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Research Article

Energy Budgeting of Dairy based Integrated Farming System under Indian Scenario

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Abstract

Energy analysis of livestock farming system seems to be a promising approach to investigate and assess the energy use efficiency, environmental problems and their relation to sustainability. Therefore, effective energy usage is one of the key factors for sustainable dairy production which provides financial savings, fossil resources preservation and air pollution reduction. Hence, the present study was workout energy budgeting of dairy based integrated farming system during 2019-21 in Karnal, Haryana. The study was conducted both at on-station and on-farm. For on-farm, one farmer practicing traditional dairy-based model was selected from Karnal district. For on-station study, dairy-based Integrated Farming System (IFS) model developed at NDRI was selected. The results revealed that with the same unit of land (1 ha), Energy budgeting was more efficient for farmer's system with energy use efficiency of 1.97 while for on-station system it was 1.73. Net energy gain of 201168.52 MJ at on-station and it was 259762.10 MJ for farmer's field. Direct and indirect energy input in on-station system and farmer's field were 29214.91 MJ, 248208.30 MJ and 35872.02 MJ, 232955.20 MJ, respectively. On-station IFS system utilized more renewable energy than farmer's field (88.62% vs 83.72%) while non-renewable energy consumption was more for farmer's field (16.28%) than the on-station system (11.38%). Based on above results it can be concluded that energy budgeting was better at farmer's field than on-station IFS system. However, on-station IFS model utilized more renewable energy.

INTRODUCTION

The energy use efficiency of livestock production is lower than that of crop production [1]. In comparison to crop production, fewer studies have been conducted on the energy efficiency of livestock farming [2]. The number of intensive livestock systems is increasing, and the land and livelihood needs of extensive systems are key challenges of livestock farming [3]. Energy analysis of livestock farming system seems to be a promising approach to investigate and assess the energy use efficiency, environmental problems and their relation to sustainability. Energy can be exploited from different inputs such as human labour, animal, fossil-based fuels, electricity and machinery to perform various operations in dairy production. Therefore, improving the management level of energy usage is crucial to combat the rising energy costs, depletion of natural resources and environmental deterioration. Energy is one of the basic requirements for the economic and social development. The analysis of energy budget is important for the planning strategies and policies of energy usage. Therefore, effective energy usage is one of the key factors for sustainable dairy production which provides financial savings, fossil resources preservation and air pollution reduction. On the other hand, livestock production is the poor converter of energy, because it is based on a double energy transformation. First, solar energy and soil nutrients are converted into biomass by green plants. Second, when crops are fed to livestock, a major share of energy intake is spent on keeping up body metabolism and only a small portion is used to produce meat and milk). Increased energy efficiency and utilization of non-renewable energy are effective to improve the productivity with environmental sustainability of other effects of increased energy efficiency could point to the reduced operating costs as well as the costs arising from agricultural production. In order to meet the increasing demands of people to animal products, technology and methods need to be adopted to improve the efficiency of animal production; it would increase the production. By integrating allied farm enterprises energy intake is confined within a farm system. Energy is used in almost all facets of life and makes possible the existence of ecosystems, human civilizations and life itself. Different regions and societies adapt to their environments and determine their own energy resources and energy uses. Energy can exist in many forms, and can be converted from one form to another with energy conversion technologies. Agriculture is both an energy user and energy supplier in the form of bio-energy. At present, the productivity and profitability of agricultural production system depend upon energy consumption [4]. Efficient use of agricultural product energies helps to achieve increased production and productivity and contributes to the profitability and competitiveness of agriculture sustainability in rural living [5]. Agricultural production hangs on fossil energy for providing fuels, fertilizer, pesticides, fodder, and machinery [6,7]. The productivity per hectare was improved with the consequence that food supply systems now use 4–10 times more fossil energy than the food energy they produce [8,9] thus the agriculture turn into a net-energy sink.

