest in high altitude farms. According to Padalia et al. (2018), higher seed input in an agroecosystem is probably due to issue of repeated crop failure.

Our results demonstrated variation in the application of organic fertilizer (farmyard manure) across the altitudinal gradient irrespective of agroecosystem sizes and season. These findings are in line with earlier studies reporting relatively higher application of farmyard manure in high altitude agroecosystems than low altitude farms (Bagwari and Todaria 2011; Kumar, 2011). Forests and agroecosystems of Himalayan region share close linkages, and the later are primarily sustained by nutrients derived from forests in the form of vegetative materials (fodder and bedding leaves) and animal wastes (Negi et al., 2018). Livestock serve as a connecting link between forests and food production systems by recycling and/or transferring nutrients through forest to the croplands (Padalia et al., 2018). At high and mid altitudes, manure is derived from the forest and livestock waste materials (dung, animal urine, bedding leaves and feed leftovers) whereas, at low and very low altitudes it is derived from animal waste only (Shahi, 2020). Bagwari and Todaria (2011) have reported that the farmyard manure energy input shares about 93–96 % of total energy input along an elevational gradient of micro-watershed in Garhwal Himalaya, India. Parihaar et al. (2015) reported the annual farmyard manure energy input as 81905.79 MJ ha\(^{-1}\) yr\(^{-1}\) for agroforestry systems and 53723 M J ha\(^{-1}\) yr\(^{-1}\) for home garden systems among different land use systems of Central Himalaya. Similar studies on energetics of different land use systems of the Central Himalaya have also reported farmyard manure as the major contributor of input energy (Bisht et al., 2021; Kumar, 2011; Negi et al., 2018; Padalia et al., 2018; Raihan et al., 1991).

Imported energy inputs (such as chemical fertilizers and fuel) are referred to as those inputs which are not produced within the system, instead are purchased from the market (Negi et al., 2018). In present study, the share of imported energy input (chemical fertilizers and fuel) of the total energy input showed decreasing trend with increasing altitude. In low altitudes, easy and approachable market facilities together with availability of mechanized facilities, fertilizers, pesticides etc. helps to alleviate total labour energy inputs and improves overall crop yield by providing more opportunities to gain maximum outputs (Bisht et al., 2021).

4.2. Output energy

The total output energy estimated in present study were comparable to values reported in the range 770000–990000 M J ha\(^{-1}\) yr\(^{-1}\) by...
Figure 8. Monetary input (A) and output (B) percentile among the agroecosystems along altitudes (where, VLA = very low altitude; LA = low altitude; MA = mid altitude; HA = high altitude).

Figure 9. Specific energy (MJ kg⁻¹) of crop yield across agroecosystem sizes and along altitudes (where, S = small; M = medium; L = large).

Figure 10. Effect of altitude, size and seasonal variation on economic yield of agroecosystems (where, VLA = very low altitude; LA = low altitude; MA = mid altitude; HA = high altitude).
Bagwari and Todaria (2011) and 844000–1101000 M J ha⁻¹ for agro-nomic yield and 1422000–1935000 M J ha⁻¹ for crop-residues by Kumar (2011) along the altitudinal gradient of Centra Himalaya. The mountain economy of Himalayan region, in their effort to maintain a subsistence livelihood, have evolved basically to increase crop productivity and economic returns by replacing traditional nutritive crops with high-yielding varieties (HYVs) of cash crops (Maikhuri et al., 2001). Our findings revealed that food grains (wheat, rice, maize and millets) showed maximum output in low altitude farms whereas, vegetables in high altitude farms. Very low and low altitudes supported the traditional agricultural practices (grains, pulses etc.) while, the mid and high altitudes favoured cash crop cultivation (potato, cabbage, beans, pea etc.) due to prevailing climatic and topographic suitability of the region. At lower altitudes, the climatic suitability, larger land holding, modern mechanized farming and easily approachable market facilities supported the proliferation of traditional crops while, a vice versa pattern was observed for the cash crop proliferation at higher altitude. Similar results were observed by Kumar (2011) in his study along the different climatic regions of Garhwal Himalaya, India. Mandal et al. (2002) and Singh et al. (1997) stated that the energy input-output relations in a cropping system varied with the type of soil, tillage operations, harvesting and threshing operations, cropping sequence, yield and biomass productions.

