Indian Journal of Agronomy (1st International Farming Systems Conference 2025, Special Issue) **70**: S54–S61
DOI: 10.59797/ija.v70.spl.5563

Farming system approach for efficient resource management, and economic security in the degraded *jhum* lands of Meghalaya

BADAPMAIN MAKDOH[1], NIRAJ BISWAKARMA[2], JAYANTA LAYEK[3], ANUP DAS[4], S. HAZARIKA[5], SUBHASH BABU[6], N. TALUKDAR[7], N.C. GULLEIBI[8], K. BAISHYA[9], RAHUL SAIKIA[10], JOYDIP LAYEK[11] AND T. GOHAIN[12]

ICAR-Research Complex for NEH Region, Meghalaya 793 103

Received: December 2024; Revised accepted: February 2025

ABSTRACT

Shifting /*jhum* cultivation*,* is the major production system in hilly agro-ecologies of Meghalaya, leading to resource degradation, reduced crop productivity, and environmental pollution. This necessitates the implementation of a micro-watershed-based integrated farming system (IFS) with effective soil and water conservation measures. Thus, an agro-pastoral-based farming system (0.64 ha) was evaluated from 2021 to 2023, to improve system productivity, and farm income and reduce reliance on external inputs. The crop planning strategy was designed across different watershed zones: single cropping in the upper zone, double cropping in the middle, and triple cropping in the lower zone, with vertical farming to optimize land use and maximize yield. Among various enterprises, the dairy unit had the highest system production efficiency (SPE) (28.1 kg/ha/day) and system productivity (SP) (10.2 Mg/ha), and overall, the agro-pastoral system recorded 75% and 47% greater SP than farmer practices I and II, respectively. The agro-pastoral system achieved ~85-92% greater net return, highest B:C ratio (1.67), system economic efficiency (SEE) (₹414/ha/day), and employment (250 man-days) than the farmer practices. The integration of different enterprises also enhanced energy dynamics. In terms of greenhouse gas emissions, the dairy unit had the highest contribution (49%), followed by maize-green gram-toria (10%), and the least in sole turmeric (6%). Additionally, the boundary tree species contributed a carbon sink of 5,707 kg CO_2eq/yr, resulting in a positive system carbon balance of 14,635 kg CO_2eq/yr. Thus, the adoption of an agro-pastoral system offers a suitable alternative for achieving higher resource efficiency, and economic security in the mid-hills of Meghalaya.

Key words: Agro-pastoral, Energy dynamics, Greenhouse gas emission, System Productivity

Approximately 20% of the world's surface is covered by mountains and hilly ecosystems, spanning from the equator to the poles (Messerli *et al*., 2008). The hilly mountains of the eastern Himalayan region of India are also endowed with bountiful natural resources of land, water, and vegetation which in turn provide a great scope for growing a wide variety of agricultural and horticultural crops besides, animal husbandry and fishery. In North-Eastern (NE) India, agriculture is the principal option of economic security, as the majority (78.9%) of the farmers are small and marginal. The rich diversity of flora and fauna, abundant rainfall (2,818 mm /annum), high soil organic matter content, and availability of fodders make the region more suitable for the cultivation of high-value crops along with cereals and pulses, besides rearing of different livestock (Das *et al*., 2019). Nevertheless, the low purchasing capacity, lack of awareness, and cultural and religious beliefs among the tribal farmers forced them to practice *Jhum* cultivation on a larger scale (Layek *et al*., 2022). *Jhum*, popularly known as shifting cultivation, is an agricultural practice where the lands are cultivated temporarily, abandoned, and allowed to revert to their original state. Around 0.44 million farm families covering a 0.76 Mha area partially or entirely depend on *Jhum* cultivation for their livelihood (Saha *et al*., 2021). Further, practicing *Jhum* is neither economically viable nor sustainable, as the reduced fallow period of 3-6 years, driven by escalating demographic pressure and a corresponding decline in available soil resources, fails to restore long-term soil productivity. Additionally, it accelerates the rate of soil erosion, leading to soil fertility deterioration, stagnant crop productivity, loss of forest cover and biodiversity, and greenhouse gas emissions (Lenka *et al*., 2012). Hence, to