Integrated farming system played an important role in reducing the dependency of fossil energy [10] The step in making agriculture into a net-energy provider is to implement strategies that enhance farm energy out-put. Various researchers have studied the scenarios for energy production in different farming systems [11] Ostergard and [12,13] through energy budgeting. An Energy budget is a balance sheet of energy income opposed to expenditure, which deals with the study of energy change and convert from one form to another. Calculation of farm productivity through energy analysis is essential to make efficient use of the naturally available recourses. In recent years due to improvement of agricultural practices, the energy consumption has increased in the form of feed, concentrates, minerals, fertilizers, fossil fuels, electricity power, modern machinery etc. causing environmental degradation. An input-output energy analysis provides farm manager and policy makers an opportunity to calculate economic intersection of energy use. Therefore, energy budgeting is essential to make efficient use of the existing natural resources [14,15]. A dairy component is both an energy consumer and an energy producer; since the use of various energy inputs would lead to produce energy outputs in the form of milk and manure (De et al., 2001). The integrated systems provide scope not only to augment income of the farmers but also bring improvement in energy use efficiency through recycling of nutrients, increases the overall productivity, profitability and sustainability of the farms. Thus, energy obtained from IFS in various forms is much higher than energy input, as the by-product/wastes of these allied enterprises provide raw material and energy required for the food chain in another system. This complimentarily when carefully chosen, keeping in view the soil and environmental conditions generates greater income. The adoption of integrated farming system instead of any individual crop-livestock enterprise will not only sustain the livelihood but also provide food security specially at the small and marginal scale of farming [16]. Thus, the need has been felt to identify appropriate energy efficient farm practices and technologies for cost effective production in integrated farming systems. Therefore, the present study has been planned on Energy Budgeting of Dairy Based Integrated Farming System: A Report.

STUDY METHODOLOGY

Energy Analysis

Inputs used and outputs produced from the system were recorded season and component wise. Input energy from seed, fuel, human labour, fertilizers, FYM, insecticides, irrigation, electricity, feed concentrates, fodders, mineral mixtures etc. and output energy from yield as grains, milk, dung, fodder, eggs, manure, live wt. of birds and other products and by-products were converted from physical to Energy Unit (MJ) using various published specific conversion coefficients (Table 2,3) and calculated total energy input and output. The energy output for the green fodder crops was estimated based on the DM. To estimate the energy input-output, energy use efficiency, net energy gain and other energy indices for the different components of IFS (Table 1). Energy equivalents (MJ/ha) of all inputs were summed to get an estimate for the total input of energy. Energy utilization in farm operations was calculated on the basis of energy consumed in field preparation and sowing, fertilizer application, irrigation, intercultural operation and weeding, plant protection, and harvesting and threshing. The direct and indirect source-wise energies (viz., human labour, seed, crop residue, diesel, plant protection chemicals, fertilizers and machinery) were calculated to compute the above farm operations on hectare basis (MJ/ha) under each treatment. Crop yield samples from the net areas were harvested

Table 1: The different energy indices were computed using the following equations.

S. No.	Energy Indices	Formulae Used
(I)	Energy use efficiency	Energy output (MJ) / Energy input (MJ)
(II)	Net Energy	Total Energy output (MJ) – Total energy input (MJ)
(III)	Energy profitability	Net energy gain (MJ) / Total Energy Input (MJ)
(IV)	Direct energy	Labour + Fuel + Electricity
(V)	Indirect energy	Seed + Feed + Fertilizers + Chemicals + Machineries
(VI)	Renewable energy	Labour + Manure + Feeds/seeds + FYM
(VII)	Non-renewable energy	Fuel + Electricity + Chem. Fertilizers + Chemicals +Machinery
(VIII)	Human energy profitability	Total Energy output (MJ) /Total Labour Energy Input (MJ)

Table 2: Resource input and their energy equivalent

Input	Unit	Equivalent (MJ/unit)	Reference
Labour	hr	1.96	[19-21]
Fuel	L	56.31	[22][20,21]
Electricity	kWh	11.93	[22][20,21] [23]
Nitrogen (N)	kg	66.14	[22] [20,21]
Phosphorous (P_2O_5)	kg	22.44	[22] [20,21]
Zn-sulphate	Kg	20.90	[24]
Manure/FYM	kg	0.33	[25]
Vermi-compost	kg	0.50	[26]
Farm machinery	kg	62.70	[25] [20,21]
Sickles (for harvesting)	Hr	0.84	[27]
Seed (Rice, wheat, maize, sorghum, cow pea, oat)	kg	14.70	[28] [20,21]
Berseem (seed)	kg	10.0	[28]
Chick (poultry)	kg	4.56	[29]
Fish fingerling	Kg	55.6	[30, 31]
Concentrate (DM basis)	Kg	9.40	Calculated*
Straw (DM basis)	Kg	5.26	Calculated*
Green fodder (DM basis)	Kg	8.60	Calculated*
Oilcake	Kg	14.40	[32]
Broken rice	Kg	15.28	[32]