4.3. Energy ratios and efficiency

Specific energy gives an estimate of the quantity of energy used to produce a unit amount of a crop in a cropping system (Shahi, 2020) and has been widely used for comparing different agroecosystems. Specific energy values in the present study ranged between 8 - 81 M J kg⁻¹ (Figure 4) indicating that 8–81 M J energy is needed per kg crop production. TaheriGaravand et al. (2010) reported specific energy as 15.1 M J kg⁻¹ for Canola production in Mazandaran province of Iran, those values are lower than the values recorded in this study. Our findings demonstrated that specific energy generally increased with increasing altitude. A higher value of specific energy signifies a less efficient cropping system and shares negative relationship with energy use efficiency (Soni et al., 2018). Specific energies of small sized farms were relatively higher than medium and large sized agroecosystems.

Efficient use of input energy enables to achieve increased yield and productivity and contributes to the profitability and competitiveness of agricultural sustainability in rural living (Shahi et al., 2019; Singh et al., 2002; Vibhuti et al., 2018). The output-input ratio of an agroecosystem is an important indicator of its efficiency. Yadav et al. (2018) stated that net energy and energy use efficiencies are important indicators for planning and designing the production system. These indicators also help in decision making in adoption of management strategies and to assess the feasibility of energy requirements in a production system. Results from present study indicated that total energy input and output were relatively high in high altitude farms. Higher output in return of higher inputs is most likely an outcome of energy intensive cropping. In the present study, large size landholdings were comparatively more energy efficient with high net returns. From the results, it can be concluded that large sized agroecosystems have high energy as well as economic productivity than small sized farms. In this regard, Fadavi et al. (2011) also stated that larger land holdings might have advantages of using sufficient quality of inputs, higher level of technology and better management due to their relatively more favourable economic outcome. Similarly, Yilmaz et al. (2005) have also reported that with increasing farm size the energy use efficiency also increased in Turkish cotton production. Energy use efficiency was highest in high altitude farms and lower in mid altitude farms. These values were towards the lower range (0.81–23.89) recorded by Sharma (1991) and exhibits higher and similar efficiencies reported by many researchers (Houpii, 1986; Padalia et al., 2017; Ralhan et al., 1991). Shahi et al. (2019) stated that energy use efficiency can be increased by improving crop biomass production or reducing energy input.
The season wise output-input ratio revealed that during rainy and winter seasons, the very low and low altitude agroecosystems were highly profitable in terms of energy efficiency ratio whereas, high altitude agroecosystems were found to be energy inefficient. In contrast, during summer season, high altitude agroecosystems were more efficient as compared to low altitude agroecosystems (Tables 4, 5, and 6). These findings suggested that energy use efficiency (output: input ratio) was significantly affected by season. The increment of net energy insured the increment of energy use efficiency but altitude and season wise, the relation between net energy and energy use efficiency did not depict any definite pattern (Figure 6). Meanwhile, the relation between energy use efficiency and net energy showed a regular pattern and resulted in a highly significant relation with agroecosystem sizes.