[2,3]**Corresponding author's Email:** biswaniraj666@gmail.com and jayanta.icar@gmail.com
[1,2]Scientist (Agronomy), [5]Pr. Scientist (Soil science), [7,8,10]Senior Research Fellow, [9]Young Professional-I, ICAR Research Complex for NEH Region, Meghalaya; [3]Sr. Scientist (Agronomy), [11]Young Professional-I, Indian Institute of Agricultural Biotechnology, Jharkhand; [4]Director, ICAR Research Complex for Eastern Region, Patna; [6]Sr. Scientist, Division of Agronomy, ICAR-IARI, New Delhi; [12]Professor (Agronomy) School of Agricultural Sciences, Nagaland university, Nagaland

minimize farmer's risk, and assure income and food security in changing climate, it is necessary to implement a stable land management strategic farming system under a community approach to increase sustainable food production and promote resilience while reducing environmental impacts on agro-ecosystems (Layek *et al*., 2023). The adoption of appropriate soil and water conservation measures, along with crop production in a farming system approach, could be a plausible alternative to improve resource use efficiencies, crop productivity, economic security, and environmental sustainability in the region.

The Integrated Farming System (IFS) is a highly location-specific resource management strategy that represents appropriate combinations of farm enterprises, viz., cropping systems, livestock, fisheries, forests, poultry, and the means available to the farmers to raise them for profitability. The complementary interaction of diversified enterprises helps in achieving climate resilience through on-farm resource recycling and increased ecosystem services besides providing balanced food and sustaining farm income (Behera and France, 2016). Further, a prior study has illustrated that the designed integrated farming had higher crop productivity, net economic return (₹2,45,932/annum), energy productivity (0.22 kg/MJ), and lesser greenhouse gas (GHG) emission than the conventional practices (Babu *et al*., 2023). Similarly, Layek *et al*. (2023) reported that the adoption of the IFS model in the farmer's field enhanced the productivity of various crops, viz. tomato, potato, chili, carrot, French bean, ginger, and turmeric, by 16.5 to 43.2%. Additionally, Shyam *et al*. (2023) in NW India registered the greater employment generation, i.e., 792 man-days/ha, and a sustainable livelihood index (70.2%) due to the integration of various enterprises over the traditional rice-wheat system. Improved ecosystem services due to the integration of livestock with arecanut in coastal agroecologies were also reported by (Sujatha and Bhat, 2015).

Suitable IFS model comprising cereals, pulses, oilseeds, vegetable crops, fruits, livestock unit, fodder crops, farm pond, and vermicomposting unit have been developed at ICAR Research Complex for NEH Region, Umiam for hills of NER of India to meet the diverse requirement of the farm household while preserving the resource base and maintaining the environment (Layek *et al*., 2023). Slopes were transformed into terraced fields, and the risers of terraced fields were planted with guinea and broom grasses along with other plants for stability and to provide green fodder. The agronomical crops were assigned in the slopes below 50% towards foothills, whereas horticultural crops cultivated in the slope between 50-100%, and slope over 100% are used for forestry/Silvi-pastoral crops. In addition to food security, the integration of livestock in the farming systems was considered to enhance the income and employment of farmers. Thus, seeing the multifaceted benefits of IFS, and aiming to double the farmer's income in Meghalaya, identification and quantification of specific enterprises in the hills are needed for developing sustainable location-specific IFS models for the enhancement of the livelihood of farmers. A field study on designed agro-pastoral-based farming systems was conducted for three consecutive years, i.e., 2021 to 2023, with the following objectives: (i) to assess the impact of agro-pastoral-based systems on system productivity and economic efficiency over the farmers' practice; and (ii) to measure the impact of different enterprises of the model on energy dynamics, greenhouse gas emissions, and system carbon balance to achieve efficient resource management and economic security in the degraded lands of Meghalaya.

MATERIALS AND METHODS

The watershed-based agro-pastoral system was established in 1983 at ICAR Research Complex for NEH Region, Meghalaya (25°41′21″ N and 91°55′25″ E and 980 above mean sea level). This research paper includes mean data for four consecutive years i.e. 2020 and 2023 of the agro-pastoral system. The experimental site has a subtropical with an average annual rainfall of 2334 mm, wherein ~70% of the total rainfall occurs during the South-West monsoon i.e. July to September. The monthly mean maximum and minimum air temperatures ranged between 18-30ºC and 6.9-20.5ºC, respectively. The soil of the experimental site was sandy clay loam in texture having acidic pH (5.12), organic carbon (19.2 g/kg), and available nitrogen (N) 238.2 kg/ha), phosphorus (P) (17.3 kg/ha) and potassium (K) (197.2 kg/ha) (Table 1).