Table 3: Resource output and their energy equivalent

Output	Unit	Equivalent (MJ/unit)	Reference
Rice, wheat, maize	kg	14.70	[19]
Sorghum, berseem, oat and maize (dry mass)	kg	18.0	[28]
By-product (dry mass) Straw (Rice and Wheat)	kg	12.5	[28]
Egg	kg	7.28	[33]
Cow milk	kg	3.25	Calculated
Buffalo milk	kg	4.60	Calculated
Goat milk	kg	3.39	[34]
Manure	kg	0.33	[25]
Poultry meat	kg	10.33	[35]
Fish	kg	55.6	[30,31]
Papaya	kg	4.01	[35]

*Feeds energy equivalent calculated on metabolizable energy of feed stuffs on dry matter basis.

manually, however, mechanised harvesting and threshing were assumed for input energy calculation on hectare basis, as mechanization in farming has been increased in India.

To investigate the relationship between the output and different forms of energy, we categorised the energy inputs into direct, indirect, renewable, and non-renewable [5] Direct energy (DE) includes human labour and electrical energies, while Indirect Energy (IDE) involved energy used for machinery and feed stuffs. On the other hand, Renewable Energy (RE) includes, human labour and feed stocks, whereas, Non-Renewable Energy (NRE) consists electricity and machinery used at dairy farms.

Estimation of Energy Inputs

The inputs-output energy values were calculated by using the energy conversion factors suggested by earlier workers. Human Labour Energy (EHL)- Human labour is required for animal husbandry, fodder harvesting and distribution, package of practices of crop and milking of animals. Human labour energy could be calculated using Eq. (1) as follows:

$$EHL = nHL \times nd \times h \times EEHL \quad (1)$$

where EHL is human labour energy in MJ per unit, nHL is number of human labours at dairy-based IFS farm, nd is production days of labour, h working hours of a labour spending at a farm in a day, and EEHL is the energy equivalent of human labour in MJ(Table 2).

Electricity Energy (EE)- Electricity was mainly used for lighting farms, electric fans, and electric motor used in chaff cutters to chop fodders. The electricity consumption could be calculated using Eq. (2) as follows:

$$EE=QE\times EEE \quad (2)$$

where EE is electrical energy in MJ per unit, QE is electricity consumption in kWh for lighting, electric fans, and electric motors, and EEE is the energy equivalent of electricity in MJ. Machinery energy (EM)- Machinery energy, includes the energy of all equipment used at dairy-based IFS farms such as electric fans, electric motors, and chaff cutters. Machinery energy could be estimated using Eq. (3) as follows:

$$EM = (m \times EEM \times t)/T \quad (3)$$

where EM is machinery energy in MJ per unit, m is mass of machine (kg), EEM is energy equivalent of the machine in MJ, t is working hours of a machine (h), and T is the economic life of a machine in Hours (h).

Feed Energy (EF)- Feed used at the dairy farm is generally expressed in terms of metabolisable energy: sorghum, millet, wheat straw, cotton seed cake and minerals in concentrate form. Feedstock energy could be calculated using Eq. (4) as follows:

$$EF = QF \times EEF \quad (4)$$

where EF represents feed energy in MJ per unit, QF is feed consumption in kg per animal, and EEF is the energy equivalent of feed in MJ.

Estimation of Energy Output

We used milk and dung production per animal as the energy output for domestic animal farms. The meat was not included in the output parameters, because domestic buffaloes were mainly kept for producing milk. Therefore, we only allocated energy inputs to milk production. The energy of milk production is estimated by multiplying the quantity of milk produced with the energy equivalent of milk (4% fat corrected milk) (Table 3).

The grain and straw yields of wheat and rice crops and their energy equivalent were converted in terms of energy (MJ/ ha) using corresponding Energy Equivalent (EE) given in Table 3.

The output energy of a crop is the sum of the total energy equivalent of grain and energy equivalent of straw yields

Output energy (MJ/ha) = [Grain yield (kg/ha) X EE of grain (MJ/kg)] + [Straw yield (kg/ha) X EE of straw (MJ/ kg)]

The output energy of the cropping system is the sum of the output energy of maize, wheat and paddy etc. An accounting approach is used to analyse some basic measures of input-output energy relation like net energy return, energy ratio and energy productivity [17,18 ,19]

Energy use indices based on energy equivalents of inputs and output (Table 2 and 3), the energy use indices such as Energy Use Efficiency (EUE), Net Energy (NE), Net Energy Gain (NEG), Energy Productivity (EP), Direct Energy (DE), Indirect Energy (IDR), Renewable Energy (RE), Non-Renewable Energy (NRE), Specific Energy (SE) and Energy Return On Investment (EROI) were calculated as follows:

Descriptive Analysis

The collected data were tabulated on master sheets in MS excel containing the pooled scores were prepared for respective categories of farming system and subjected to appropriate descriptive statistical analysis.