4.4. The economic yield of agroecosystems

The economic yield of crops was highest at high altitude (11186 kg ha\(^{-1}\) yr\(^{-1}\)) followed by mid altitude (10443 kg ha\(^{-1}\) yr\(^{-1}\)) > very low altitude (5659 kg ha\(^{-1}\) yr\(^{-1}\)) > low altitude (4985 kg ha\(^{-1}\) yr\(^{-1}\)) and the yield was positively influenced by the altitudinal gradient. This pattern clearly implies tremendous shift from subsistence to commercial farming in this region. Many areas of the Central Himalaya where agriculture has undergone considerable transformation (cultivation of cash crops tuber, green vegetables, tomato etc.), the proportion of imported energy input was lower than the modern mechanized agroecosystems due to the dependencies on natural resources and subsidies. Traditional agricultural methods tend to rely upon the inputs produced within the system. However, the transformation of traditional agricultural practices to modern land use practices (cultivation of cash crops) have increased pressure on forests by severalfold (Negi et al., 2018; Padalia et al., 2018). The cultivation of cash crops is a high energy-intensive based cropping system which requires high input energy at high altitude (in present study), is most likely in the form of organic matter and nutrients derived from forests. It is estimated that around 2–15 ha of forest area is required to sustain 1 ha of crop land (Kumar, 2011). Overexploitation of forest derived resources can further accelerate the processes of resource degradation. Maikhuri and Ramakrishnan (1999) have reported a range (583–2188 kg ha\(^{-1}\) yr\(^{-1}\)) of economic yield for different crops (Oryza sativa, Zea. mays, Eleusine coracana, Perrilla frutesence, Solanum melongana, Colocasia antiquorum etc.) among North-eastern land use systems in India. Nautiyal et al. (2007) reported the yield for Brassica campestris (504 kg ha\(^{-1}\) yr\(^{-1}\)) < Triticum aestivum (1040 kg ha\(^{-1}\) yr\(^{-1}\)) < Pisum sativum (3840 kg ha\(^{-1}\) yr\(^{-1}\)) < Solanum tuberosum (7000 kg ha\(^{-1}\) yr\(^{-1}\)) < Solanum lycopersicum (35620 kg ha\(^{-1}\) yr\(^{-1}\)) amongst various cultivated systems in Indian Himalaya.

4.5. Monetary input-output and benefit-cost ratios

Our result showed that total monetary input increased with increasing altitude. This was mainly due to prevalence of energy intensive cropping systems which require more input, labour and other costs involved for the management of crops throughout the year (Babu et al., 2020). In the present study, highest monetary input was accounted for human labour in low altitude farms while, for seeds in high altitude farms. Similar to our results, Yilmaz et al. (2005) reported the highest cost input for human labour (24.81 %) followed by land rent (19.49 %), pesticides (10.84 %) and diesel (9.91 %). Singh et al. (2002) reported the range of monetary input as 75–447 $ ha\(^{-1}\) yr\(^{-1}\) and monetary output as 88–839 $ ha\(^{-1}\) yr\(^{-1}\), in context of different land use systems among Indian Himalayas. Our results showed highest monetary returns (output) by food grains in low altitude croplands whereas, by vegetables in high altitude farms. Modernization of energy inputs at very low altitude surely increased the efficiency of agroecosystems in terms of energy and money as well but this trend makes those systems highly energy intensive thus emaciating its sustainability.

The decreasing pattern of benefit-cost ratio with increasing altitude clearly indicated that high altitude agroecosystems are capital intensive. Benefit-cost ratios observed in our study are in line with previously reported values i.e. 1.56 by Qasemi-Kordkheili et al. (2013), 0.86 by TaheriGaravand et al. (2010), 1.10–2.30 by Mandal et al. (2002), 0.75–2.16 by Singh et al. (2002) and 2.62–7.28 by Nautiyal et al. (1998). In this study, high benefit-cost ratio was recorded in large sized farms. Cetin and Vardar (2008) reported that large sized farms are more successful from energy use and economic profitability point of view due to their high benefit-cost ratio.

5. Conclusion

Input and output energy flow within agroecosystem differ markedly along altitude due several factors such as different climatic regions, cropping systems, land use patterns and edaphic factors. Low altitude agroecosystems in the present study support traditional agricultural practices (cultivation of cereal, pulse crop etc.) while, high altitude agroecosystems favour cash crop cultivation (cash crops like vegetables). Regardless of agroecosystem sizes and seasons, organic fertilizer (farm yard manure) contributed major share (>50%) of total energy inputs across all the altitudes. On the basis of size classes, no marked differences were observed however, seasons and altitudes had significant impact on the energetics and economic flow of the agroecosystems. Even though agroecosystem of higher altitudes are energetically efficient but are highly energy intensive and imposing indirect pressure on adjacent forests. Management of agricultural inputs (inclusive of efficient and sustainable use of natural linking resources viz., forests, forest floor biomass, fuel wood and fodder) is necessary to increase livelihood security and reduce vulnerability to climate and environmental change. Adoption of traditional land management options such as, agroforestry systems in high altitude agroecosystems may reduce pressure on forested lands. Low altitude agroecosystems are less energy intensive however, the share of imported energy was maximum. Excessive use of fertilizers and pesticide would be dangerous and ultimately result in shrinking of natural resources and deterioration of environmental health thus should be avoided and use of biofertilizer should be promoted.