Table 1. Initial soil properties of the experimental site

Soil properties	Values	Analysis Method
Soil *p*H	5.12	(1:2.5 soil and water ratio; Piper, 1950)
Soil organic carbon (g/kg)	19.2	Walkey and Black (1934)
Available N (kg/ha)	238.2	Subbiah and Asija (1956)
Available P (kg/ha)	17.3	Bray and Kurtz (1945)
Available K (kg/ha)	197.2	Hanway and Heidel (1952)

The total area of the agro-pastoral farming system model was 0.64 ha with an average slope of 32.4%. To reduce the slope of the land, an individual bench terrace of size (50-200 m^2) having an inward slope with contour bunds was configured in such a way that the vertical interval did not exceed 1.25 m by excavating parabolic channels (0.3 m top and 0.2 m deep) on contours followed by keeping the dugout soil in form of a bund at the lower edge of the channel. After land configuration, an entire area of the hill slope was divided into 60 numbers of terraces of width varying from 0.6 m to 2.7 m. Subsequently, the terraced land was allocated for different components of the farming system which were presented in Fig. 1 and 2.

Further, the crop planning was done in such a way that the top portion of the watershed was utilized with single crop middle portion with double cropping, and the bottom portion with triple cropping. Each year similar cropping system was maintained in the same plot during all four years. In the pre-rainy season, the soil was thoroughly tilled with a power tiller for the sowing of the maize crop. Further, the farmyard manure (FYM) containing ~30% moisture 0.50%±0.02 N, 0.30%±0.01 P_2O_5 and 0.49%±0.02 K_2O was applied at the rate of 8 Mg/ha/year

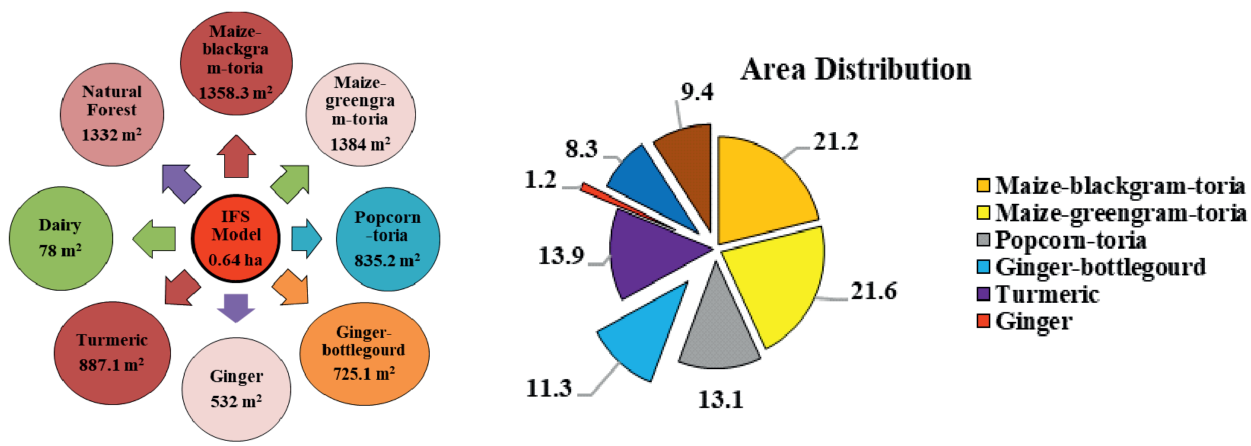

Fig. 1. Area allocated for different components of the agro-pastoral-based farming system model