RESULTS AND DISCUSSION

Energy Budgeting of Whole System

Source-Wise Energy Use Patterns: Source-wise energy use pattern of food crops, fodder crops, dairy and subsidiary components at on-station and farmer's field are presented in Table 8. It showed that in food crops, fertilizers (4743.71 MJ ha-1, 36.26%) followed by electricity (4140.75 MJ ha-1, 31.65%) and diesel (2319.33 MJ ha-1, 17.73%) were the most energy intensive source among all the energy sources at on-station as well as farmer's field (6739.89 MJ ha-1, 35.05%, 5339.87 MJ ha-1, 27.77%, 4955.28 MJ ha-1, 25.77%) respectively. However, fodder crops energy use consumption pattern was like fertilizers (4279.05 MJ ha-1, 35.00 %), electricity (3356.63 MJ ha-1, 27.45 %) and diesel (2037.78 MJ ha-1, 16.67%) in on-station. Whereas, source-wise energy use pattern was almost similar except electricity (8365.79 MJ ha-1, 38.02%) in fodder crops at farmer's field consumed higher proportion. The energy balance of rice and wheat production were found 46.33 GJ/hm2 (hill) to59.29 GJ/hm2 (terai) and 27.14 GJ/hm2 (terai) to 38.52 GJ/hm2 (hill), respectively, where energy use efficiency in terai and hills were found to be 7.14 and 4.97 in rice, and 3.49 and 5.59 in wheat, respectively. The contribution of fertilizer on impacts was significant among other energy inputs in rice and wheat production in both geographical regions [36] Results revealed that source-wise energy use pattern of dairy unit at on-station indicated that feeds (233260.61MJ per year/6 cows, 3 buffaloes, 10 goats) were followed by electricity (8768.55 MJ per year/3 cows,3 buffaloes,10 goats), whereas, in case of farmer's field source-wise energy use pattern in dairy feeds (215629.56 MJ per year/3 cows and 3 buffaloes) were followed by electricity (7506.12 MJ per year/3 cows and 3 buffaloes) respectively. In dairy component these were the most energy intensive source among all the energy input sources. Results showed that source-wise energy use pattern of subsidiary components at on-station feeds/seeds (2992.53 MJ) were followed by electricity (1049.84 MJ) and labour (627.20 MJ) respectively. These were observed the most energy intensive source among all the energy source inputs in subsidiary component For whole IFS system of the source-wise energy use pattern in food crops at on-station was in the order: -fertilizers (4743.71 MJ ha-1, 36.26%)> electricity (3356.63 MJ ha-1, 27.45%) >diesel (2319.33 ha-1, 17.73%)>seed (4743.71 MJ ha-1, 5.34%)> labour (627.20 MJ ha-1, 4.79%) >machinery (4.24 MJ ha-1, 4.24%). Source-wise energy use pattern in food crops at farmer's field was in the order: -fertilizers (6739.89 MJ ha-1, 35.05%)>electricity (5339.87 MJ ha-1, 27.77%)>diesel (4955.28 MJ ha-1, 25.77 %) >machinery (769.38 MJ ha-1, 4.00%)>seed (735.00

MJ ha-1, 3.82%)>labour (689.92 MJ ha-1, 3.59%). The overall source-wise energy use pattern in fodder crops at on-station was in the order: -fertilizers (4279.05 MJ ha-1, 35.00%)> electricity (3356.63 MJ ha-1, 27.45 %) >diesel (2037.78 MJ ha-1, 16.67%)>labour (1309.28 MJ ha-1, 10.71%)>machinery (896.30 MJ ha-1, 7.33%)>seed (348.40 MJ ha-1, 2.85%). Source-wise energy use pattern in fodder crops at farmer's field was in order: -fertilizers (6951.88 M ha-1, 31.59%)>electricity (8365.79 MJ ha-1, 38.02%)>diesel (3589.76 MJ ha-1, 16.31%)>labour (1034 MJ ha-1, 4.70 %)> machinery (1031.83 MJ ha-1, 4.69%)>seed (1029.00 MJ ha-1, 4.68%). The overall source-wise energy use pattern in dairy component at on-station was in the order: -feeds (233260.61MJ year-1, 94.44%)> electricity (8768.55 MJ year-1, 3.55 %) > labour (4860.80 MJ year-1, 1.97%) >machinery (102.98 MJ year-1, 0.04%). Source-wise energy use pattern in dairy component at farmer's field was in the order: -feeds (215629.56 MJ year-1, 94.74%)>electricity (7506.12 MJ year-1, 3.30 %) >labour (4390.40 MJ year-1, 1.93%)> machinery (68.66 MJ year-1, 0.03%).The overall source-wise energy use pattern in subsidiary component at on-station was in the order: -feeds/seeds (2992.53 MJ, 58.46%)>electricity (1049.84 MJ, 20.51%) >labour (627.20 MJ, 12.25%)>chicks (205.20 MJ, 4.01%)>machinery (117.56 MJ, 2.30%).