Declarations

Author contribution statement

Surendra Singh Bargali, Ph.D; Kiran Bargali, Ph.D: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Charu Shahi, Ph.D: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Bhawna Negi, M.Sc; Kavita Khatri, M.Sc: Contributed reagents, materials, analysis tools or data.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data included in article/ supp. material/ referenced in article.

Declaration of interest’s statement

The authors declare no conflict of interest.
Additional information

Supplementary content related to this article has been published online at https://doi.org/10.1016/j.heliyon.2022.e11500.

Acknowledgements

The authors sincerely thank the Head, Department of Botany, D.S.B. Campus, Kumaun University, Nainital, Uttarakhand for providing necessary lab facilities. The response and cooperation of villagers during field work is duly acknowledged by authors. The authors are highly thankful for the constructive comments of the Editor and the Reviewers that improved our manuscript.

References

Abbas, A., Zhao, C., Waseem, M., Ahmad, R., 2022. Analysis of energy input-output of farms and assessment of greenhouse gas emissions: a case study of cotton growers. Front. Environ. Sci. 7, 252.

Babu, S., Mohapatra, K.P., Das, A., Yadav, G.S., Sahasrabuddhe, M., Singh, R., Panwar, A.S., Yadav, V., Chandra, P., 2022. Designing energy efficient, economically sustainable and environmentally safe cropping system for the rainfed maize-fallow land of the Eastern Himalayas. Sci. Total Environ. 822, 139787.

Bagwari, H.K., Todaria, N.P., 2011. Resource use pattern and agroecosystem functioning in Rawanganga micro-watershed in Garhwal Himalaya, India. J. Agric. Rural Dev. Tropics Subtropics 112, 101–112.

Bargali, S.S., Padalia, V., Bargali, K., 2015. Agroecosystems of Kumaun Himalaya: Ecology, Productivity, Nutrient Dynamics and Energy Budget. Kumaun University, Nainital.

Mohammadi, A., Omid, M., 2010. Economical analysis and relation between energy consumption, input-output relationship and economic analysis for nectarine production in Sari region, Iran. Int. J. Agric. Crop Sci. 5, 125–131.

Babu, S., Mohapatra, K.P., Das, A., Yadav, G.S., Sahasrabuddhe, M., Singh, R., Panwar, A.S., Yadav, V., Chandra, P., 2022. Designing an ecofriendly and carbon-cum-energy efficient cropping system of South Asia. Energy 214 (118860), 1–16.

Maikhuri, R.K., Ramakrishnan, P.S., 1990. Ecological analysis of a cluster of villages emphasizing land use of different tribes in Meghalaya in north-east India. Agric. Ecosyst. Environ. 34, 268–282.

Fadavi, R., Keyhani, A., Mohtasebi, S.S., 2011. An analysis of energy use, input costs and relation between energy inputs and yield of apple orchard. Res. Agric. Eng. 57, 85–96.

Gopalani, C., Ramasastri, B.V., Balasubramaniam, S.C., 1978. Nightive Value of Indian Foods. National Institute of Nutrition, Hyderabad, India, p. 204.

Hercher-Pasteur, J., Loiseau, E., Sinfort, C., Helias, A., 2020. Energetic assessment of the agricultural production system. A review. Agron. Sustain. Dev. 40 (4), 1–23.

Houpi, L., 1986. Energy conservation efficiencies of farmland ecosystem in Jatia Basin, China. In J. H. Cooley (Ed.), Ecology of the Development of Tropical and Subtropical Mountain Areas, INTECOL Bulletin, 13, pp. 61–68.

Khan, M.A., Singh, G., 1996. Energy inputs and crop production in Western Pakistan. Energy 21, 45–53.

Kumar, M., 2011. Yield production and energy budget of traditional agricultural crops in Garhwal Himalaya. Agric. Sci. China 10, 78–85.