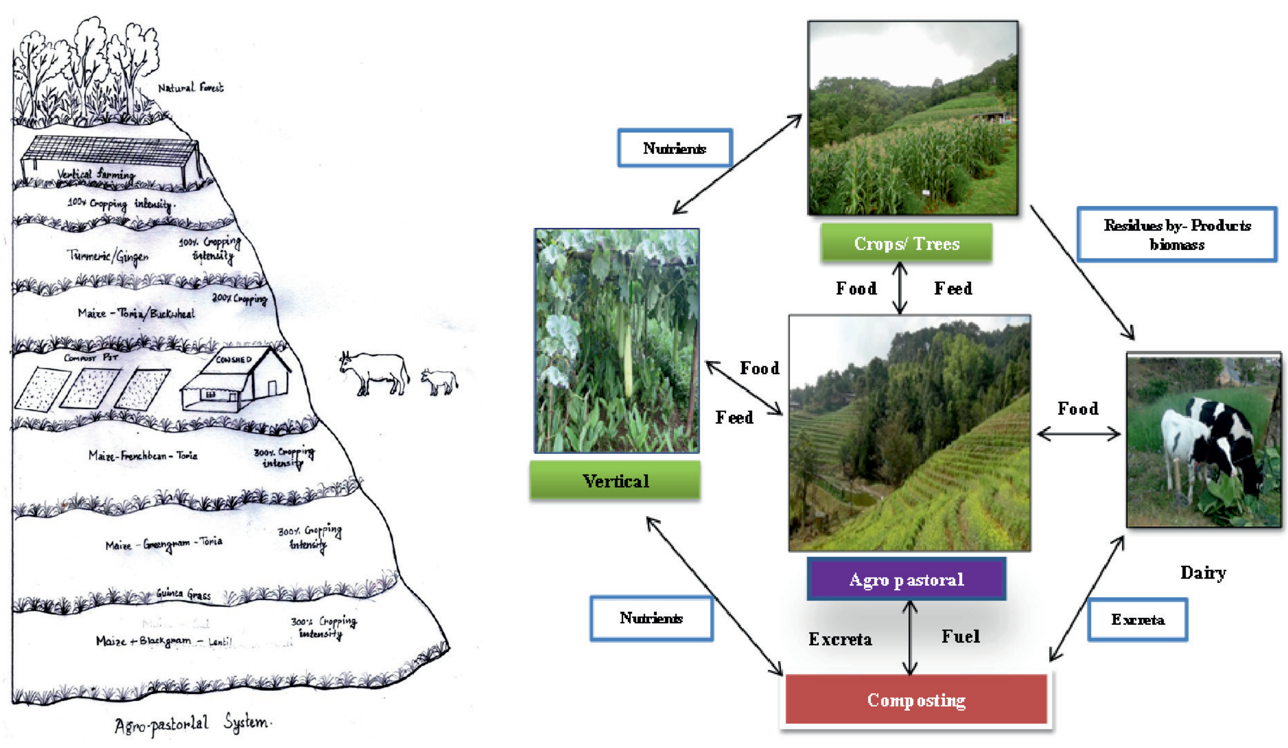

Fig. 2. Bio-resource flow in Agro-pastoral based farming system

in all the cropping systems. Further, the post rainy season crops namely black gram and green gram were sown in September and toria/rapeseed in October. The details about crop culture and management practices are given in Table 2.

Further, the field crop yield such as maize, green gram, toria etc. was estimated from the net plot size of 2 x 2 m^2 area; and were expressed in kg per unit area. Additionally, the yield obtained from individual crops in a cropping system was expressed in rice equivalent yield (REY), which were added together to obtain the system productivity (SP) (t /ha). Similarly, the system production efficiency (SPE) of each practice (kg /ha /day) was calculated using the following expression:

$$\text{SPE} = \frac{\text{System yield (kg/ha)}}{\text{365 days}} \quad \text{.................. (i)}$$

Further, the scheduled harvests of horticultural crops, including bottle gourd, ginger, and turmeric were also made and the fresh weights of these crops were noted. Similarly, every year the need-based insect pest and disease management was followed as per the plan of the experiment. In the case of dairy, there were 3 nos. *Holstein Friesian* (HF) breed and standard recommended feeding was provided including paddy straw, concentrate, and green feed (mixture of all in an amount of ~2% dry weight of their body weight). During the study period, the production cost was computed based on the prevailing market prices of the various inputs, whereas, the gross returns (GR) were calculated by summing the total price of grain, stover milk, etc. using the prevailing local market rate. Further, the net returns were calculated by taking the difference between gross return and cost of cultivation. Furthermore, the system economic efficiency (SEE) (₹/ha/day) was obtained by dividing the net returns by the duration (365 days). Similarly, the benefit-cost ratio was calculated for each practice by dividing gross returns (₹/ha) by production cost (₹/ha). In this study, the energy source comprises human labor, fuel, machinery, seed, residue, chemical fertilizers, fodder grass, straw, concentrated feed, water, and plant protection chemicals i.e., insecticide and fungicide, etc. For computing the energy input, and output of the respective practices, standard energy coefficients (MJ per 0.64 ha) and converted to GJ per 0.64 ha. All energy input coefficients were summed to get the total input energy. Accordingly, various energy indices were computed using the following formula.