Direct and Indirect Energy

Results showed that food crops consumed higher amount of direct energy (7087.27 MJ ha-1 and 54.16%) over indirect energy (5996.73 MJ ha-1 and 45.84%) at on-station. Likewise, at farmer's field also these consumed higher amount of direct energy (10985.07 MJ ha-1 and 57.13%) over the indirect energy (8244.27 MJ ha-1 and 42.87%) (Table 4.39). However, the comparison between farmer's field and on-station showed maximum amount of direct energy at farmer's field as compared to on-station (10985.07 MJ ha-1 v/s 7087.27 MJ ha-1 respectively). In case of indirect energy also higher amount was used in food crops at farmer's field as compared to on-station (8244.27 MJ ha-1 v/s 5996.73 MJ ha-1, respectively). Results indicated that fodder crops consumed higher amount of direct energy (6703.68 MJ ha-1 and 54.82 %) over indirect energy (5523.75 MJ ha-1 and 45.18 %) at on-station. Likewise, higher amount of direct energy (12990.44MJ ha-1 and 59.04 %) was consumed over the indirect energy (9012.71 MJ ha-1 and 40.96 %) at farmer's field (Table 9). However, the comparison between farmer's field and on-station showed maximum amount of direct energy at farmer's field as compared to on-station (12990.44 MJ ha-1vs. 6703.68 MJ ha-1 respectively). In case of indirect energy also, higher amount was used in fodder crops at farmer's field as compared to on-station (9012.71 MJ ha-1vs. 5523.75 MJ ha-1, respectively). Further, results revealed that dairy consumed higher amount of indirect energy (233363.59 MJ year-1 and 94.48 %) over direct energy (13629.35 MJ year-1 and 5.52%) at on- station. Likewise, higher amount of indirect energy (215698.22 MJ year-1 and 57.13%) over the direct energy (11896.52 MJ year-1 and 5.23%) was used at farmer's field (Table 4.39). However, the comparison between farmer's field and on-station showed use of maximum amount of indirect energy at on-station as compared to farmer's field (233363.59 year-1vs. 215698.22 MJ year-1 respectively). In case of direct energy also, higher amount was used in dairy at on-station as compared to farmer's field (13629.35 MJ year-1vs. 11896.52 MJ year-1, respectively). Subsidiary components consumed higher amount of indirect energy (3324.22 MJ year-1 and 65.00%) over direct energy (1794.60MJ year-1 and 35.00%) at on-station.

The present observations were similar to the findings of Palsaniya et al., [37] They observed higher energy efficiency, net energy gain and energy profitability in groundnut– wheat cropping system. However, the share of indirect energy (71%) and renewable energy (67%) was more in IFS making it more self-reliant and sustainable.

Table 4: Enterprises-wise energy budgeting of dairy-based IFS at on-station.

Particulars	Food	Fodder	Dairy	Subsidiary	Total
Yield (kg)	3987.50	14005.62	16917.10	3016.06	37926.28
Input (MJ/unit)	13084.01	12227.43	246992.94	5126.84	277431.23
Output (MJ/unit)	107660.00	252101.20	89351.32	29487.23	478599.75
Net energy (MJ)	94575.99	239873.76	-157641.63	24360.39	201168.52
EUE	8.23	20.62	0.36	5.75	1.73
E Profitability	7.23	19.62	-0.64	4.75	0.73
E Productivity	0.30	1.15	0.07	5.75	0.14
Specific Energy	3.28	0.87	14.60	0.17	7.32
Direct (MJ)	7087.27	6703.68	13629.35	1794.60	29214.91
Indirect (MJ)	5996.73	5523.75	233363.59	3324.22	248208.30
Renewable (MJ)	1325.45	2485.18	238121.41	3951.42	245883.46
Non-renewable (MJ)	11758.56	9742.25	8871.53	1167.40	31539.75
Human Energy Prof. (MJ h^{-1})	171.65	192.55	18.38	47.01	64.46

