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Energy Auditing of Pearl Millet Productionin Southern Haryana, India: A Case Study

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ABSTRACT

The aim of this study was to analyze the energy input and output for pearl millet production in rainfed area of south-west Haryana was selected as rainfed area for studying energy consumption pattern. Three category of farmers (marginal, small and medium) were selected on the basis of land holdings. The data were collected through a questionnaire by face to face interviews. The amount of energy consumed in preparatory tillage, sowing, interculture, fertilizer, irrigation, pesticide, harvesting, threshing and transportation were calculated for pearl millet cultivation. Results showed that the energy input of the fertilizers had the highest share (43.51%) in the total energy inputs followed by the diesel fuel (29.11%). The average energy output-input ratio, specific energy and energy productivity were computed as 5.23, 3.16 MJ/kg and 0.39 kg/MJ, respectively. The source-wise energy inputs in human, animal, machinery, fuel/diesel, fertilizer, pesticide and seed energy were taken into consideration to determine the amount of energy that was used in pearl millet production. The share of each source of energy varied with category of farmer. Total energy consumption for pearl millet production of marginal, small and medium were found to be 4689.11 MJ/ha, 4933.11 MJ/ha and 6128.95 MJ/ha, respectively. Among the total energy, fertilizer was found to be the major source of energy consumption followed by diesel, human, pesticide, seed and machinery, respectively. It was found after the study that there is lot of scope of energy conservation in pearl millet production.

Keywords Energy input, Energy output, Energy ratio, Specific energy, Energy productivity.

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INTRODUCTION

Energy has a key role in economic and social development but there is a general lack of rural energy development policies that focus on agriculture. Agriculture has a dual role as user and supplier of energy. This energy function of agriculture offers important rural development opportunities as well as climate change mitigation by substituting bio-energy for fossil fuels (FAO 2000). However, energy is one of the most valuable inputs in agricultural production. It is consumed in various forms such as mechanical (farm machines, human power and animal draft), chemical fertilizer (pesticides and fertilizer) and electrical. The amount of energy used in agricultural production, processing and distribution needs to be adequate in order to feed the rising population and to meet other social and economic goals. Sufficiency of energy and its effective and efficient use are prerequisites for improved agricultural production. It was realized that crop yields and food supplies are directly linked to energy (Stout 1990). In developed countries, rise in crop yields were mainly attributed to rise in use of improved commercial energy inputs in addition to improved crop varieties (Faidly 1992).

Pearl millet (*Pennisetum glaucum* (L.) R.Br.) is the world's hardiest warm season coarse cereal crop. It can grow even on highly saline soils in the driest regions and in the hottest climates. India is the largest single producer of pearl millet, both in terms of area (9.3 million hectares) and production (8.3 million tons). Pearl millet is an important coarse cereal crop in western India and occupies about 38% of the total cereal cropped area in the region. About 6.5 million ha of cropped area is under pearl millet in western India with 5.5 million tons production with an average yield of 852 kg/ha of grain and 2.5 t/ha of stover yield in Triennium Ending (TE) 2008. Given substantial economic importance of pearl millet as a mainstay for small and marginal farmers in this region, the paper tries to examine demand and supply balance of pearl millet grain and fodder by 2020 in western India comprising Rajasthan, Gujarat and Haryana. The information on different uses of pearl millet grain and on demand and supply balance of grain and fodder would be useful to crop scientists to target their research effort for the region (Reddy *et al.* 2013). Pearl millet is also known as Bajra one of the major kharif food crop of arid and semi-arid cropping region of India. It ranks first under the category of millet in India in terms of area, production and productivity (Kargwal *et al*. 2019). It is sown in the first fortnight of July after first monsoon shower in rainfed areas and harvested in the month of September. Though pearl millet is grown mainly for human consumption, it also serves as fodder for cattle and raw material for cattle feed industries.

The main aim of studying energy use pattern in pearl millet crop production system is efficient use of available natural resources, proper energy management/conservation and minimization of energy losses

Table 1. Energy equivalents of various sources (Muazu *et al.* 2 015, Karimi *et al*. 2008).