Net energy (GJ per 0.64 ha) = Energy output – Energy input .... (ii)

Energy use efficiency = Energy output / Energy input .....(iii)

Additionally, the greenhouse gas (GHG) emission from each cropping system was estimated using the different coefficients. Further, the GHG (CO_2, and N_2O) emitted was computed and expressed in a CO_2 equivalent by multiplying the global warming potential (GWP) equivalent of 1 and 265 for CO_2 and N_2O, respectively for a 100 years time span (Lal, 2004). The emission factor of 0.01 was multiplied by the total quantity of N supplied through mineral fertilizers, organic manures, and crop residue to quantify the N_2O emission and was expressed in N_2O kg N/input

Table 2. Description of crops, varieties, spacing, seed rate, and fertilizer schedule adopted in the different cropping systems under an agro-pastoral-based farming system (0.64 ha)

Enterprises	Growing seasons	Variety	Spacing (cm)	Seed rate (kg/ha)	Fertilizer dose N:P: K (kg/ha)
Maize-Blackgram-Toria					
Maize	April-August	DA 61-A	40 x 60	20-25	60:40:40
Blackgram	August-October	PD-3	25 x 10	10-20	15:35:10
Toria	November-February	TS-67	15 x 30	8-11	40:35:15
Maize-Greengram-Toria					
Maize	April-August	DA 61-A	40 x 60	20-25	60:40:40
Greengram	August-October	Tripura-1	25 x 10	10-20	15:35:10
Toria	November-February	TS-67	15 x 30	8-11	40:35:15
Popcorn-Toria					
Popcorn	April-August	RCM 1-2	40 x 60	20-25	80:60:40
Toria	November-February	TS-67	15 x 30	8-11	40:35:15
Ginger-Bottle gourd					
Ginger	March-January	Mizo	30 x 20	1800-2000	20:60:20
Bottle gourd	April-June	HYV	200 x 250	5	40:30:30
Turmeric	March-January	Megha Turmeric-1	30 x 20	1500	30:50:60
Grasses, and MPTS	Broom grass, Guinea grass, Ficus, Alder, Juniper, Mangolia. Tecoma, and Toona etc.				

Where, MPTS = multi-purpose tree species

N_2O emission (kg/year) = amount of N supplied by N inputs x 0.01 × 44/28 ….(iv)

GWP from all crops in the cropping system was estimated with the following formula:

GWP = (Total N_2O emission × 265) + Total CO_2 emission………(v)

While, the GHG emission from dairy components was estimated using the Tier 1 method (IPCC, 2006). Additionally, to compute the carbon balance, we have calculated the carbon sequestration potential of tree species using the procedure described by the Forest Survey of India (2019). Further, the different carbon use efficiency was computed using the formula:

Carbon efficiency (C_E) = Carbon output / carbon input…….(vi)

RESULT AND DISCUSSION

Among the various enterprises, the dairy unit (3 milch cows) had the highest REY (10,260 kg/0.64 ha), followed by ginger-bottle gourd (1286 kg/0.64 ha), ginger-fallow (802.7 kg/0.64 ha), and turmeric-fallow (768.7 kg/0.64 ha). In contrast, the lowest REY was registered in popcorn-toria (325 kg/0.64 ha) (Table 3). Similarly, the system productivity was found to be 16.9 Mg /ha, wherein the dairy unit and cropping system contributed 60.3% and 39.6%, respectively. Further, the agro-pastoral-based system had 75% and 47% higher system productivity than the regional farmer practices I (maize fallow) and II (maize-vegetable), respectively. System production efficiency (SPE) was also documented higher in dairy (28.1 kg/ha/day) followed by cropping system (18.3 kg/ha/day) with an overall SPE of 46.4 kg/ha/day. The improvement in productivity under an agro-pastoral-based system might be ascribed to synergistic impact due to the integration of more diverse enterprises as it facilitates the effective utilization of farm resources such as water, nutrients, and light, etc. than the regional farmer's practices (Das *et al*., 2019). Further, agronomic practices such as crop rotation, and long-term application of organic manures help to restore soil fertility; and thus, improve overall system productivity.