Renewable and Non-Renewable Energy

Results showed that food crops consumed higher amount of non-renewable energy (11758.56 MJ ha-1 and 89.86%) over renewable energy (1325.45 MJ ha-1 and 10.14%) at on-station. Likewise, farmer's field consumed higher amount of non-renewable energy (17804.42 MJ ha-1 and 92.59 %) over the renewable energy (1424.92 MJ ha-1 and 7.41%) **(**Table 4.39**).** However, the comparison between farmer's field and on-station showed consumption of maximum amount of non-renewable energy at farmer's field as compared to on-station (17804.42 MJ ha-1 v/s

11758.56 MJ ha-1 respectively). In case of renewable energy also, its higher amount was used in food crops at farmer's field as compared to on-station (1424.92 MJ ha-1 v/s 1325.45 MJ ha-1, respectively). Results indicated that fodder crops consumed higher amount of non-renewable energy (9742.25 MJ ha-1 and 79.68 %) over renewable energy (2485.18 MJ ha-1 and 20.32 %) at on-station. Likewise, at farmer's field consumed higher amount of non-renewable energy (19939.26 MJ ha-1 and 90.63 %) over the renewable energy (2063.88 MJ ha-1 and 9.37 %) (Table 4.39). However, the comparison between farmer's field and on-station showed use of maximum amount of non-renewable energy at farmer's field as compared to on-station (19939.26 MJ ha-1 v/s 9742.25 MJ ha-1 respectively). In case of renewable energy also, its higher amount was used in fodder crops at on-station as compared to farmer's field (2485.18 MJ ha-1 v/s 2063.88 MJ ha-1, respectively). In case of dairy animals, higher amount of renewable energy (238121.41 MJ year-1 and 96.40 %) over non-renewable energy (8871.53 MJ year-1 and 3.60%) was consumed at on-station. Similarly at farmer's field, higher amount of renewable energy (220019.96 MJ year-1 and 96.67%) was consumed over the non-renewable energy (7574.77 MJ year-1 and 3.33 %) (Table 9). However, the comparison between farmer's field and on-station showed use of maximum amount of renewable energy at on-station as compared to farmer's field (238121.41 MJyear-1 v/s 220019.96 MJ year-1 respectively). In case of non-renewable energy also higher amount was used in dairy at on-station as compared to farmer's field (8871.53MJ year-1 v/s 7574.77MJ year-1, respectively). Subsidiary components consumed higher amount of renewable energy (3951.42 MJ year-1 and 77.07%) over non-renewable energy (1167.40MJ year-1 and 22.93%) at on-station. Paramesh et al., [38] estimated share of direct and indirect energy inputs to the total energy input of mixed farming system to be 14% and 86%, respectively, whereas renewable and non-renewable energy inputs, were recorded as 19% and 81%, respectively. They highlighted the importance of conservation of tillage practices, organic farming, improved irrigation technology, and judicious use of non-renewable inputs to enhance the energy use efficiency of the mixed farming system model [38]

Energy Input-Output Relationship

The total energy input consumption of food crops cultivation was higher at farmer's field (19229.34 MJ ha-1) as compared with on-station (13084.01 MJ ha-1) (Table 4 and 5). In case of farmer's field higher amount of output energy was observed (128938.00 MJ ha-1) than at on-station (107660.00 MJ ha-1). The net energy was also higher at farmer's field (109708.66 MJ ha-1) as compared to on-station (94575.99 MJ ha-1). Further comparison between farmer's field and on-station showed that total energy input, energy output and net energy of food crops at on-station and farmer's field varied from 13084.01, 107660.00 and 94575.99 MJ ha-1, respectively at on-station to as high as 19229.34, 128938.00 and 109708.66 ha-1, respectively with farmer's field.

In fodder crops, total energy input was higher at farmer's field (22003.14MJ ha-1) as compared with on-station (12227.43MJ ha-1) (Table 4.34 and 4.36). In case of farmer's field, higher amount of output energy was observed (309898.62 MJ ha-1) whereas on-station recorded lower output (252101.20 MJ ha-1). The net energy was also higher at farmer's field (287895.48 MJ ha-1) as compared to on-station (239873.76 MJ ha-1).

Further comparison between farmer's field and on-station showed that total energy input, energy output

Table 5: Energy budgeting of system at farmer's field (2020-21).