Energy source Human labor		Units	Energy equivalent (MJ/unit)
	Man	1h	1.96
	Woman	1h	1.75
	Child	1h	0.98
Animal			
	Bullock	Pair hour	14.07 (if body weight more than 450) 10.10 (if body weight 350-450)
Fuel			
	Diesel	1L	56.31
	Farm yard manure	1kg	0.3
Fertilizer			
	Nitrogen	1kg	60.6
	Phosphorus	1kg	11.1
	Potash	1kg	6.70
Chemical application			
	Superior	1kg	120
	Inferior	1kg	10.0
Seed		1kg	14.7

Table 2. Energy equivalents of farm equipments (Mittal *et al.* 1988).

Energy source	Equipment	Energy coefficient
Manual	Sickle	0.031
	Sprayer	0.502
	Hand hoe	0.314
	Bund former	0.502
Animal	Plough	0.627
	Cultivator	1.881
Tractor	M B Plough	2.508
	Harrow	7.336
	Rotavator	3.762
	Seed- drill	8.653
	Cultivator	3.135
	Leveler	4.703
Others	Thresher	7.524
	Centrifugal pump	0.502
	Electric motor	0.216
	Tractor	10.944

during different unit operations of pearl millet production. Pearl millet is basically grown in rainfed area such as Mahendergarh, Bhiwani, Hisar, Jhajar and Fatehabad are the top pearl millet producing district of Haryana. So Mahendergarh Districts were selected for carrying out the present study in rainfed region.

MATERIALS AND METHODS

A brief description of study area, methodology adopted for data collection and the procedure used for data analysis is showed as below.

Selection of work area

The following locations were selected for studying the energy analysis in the pearl millet production. Mahendergarh District was selected as a rainfed region.

Selection of the farmers

The farmers were categorized in three groups such as marginal (0.5<1ha), Small (1<2 ha) and medium (3<7.5 ha) farmers on the basis of land holdings (Agricultural census 2018).The farmers were grouped into three categories viz. marginal, small and medium-farmers on the basis of land holdings. Different unit operations for pearl millet production were studied in terms of energy use pattern at selected villages.

Collection of pearl millet production data

Questionnaire was prepared for collecting data in a face to face interview schedule from farmers regarding different operations Preparatory tillage, Pre-sowing and post-sowing irrigation, Seed treatment prior to sowing, Sowing, Fertilizer Application, Interculture, Pesticides Application, Harvesting, Threshing, Transportation and quantity of each input (i.e. machinery, fuel, fertilizer, pesticide, irrigation water, labor). Energy used in the production of pearl millet was calculated using energy analysis technique.

Analysistools

Source-wise (Direct and Indirect) and operation -wise energy use pattern for pearl millet production was analyzed in selected region. Direct energy sources of energy subsumed human, animal and diesel energy. Indirect energy sources included fertilizer, pesticide, seed and machinery.

Various unit operations such as preparatory

Table 3. Useful life of machinery and implements (source: IS: 9164-1979).

Machine/ Implements	Useful life/ Salvage value
Sickle	100
Hand hoe	300
Bund former	1500
Animal drawn plough	1200
Animal drawn harrow	800
Plough	3000
Cultivator	4000
Harrow	2000
Rotavator	2400
Seed- drill	2500
Leveler	3000
Tractor	10000
Thresher	2500

tillage, sowing, interculture, irrigation, fertilizer application, pesticide application, harvesting, threshing and transportation were performed.

Tables 1 and 2 presents the values for the energy equivalent factor showed in equations (1) to (7) and were used in calculating the direct and indirect energy inputs (Muazu *et al.* 2015, Khambalkar *et al.* 2010, Chaudhary *et al.* 2009, Bockari-Gevao *et al.* 2005). The useful life/salvage values of machinery and implements given in Table 3.

$$HE = \frac{(H \times T \times HEf)}{A} \qquad (1)$$

Where HE is human energy (MJ/ha), H is the duration of operation number of humans, T is operating time (h), A is area, (ha) and HEf is human energy equivalent factor (MJ h^{-1}).

$$AE = \frac{(AN \times T \times AEf)}{A} \qquad (2)$$

Where AE is animal energy (MJ/ha), AN is the duration of operation number of animals, T is operating time (h), A is area, (ha) and AEf is animal energy equivalent factor (MJ h^{-1}).