Overall, the cost of cultivation of different enterprises was ₹1,44,937/- per 0.64 ha, where the dairy unit incurred the highest cost of ₹85,647/- followed by ginger–bottle gourd system (₹13,544/-), and least in popcorn-toria system (₹6,245/-) indicating that the production cost increased directly with increasing level of integration (Table 4). Our findings were inconsistent with the report of Ansari *et al*. (2013). Further, the gross and net return from 0.64 ha was ₹2,41,875/- and ₹96,938/-, respectively wherein, the dairy unit followed by sole turmeric had the maximum returns and least in the popcorn-toria system. Overall, in the 1.0 ha area though the production cost was higher for the agro-pastoral-based systems it provided 88-94% and 85-92% greater gross and net return than the regional practices i.e. maize-fallow, and maize-vegetable systems respectively. As per Panwar *et al*. (2018), the diversification of the existing systems with high-value crops, and judicious integration of livestock creates additional farm income due to the higher price of milk, turmeric, and ginger besides recycling of the farm residue into feed. Similarly, the agro-pastoral-based farming

Table 3. Rice equivalent yields per 0.64 ha, total system productivity and production efficiency of the different cropping systems, and dairy under an agro-pastoral based farming system

Enterprises	Rice equivalent yield (REY) (kg/0.64 ha)			Total System Productivity (t/ha)	SPE (kg/ha/day)
	Kharif	*Rabi*	*Zaid*		
Maize-black gram- toria	-	-	393.3		
	66.7	-	-		
	-	101.6	-		
Maize-green gram-toria	-	-	375.2		
	67.2	-	-		
	-	109.3	-	6.7	18.3
Popcorn-toria	-	-	229		
	-	96	-		
Ginger-bottle gourd	-	-	1118.7		
	-	-	167.3		
Turmeric	-	-	768.7		
Ginger	-	-	802.7		
Dairy (3 milch cow)	10,260	10.2	28.1		
In 1 ha area	-	16.9	46.4		
FP-I Maize-fallow	-	4.18	11.4		
FP-II Maize-vegetable	-	8.88	24.3		

Note: Allocation of the areas under different cropping systems and dairy units were provided in Fig. 1 system B: C ratio is 1.67 as compared to farmers' practice I (1.20 and 1.02). In addition, the agro-pastoral-based system also provides greater SEE ₹265/ha/day, where the dairy unit has alone contributed 70% as compared to others. The increase in economic efficiency was chiefly attributed to increased net return over the farmers' practice I. Moreover, the agro-pastoral-based system also generated man days of 160 days from 0.64 ha; and 250 per hectare (Table 4), which was only 78 days and 115 days in farmer practice I and II, respectively.

As integration of the different enterprises engages the farm labor due to the year-round nature of the diversified production system, and varied farming activities; thus, creating greater employment opportunities than the conventional system. The energy input of all the enterprises varied depending on the type of integration with the enterprises (Table 5). Overall, the energy input of the system was 675.9 GJ 0.64/ha, wherein the maximum input was registered in the dairy unit (605 GJ) followed by maize-green gram-toria (22.1 GJ) and maize-blackgram-toria (21.7 GJ), and least in the sole ginger system (2.8 GJ). Which were mainly attributed to the greater use of labor, water, concentrated feed, and fodder than the cropping system. Similarly, out of total energy output, and net energy, the dairy unit had the maximum values of energy output (863.9 GJ) and net energy (258.9 GJ) and the least in sole ginger. This was mainly ascribed to efficient recycling of farm by-products such as cow manures, urine; and higher yield levels of fodder grasses in the system (Babu *et al*., 2023). While, in contrast, the energy use efficiency was registered in the maize-based cropping system (8.8; 8.7) and spice-based system (7.8; 7.5, and 6.0) than in the dairy-based system (1.4) as the energy utilization pattern was much lesser under cropping system as compared to dairy unit (Kumar *et al*., 2018).

GHG emission in terms of carbon equivalent from the different enterprises is presented in Table 6. The total carbon input, output, and net carbon of the agro-pastoral-based system were 14,762, 38,452, and 23,690 kg CO_2 eq/yr, respectively. Out of which the dairy unit had the highest contribution (49%) followed by maize-green gram-toria (10%) and the least in sole turmeric (6%). This indicates that the integration of dairy units will intensify greenhouse gas i.e. CH_4 and N_2O emissions than the cropping system (Paramesh *et al*., 2019; Babu *et al*., 2023). Further, the highest carbon output and net carbon were in

Table 4. Economics and employment generation of the different cropping systems and dairy under agro-pastoral based farming system