Particulars	Food	Fodder	Dairy	Total
Production (kg)	4165.00	17216.59	16439.59	37821.18
Input (MJ/unit)	19229.34	22003.14	227594.73	268827.22
Output (MJ/unit)	128938.00	309898.62	89752.70	528589.32
Net energy (MJ)	109708.66	287895.48	-137842.04	259762.10
EUE	6.71	14.08	0.39	1.97
E Profitability	5.71	13.08	-0.61	0.97
E Productivity	0.22	0.78	0.07	0.14
Specific Energy	4.62	1.28	13.84	7.11
Direct (MJ)	10985.07	12990.44	11896.52	35872.02
Indirect (MJ)	8244.27	9012.71	215698.22	232955.20
Renewable (MJ)	1424.92	2063.88	220019.96	223508.76
Non-renewable (MJ)	17804.42	19939.26	7574.77	45318.46
Human Energy Prof. (MJ h^{-1})	186.89	299.45	20.44	85.89

Table 6: Source-wise consumption of energy (MJ) inputs in enterprises-wise at on-station (2019-21).

Particulars	Food	Fodder	Dairy	Subsidiary	Total
Machinery	554.78	896.30	102.98	117.56	1671.62
Diesel	2319.33	2037.78	0.00	0.00	4357.10
Labour	627.20	1309.28	4860.80	627.20	7424.48
Seeds/feeds/ chicks	698.25	348.40	233260.61	3197.73	237504.99
Fertilizer	4743.71	4279.05	0.00	0.00	9022.76
Electricity	4140.75	3356.63	8768.55	1049.84	17315.76

Table 7: Source-wise consumption of energy inputs (MJ) in system at farmer's field (2020-21).

Particulars	Food	Fodder	Dairy	Total
Machinery	769.38	1031.83	68.66	1869.86
Diesel	4955.28	3589.76	-	8545.04
Labour	689.92	1034.88	4390.40	6154.40
Seeds/feeds	735.00	1029.00	215629.56	217354.36
Fertilizer	6739.89	6951.88	-	13691.78
Electricity	5339.87	8365.79	7506.12	21211.78
Total	19229.34	22003.14	227594.73	268827.22

Table 8: Percentage share of source-wise in total inputs in systems at on-station and farmer's field.

Particulars	Food	% Share in Inputs	Fodder	% Share in Inputs	Dairy	% Share in Inputs	Subsidiary	% Share in Inputs	Total
On-station									
Machinery	554.78	4.24	896.30	7.33	102.98	0.04	117.56	2.30	1671.62
Diesel	2319.33	17.73	2037.78	16.67	0.00	0.00	0.00	0.00	4357.10
Labour	627.20	4.79	1309.28	10.71	4860.80	1.97	627.20	12.25	7424.48
Seeds/feeds/Chicks	698.25	5.34	348.40	2.85	233260.61	94.44	3197.73	62.47	237504.99
Fertilizer	4743.71	36.26	4279.05	35.00	0.00	0.00	0.00	0.00	9022.76
Electricity	4140.75	31.65	3356.63	27.45	8768.55	3.55	1049.84	20.51	17315.76
Total	13084.01		12227.43		246992.94		5118.82		277296.72
Farmer's field									
Machinery	769.38	4.00	1031.83	4.69	68.66	0.03			1869.86
Diesel	4955.28	25.77	3589.76	16.31	-	0.00			8545.04
Labour	689.92	3.59	1034.88	4.70	215629.56	94.74			6154.40
Seeds/feeds	735.00	3.82	1029.00	4.68	4390.40	1.93	-	-	217354.36
Fertilizer	6739.89	35.05	6951.88	31.59	-	0.00			13691.78
Electricity	5339.87	27.77	8365.79	38.02	7506.12	3.30			21211.78
Total	19229.34		22003.14		227594.73				268827.22

Table 9: Percentage share of direct/indirect and renewable/non-renewable energy sources in total inputs in IFS system at on-station and farmer's field.

Particulars	Food	% Share in Inputs	Fodder	% Share in Inputs	Dairy	% Share in Inputs	Subsidiary	% Share in Inputs	Total	% Share in Inputs
On-station										
Input (MJ/unit)	13084.01	-	12227.43	-	246992.94	-	5126.84	-	277431.23	-
Direct (MJ)	7087.27	54.16	6703.68	54.82	13629.35	5.52	1794.60	35.00	29214.91	10.53
Indirect (MJ)	5996.73	45.84	5523.75	45.18	233363.59	94.48	3324.22	65.00	248208.30	89.47
Renewable (MJ)	1325.45	10.14	2485.18	20.32	238121.41	96.40	3951.42	77.07	245883.46	88.62
Non-renewable (MJ)	11758.56	89.86	9742.25	79.68	8871.53	3.60	1167.40	22.93	31539.75	11.38
Farmer's field										
Input (MJ/unit)	19229.34	-	22003.14	-	227594.73	-			268827.22	-
Direct (MJ)	10985.07	57.13	12990.44	59.04	11896.52	5.23			35872.02	13.34
Indirect (MJ)	8244.27	42.87	9012.71	40.96	215698.22	94.77	-	-	232955.20	86.66
Renewable (MJ)	1424.92	7.41	2063.88	9.37	220019.96	96.67			223508.76	83.72
Non-renewable (MJ)	17804.42	92.59	19939.26	90.63	7574.77	3.33			45318.46	16.28