$$FE = \frac{(Fcon \times FEf)}{A} \qquad (3)$$

Where FE is fuel energy (MJ/ha), Fcon is fuel consumed during operation, A is area, (ha) and FEf is animal energy equivalent factor (MJ h^{-1}).

$$SE = \frac{(Sq \times SEf)}{A} \qquad (4)$$

Where SE is seed energy (MJ/ha), Sq is weight of seed (kg), A is area (ha) and SEf is seed energy equivalent factor (MJ/kg).

$$PE = \frac{(Pq \times PEf)}{A} \qquad (5)$$

Where PE is pesticides energy (MJ/ha), Pq is weight of pesticides (kg), A is area (ha) and PEf is pesticides energy equivalent factor (MJ/kg).

$$FTE = \frac{(FTq \times \sum_{t-1}^{n} FTi \times FTci}{A} \qquad (6)$$

Where FTE is fertilizer energy (MJ/ha), FTq is weight of fertilizer used (kg), A is area (ha), FTi is percent composition of the ith element (decimal) and FTci is pesticides energy equivalent factor (MJ/kg).

$$ME = \frac{(W \times MEf)}{(FC \times L)} \qquad (7)$$

Where ME is machine energy (MJ/ha), W is weight of machine (kg), FC is the effective field capacity (ha/h), L is useful life of machine and MEf is machine energy equivalent factor (MJ/kg).

Indices of energy analysis

After collecting data regarding different unit operations in pearl millet cultivation calculations were made regarding energy use efficiency, energy productivity, energy ratio and net energy gain. These indices determined with the help of Equation (8) to (11) (Muazu *et al*. 2015,Yadav and Khandelwal 2013).

$$\text{Energy use efficiency} = \frac{(\text{Energy output (MJ ha}^{-1}))}{(\text{Energy input (MJ ha}^{-1}))} \qquad (8)$$

$$\text{Energy productivity (kg MJ}^{-1}) = \frac{\text{Grain yield (kg ha}^{-1})}{\text{Total energy input (MJ ha}^{-1})} \qquad (9)$$

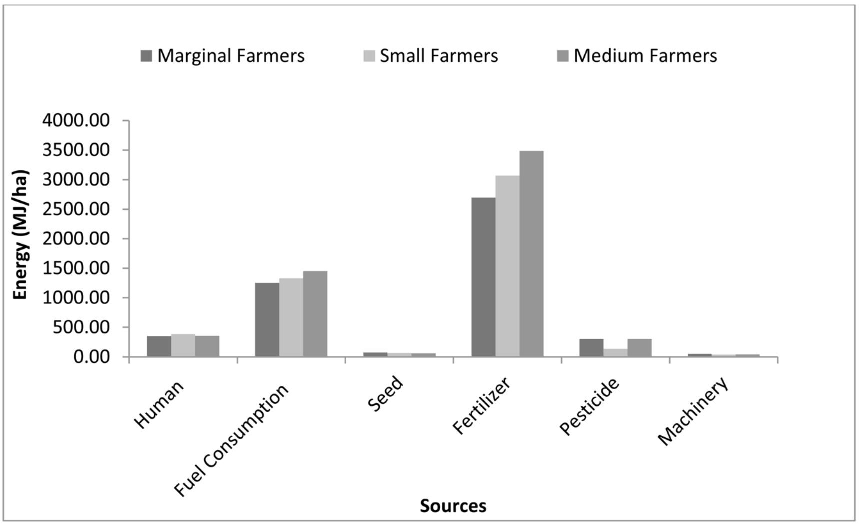

Fig. 1. Source-wise energy use pattern in pearl millet production.

$$\text{Net Energy Gain (MJ ha}^{-1}) = \text{Energy output (MJ ha}^{-1}) - \text{Energy input (MJ ha}^{-1}) \quad (10)$$

$$\text{Specific Energy (MJ ha}^{-1}) = \frac{\text{Energy input (MJ ha}^{-1})}{\text{Pearl Millet Yield (kg ha}^{-1})} \quad (11)$$

Cobb–Douglas function was used in the present study to develop a model in MS-EXCEL to examine the relationship between energy inputs and yield for pearl millet production. The developed model was validated for the pearl millet production data collected for the irrigated region of Haryana. The objective of production function was to analyze the efficiency of all operations which were used in production process such as preparatory tillage, sowing, interculture, harvesting, threshing.