Enterprises	Cost of cultivation (₹)	Gross Return (₹)	Net Return (₹)	B:C ratio	SEE (₹/ha/day)	Employment (Man days)
Maize-black gram-toria	9635	12675	3040	1.32	8.3	23
Maize-green gram-toria	9256	12675	3419	1.37	9.4	27
Popcorn-toria	6245	8235	1990	1.32	5.5	19
Ginger-bottle gourd	13544	19290	5746	1.42	15.7	23
Turmeric	11365	23060	11695	2.03	32.0	20
Ginger	9245	12040	2795	1.30	7.7	15
Dairy	85647	153900	68253	1.80	187.0	33
In 0.64 ha area	1,44,937	241875	96938	1.67	265	160
In 1.0 ha area	2,26,450	3,77,906	1,51,456		414	250
FP-I Maize-fallow	9068	19996	10928	1.2	54	78
FP-II Maize-vegetable	20999	42454	21454	1.02	58.7	115

Note: Allocation of the areas under different cropping systems and dairy units were provided in Fig. 1

Table 5. Energy dynamics of the different cropping systems, and dairy under agro-pastoral based farming system

Enterprises	Total input energy (GJ)	Total output energy (GJ)	Net energy (GJ)	EUE (%)
Maize-blackgram-toria	21.7	190	168.3	8.8
Maize-greengram-toria	22.1	192	169.9	8.7
Popcorn-toria	16.2	143	126.8	8.8
Ginger-bottle gourd	3.8	29.7	25.9	7.8
Turmeric	4.3	32.2	27.9	7.5
Ginger	2.8	16.8	14	6.0
Dairy	605	863.9	258.9	1.4
In 0.64 ha area	675.9	1467.6	791.7	2.2

Note: Allocation of the areas under different cropping systems and dairy units were provided in Fig. 1

Table 6. Greenhouse gas emissions from the different cropping systems, and dairy under agro-pastoral farming system

Enterprises	Carbon input (kg CO_2 eq./yr) (A)	Carbon output (kg CO_2 eq./yr) (B)	Net carbon (kg CO_2 eq./yr) (C)	Net carbon sink from trees kg CO_2eq. (D)	Carbon balance kg CO_2eq. (C+D-A=E)	Carbon use efficiency (%)
Maize-black gram-toria	1483	2181	698			1.47
Maize-greengram-toria	1570	2417	847			1.54
Popcorn-toria	1150	2461	1311	5707	14635	2.14
Ginger-bottle gourd	1345	1599	254			1.19
Turmeric	940	1779	839			1.89
Ginger	1020	2458	1438			2.41
Dairy	7,254	25,554	18300			3.52
In 0.64 ha area	14762	38452	23690	-		2.02

similar trends with carbon input (Table 6). Additionally, the agro-pastoral-farming system consisted of 17 trees (natural forest) and had a carbon sink of 5,707 kg CO_2 eq/yr and system carbon balance of 14,635 kg CO_2 eq/yr. Thus, the simple integration of agro-forestry or boundary plantation helps in reducing GHG emissions through carbon sequestration, leading to create a positive carbon balance in the system. Likewise, the carbon use efficiency of the system was 2.02% of which dairy unit (3.52%) followed by sole ginger (2.41%) had the maximum values with the least in ginger-bottle gourd system (1.19%) indicating that, the productive enterprises have always high resource conversion efficiency.

Thus, the adoption of an agro-pastoral-based farming system helps in enhancing crop and livestock productivity due to efficient resource recycling along with greater farm profitability, and employment generation than the regional farmer practices. Besides this, crop diversification and livestock integration also enhance energy dynamics; and amalgamation of the agroforestry component (natural forest on the hilly slope) resulted in reduced environmental footprints and created a positive carbon balance, thereby promoting a green and circular economy.

REFERENCES

Ansari, M.A., Prakash, N., Baishya, L.K., Punitha, P., Yadav, J.S. and Sharma, P.K. 2013. Comparative study on conventional and improved integrated farming systems for sustainable production, income generation and employment opportunity among the tribal farmers in hilly Regions of Manipur. *Indian Journal of Agricultural Sciences* **83**: 765–72.

Babu, S., Das, A., Singh, R., Mohapatra, K.P., Kumar, S., Rathore, S.S., Yadav, S.K., Yadav, P., Ansari, M.A., Panwar, A.S. and Wani, O.A. 2023. Designing an energy efficient, economically feasible, and environmentally robust integrated farming system model for sustainable food production in the Indian Himalayas. *Sustainable Food Technology* **1**(1): 126–142.

Behera, U. K. and France, J. 2016. Integrated farming systems and the livelihood security of small and marginal farmers in India and other developing countries. *Advances in Agronomy* **138**: 234–274.