Kumar, R., Mishra, J.S., Mondal, S., Meena, R.S., Sundaram, P.K., Bhattacharjee, B.P., Pan, R.S., Lal, R., Saurabh, K., Chandra, N., Samal, S.K., Hams, H., Ramak, R., 2021. Designing an ecofriendly and carbon-cum-energy efficient production system of South Asia. Energy 214 (118860), 1–16.

Maikhuri, R.K., Ramakrishnan, P.S., 1990. Ecological analysis of a cluster of villages emphasizing land use of different tribes in Meghalaya in north-east India. Agric. Ecosyst. Environ. 34, 268–282.

Shah, C., Bargali, S.S., Bargali, K., 2010. Energy use efficiency of rice-based traditional agroecosystems in Kumaun Himalaya, India. Ann. Biol. 35, 303–309.

Sharma, S., 1991. Energy budget studies of some multiple cropping patterns of the Central Himalaya. Agric. Ecosyst. Environ. 36, 199–206.

Shrestha, D.S., 1998. Energy use efficiency indicator for agriculture. Singh, J.S., 2006. Sustainable development of the Indian Himalayan region: linking ecological and economic concerns. Curr. Sci. 90, 784–788.

Singh, G.S., Rao, K.S., Saxena, K.G., 1997. Energy and energy efficiency of the mountain farming system: a case study in Garhwal Himalaya, India. J. Sustain. Agric. 9, 25–49.

Singh, H., Mishra, B., Nahar, N.M., 2002. Energy use pattern in production agriculture of typical villages in arid zone. India-part-I. Energy Convers. Manag. 43, 2275–2286.

Son, P., Sinha, R., Perret, S.R., 2018. Energy use and efficiency in selected rice-based cropping systems of the Middle-Indo Gangetic Plains in India. Energy Rep. 4, 554–564.

Schnepf, R.D., 2004, November. Energy Use in Agriculture: Background and Issues. Congressional Information Service, Library of Congress.

Shahi, C., 2020. Agroecosystems of Kumaon Himalaya: Ecology, Productivity, Nutrient Dynamics and Energy Budget. Kumaon University, Nainital. Soni, P., Sinha, R., Perret, S.R., 2018. Energy use and efficiency in selected rice-based cropping systems of the Middle-Indo Gangetic Plains in India. Energy Rep. 4, 554–564.

TaheriGavarev, A., Asakerh, A., Haghani, K., 2010. Energy elevation and economic analysis of canola production in Iran a case study: Mazandaran Province. Int. J. Environ. Sci. 1, 236–242.

Uziah, J., Loencowsicz, E., 2017. Sustainable Agriculture–Developing Countries Perspective. Valdivia, K.S., 1980. Geography of Kumaon Lesser Himalaya. 66. Wadia Institute of Himalayan Geology, Dehra Dun, India, pp. 323–348.

Vibhuti, Bargali, K., Bargali, S.S., 2018. Effects of homestead garden on floristic composition and diversity along an altitudinal gradient in Central Himalaya, India. Curr. Sci. 114, 2494–2503.

Yadav, G.S., Dar, A., Lal, R., Babu, S., Meena, R.S., Saha, P., Singh, R., Datta, M., 2018. Energy budget and carbon footprint in a no-till and mulch based rice-mustard cropping system. J. Clean. Prod. 191, 144–179.

Yasmeen, R., Tao, R., Shah, W.U.H., Padda, I.U.H., Tang, C., 2022. The nexuses between carbon emissions, agriculture production efficiency, research and development, and government effectiveness: evidence from major agriculture-producing countries. Environ. Sci. Poll. Res. 1–14.

Yilmaz, I., Akçaoz, H., Ozkan, B., 2005. An analysis of energy use and input costs for sheep-crop farming systems. J. Clean. Prod. 144, 171–179.

Yilmaz, I., Akcaoz, H., Ozkan, B., 2005. An analysis of energy use and input costs for sheep-crop farming systems. J. Clean. Prod. 144, 171–179.

Zaman, S., Adnan, W., 2016. Energy and environmental analysis of selected multiple cropping patterns of the Middle-Indo Gangetic Plains in India. Energy Rep. 4, 303–309.