The usual form of production function (Hamedani *et al.* 2011, Komleh *et al.*2011) is given below:

$$Y = aX_1^{b1}\, aX_2^{b2} \ldots\ldots .aX_n^{bn} .\ U \quad (12)$$

The function is easy to estimates in logarithmic form as:

$$\log Y = \log a + b_1 \log X_1 + b_2 \log X_2 + \ldots + b_n \log X_n .\ U \quad (13)$$

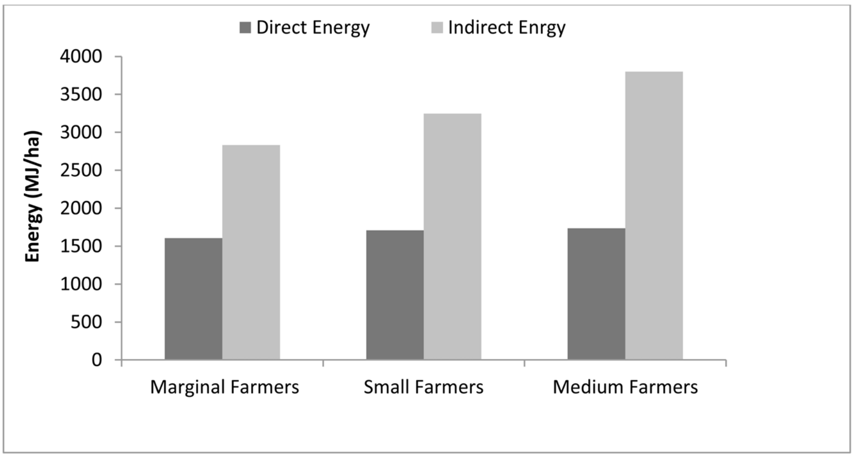

Fig. 2. Variation of direct and indirect energy.

Table 4. Operation-wise energy use pattern in pearl millet production.

Operations Farmers	Energy utilized by marginal farmers (MJ/ha)	Energy utilized bysmall farmers (MJ/ha)	Energy utilized by medium farmers (MJ/ha)
Preparatory tillage	725.63	718.49	837.44
Sowing	364.83	368.45	347.63
Interculture	110.33	108.86	613.75
Irrigation	0	0	0
Fertilizer application	2698.06	3070.54	3488.12
Pesticide application	315.00	109.96	310.80
Harvesting	193.12	217.35	168.40
Threshing	282.17	290.20	279.35
Transportation	0	50.00	84.46
Total energy (MJ/ha)	4689.11	4933.11	6128.95

Where,
Y = Dependent variable,
X_1, X_2, X_n = Independent variables,
b_1, b_2, b_n = Regression coefficient of independent variables,
U = Disturbance term,
a = Constant.

RESULTS

Source-wise energy use pattern

It can be seen from Fig. 1 that the largefarmersused more human energy as compared to marginal and small farmers so less time was needed to complete one operation, therefore, medium farmers (355.00 MJ ha^{-1}) consumed less human energy than small farmers (384.00 MJha^{-1}) because two operations of interculture and harvesting were totally done manually using human labor. So as the farm size increased number of labor was also increased for performing these operations. Animal energy was not used by any category of farmers in rainfed region. Diesel energy consumed by marginal, small and medium farmers were 1252.09 MJ ha^{-1}, 1330 MJ ha^{-1} and 1449.85 MJ ha^{-1}, respectively which showed that as the size of farm increased, use of machinery also increased. Maximum amount of seed energy was consumed by marginal farmers because marginal farmers used more amounts hybrid seeds of private company amounts of seed as compared to small and medium farmers. Almost all category of farmers used hybrid variety (PRO-AGRO, PIONEER) at the rate of 4.5-6 kg ha^{-1}, had yield of 30-45 q ha^{-1}. Among the total energy, fertilizer application was found to be the major source of energy for all category of farmers because all of them applied high dose of fertilizer (urea) at the rate of 150-170 kg ha^{-1}. Application of pesticide (Atrazine) was done by all farmers at the rate of 2.5 kg ha^{-1}.This is similar with research reported by (Kargwal *et al.* 2019,Ozturk 2016).