Das, A., Layek, J., Ramkrushna, G.I., Babu, S., Devi, M.T., Dey, U., Suting, D., Yadav, G.S., Lyngdoh, D.B. and Prakash, N.A. 2019. Integrated organic farming system: An innovative approach for enhancing productivity and income of farmers in north eastern hill region of India. *Indian Journal of Agricultural Sciences* **89**: 1,267–1,272.

Forest survey of India, Ministry of Environment and Forests, Government of India. 2019. Available from: https://fsi.nic.in/carbon_stock/contents-message-preface.pdf (accessed: January 15, 2022).

IPCC. 2006. Guidelines for National Greenhouse Inventories. Vol. 4: Agriculture, Forestry and Other Land Use. Geneva: Intergovernmental Panel on Climate Change. (accessed: January 10, 2021).

Kumar, R., Patra, M.K., Thirugnanavel, A., Deka, B.C., Chatterjee, D. and Borah, T.R. 2018. Comparative evaluation of different integrated farming system models for small and marginal farmers under the eastern Himalayas. *Indian Journal of Agricultural Sciences* **88**: 1,722–1,729.

Lal, R. 2004. Carbon emission from farm operations. *Environment international* **30**(7): 981–990.

Layek, J., Das, A., Ansari, M.A., Mishra, V.K., Rangappa, K., Ravisankar, N., Patra, S., Baiswar, P., Ramesh, T., Hazarika, S. and Panwar, A.S. 2023. An integrated organic farming system: innovations for farm diversification, sustainability, and livelihood improvement of hill farmers. *Frontiers in Sustainable Food Systems* **7**: 1151,113.

Layek, J., Das, A., Ghosh, P.K., Rangappa, K., Lal, R., Idapuganti, R.G., Nath, C.P. and Dey, U. 2022. Double no-till and rice straw retention in terraced sloping lands improves water content, soil health and productivity of lentil in Himalayan foothills. *Soil and Tillage Research* **221**: 105,381.

Lenka, N.K., Choudhury, P.R., Sudhishri, S., Das, A. and Patnaik, U.S. 2012. Soil aggregation, carbon build up and root zone soil moisture in degraded sloping lands under selected agroforestry-based rehabilitation systems in eastern India. *Agriculture, Ecosystems and Environment* **150**: 54–62.

Messerli, B., Viviroli, D. and Weingartner, R. 2008. Mountains of the world. In: *Managing Water Resources in a Time of Global Change: Contributions from the Rosenberg International Forum on Water Policy*. pp.11, Taylor and Francis.

Panwar, A.S., Syiemlieh, H., Kalita, L., Tahashildar, M. and Layek, J. 2018. Food and nutritional security through farming system approach. In: *Conservation Agriculture for Advancing Food Security in Changing Climate, Volume I (Crop Produc-*

tion, Farming System and Soil Health). (Das, A., Mohapatra, K.P., Ngachan, S.V., Panwar, A.S., Rajkhowa, D.J., Ramkrushna, G.I. and Layek, J. Eds.). pp.223-44, Today and Tomorrow's Printers and Publishers, New Delhi.

Paramesh, V., Parajuli, R., Chakurkar, E., Sreekanth, G., Kumar, H.C. and Gokuldas, P. 2019. Sustainability, energy budgeting, and life cycle assessment of crop-dairyfish- poultry mixed farming system for coastal lowlands under humid tropic condition of India. *Energy* **188**: 116,101.

Saha, S., Yadav, D., Layek, A., Babu, S., Ansari, M.A., Das, B., Chowdhury, S., Singh, R., Rajkhowa, D.J., Ghosh, P.K. and Das, A. 2021. Potential of conservation agriculture in hill ecosystems: impact on resource sustainability. *Indian Journal of Agronomy* **66**(516): 128–141.

Shyam, C.S., Shekhawat, K., Rathore, S.S., Babu, S., Singh, R.K., Upadhyay, P.K., Dass, A., Fatima, A., Kumar, S., Sanketh, G.D. and Singh, V.K. 2023. Development of integrated farming system model-A step towards achieving biodiverse, resilient and productive green economy in agriculture for small holdings in India. *Agronomy* **13**(4): 955.

Sujatha, S. and Bhat, R. 2015. Resource use and benefits of mixed farming approach in arecanut ecosystem in India. *Agricultural Systems* **141**: 126–137.