and net energy of fodder crops at on-station and farmer's field varied from 12227.43, 252101.20 and 239873.76 MJ ha-1, respectively at on-station to as high as 22003.14, 309898.62 and 287895.48 MJ ha-1, respectively with farmer's field.

Total energy input consumption in dairy components was higher at on-station (246992.94 MJ year-1) as compared with farmer's field (227594.73 MJ year-1) (Table 4.34 and 4.36). In case of farmer's field higher amount of output energy was observed (89752.70 MJ year-1) than at on-station (89351.32 MJ year-1). The net energy was also higher at farmer's field (-137842.04 MJ year-1) as compared to on-station (-157641.63 MJ year-1).

Further comparison between farmer's field and on-station showed that energy output and net energy of fodder crops at on-station and farmer's field varied from 89351.32 MJ year-1and -157641.63 MJ year-1, respectively at on-station to as high as 89752.70 MJ year-1and - 137842.04 MJ year-1, respectively with farmer's field. Whereas, higher amount of the total energy input was used at on-station and varied from (227594.73 MJ year-1) to as high as (246992.94 MJ year-1) with farmer's field. Total energy input consumption in subsidiary components at on-station was 5126.84 MJ year-1and amount of output energy was obtained 29487.23 MJ year-1with net energy as 24360.39 MJ year-1during experiment was recorded as an additional benefit gained by farms outputs.

Energy Indices

The various energy efficiency indices such as energy use efficiency, energy profitability and specific energy of food crops, fodder crops, dairy and subsidiary enterprises at on-station and farmer's field have been presented in Table 4 and Table 5. For food crops at on-station and farmer's field energy use efficiency (8.23 vs. 6.71), energy profitability (7.23 vs. 5.71) energy productivity (0.30 v/s 0.22) and specific energy (3.28 vs. 4.62) respectively were observed. Human energy profitability was found higher in food crops at farmer's field (186.89 MJ h-1) followed byon-station (171.65 MJ h-1). For fodder crops higher energy use efficiency, energy profitability, energy productivity and specific energy were recorded at on-station as compared to farmer's field (20.62 vs. 14.08), (19.62 vs. 13.08), (1.15 vs. 0.78) and (0.87 vs. 1.28) respectively. Human energy profitability was found higher in fodder crops at farmer's field (299.45 MJ h-1) as compared to on-station (192.55 MJ h-1). In dairy components at on-station and farmer's field, energy use efficiency (0.36 vs. 0.39), energy profitability (-0.64 vs. -0.61) energy productivity (0.07 vs. 0.07) and specific energy (14.60 vs. 13.84) were observed. Human energy profitability was found higher in dairy components at farmer's field (20.44 MJ h-1) as compared to on-station was observed (18.38 MJ h-1). The energy use efficiency, energy profitability and specific energy for subsidiary enterprises was 5.75, 4.75 and0.17, respectively. Higher human energy profitability was recorded (47.01 MJ h-1) in subsidiary components at on-station. Liu et al. [39] reported that co-culture of rice-turtle-fish was energy efficient as compared to rice monoculture. Paramesh et al. [40] also observed higher energy efficiency with poultry system followed by dairy; this was mainly due to lower energy consumption. Fishery recorded lower energy efficiency, among all the systems. The higher energy efficiency in the dairy system was mainly due to the efficient recycling of green fodder and azolla as animal feed. Results indicated that dairy based farming system both at on station and farmers field were energy efficient, conserves energy and energy profitable. However, the farmers system was better as compared to on-station. Kumar et al [41], reported an energy efficiency of 2.27 in crop-livestock- poultry system. A similar study in prawn-fish-rice system reported an energy efficiency of 1.72 with a net energy balance of 18,510 MJ ha-1 [32]

CONCLUSIONS

Therefore, it can be concluded that dairy based farming system both at on station and farmer's field were energy efficient, conserves energy and energy profitable. However, the farmers system was better as compared to on-station.

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