Table 5.Variation of Indices of energy usage efficiency for different category of farmers.

Area Farmers	Rainfed Marginal farmer	Small farmer	Medium farmer
Net energy gain (MJ/ha)	8687.89	25054.89	40910.05
Energy ratio	2.85	6.07	7.67
Specific energy(MJ/kg)	5.20	2.42	1.85
Energy productivity (kg/MJ)	0.19	0.41	0.57

Operation–wise energy use pattern in pearl millet production

Table 4 shows the operation wise energy consumption of marginal, small and medium farmers in rainfed area which were 4689.11MJ ha^{-1}, 4933.11MJ ha^{-1} and 6128.95 MJ ha^{-1}, respectively. The energy consumption depends on farm size and level of production activities.

Energy used by fertilizer was highest among all the operation in all category of farmers followed by preparatory tillage. This result is similar with the research conducted by (Hamedani 2011,Baran 2016). It was maximum in case of large farmers

Table 6. Operation-wise overall production function of pearl millet. *Significance at 10%, ***Significance at 1%, ns non-significance.

Variables		Irrigated region	t-value
Preparatory tillage	X_1	0.84	-0.85***
Sowing	X_2	0.94	1.09*
Interculture	X_3	0.44	0.48***
Irrigation	X_4	0.21	-0.15
Fertilizer application	X_5	-0.49	-0.54ns
Pesticide application	X_6	0.02	0.15
Harvesting	X_7	0.04	1.55
Return to scale	(∑bi)	2.98	
Constant		14.41	
R^2	0.98		

followed by small and marginal farmers. As the farm size increased fertilizer application also increased followed by preparatory tillage. Energy consumption in preparatory tillage was more in case of large farmers because as the size of land holding increased, fuel consumption and manual energy also increased. Sowing was found to be the third energy consuming operation in case of marginal and small farmers but fourth in medium farmers. Since medium farmers were low seed rate as compared to them. Interculture was found to be third largest energy consuming operation in case of medium farmers because they are using less number of labor and so more time was consumed in performing this operation. Pesticide application was not done by many of the small farmers so their energy use was low as compared to marginal and medium farmers. Energy consumption of large farmers is low as compared to small and marginal farmers because they used more number of labor which took less time to perform the operation. Harvesting is the higher energy consuming operation in case of small farmers in comparison of marginal and medium farmers because small farmers used less human labor and took more time. Transportation energy was nil for marginal farmers because they kept all the pearl millet for personal consumption while some of small and medium farmers sold the produce after storage for personal use. Energy consumed in threshing and harvesting was less in case of large farmers because they used efficient thresher and more number of labor so performed these operations in lesser time and thus energy consumed was less in both these operations.

Variation of direct and indirect energy sources

Fig.2 indicates that indirect form of energy was analyzed the major contributor of energy in total energy consumption as compared to direct energy due to the higher dose of fertilizer application. These results were similar to ones available in the literature (Hamedani 2011, Komleh 2011,Yadav and Khandelwal 2013).By all farmers, fertilizer applied was more than recommended dose which was wastage of energy because it did not result in increase of yield.

Variation of Indices of energy usage efficiency for different category of farmers

Table 5 shows energy use ratio for different category of farmers varied from 2.85-7.67. High energy use ratio of 6.07 and 6.67 were found in small and medium farmers which indicated efficient level of energy usage. The findings are similar with the results of (Sidhpuria *et al.* 2014) who conducted work on resource conservation practices in rainfed pearl millet. The lowest energy ratio of 2.85 was obtained for marginal farmers which indicated low level of energy output as compared to input. Energy productivity of different category of farmers was computed to be 0.21 kg/MJ, 0.65 kg/MJ and 0.92 kg/MJ. The values of small and medium farmers are similar to the findings of (Yadav and Khandelwal 2013) who reported for wheat production in MP, India.

The results presented in Table 6 indicate that 98% (R^2 = 0.98) of variation in gross return was explained by seven explanatory variables in all the category of farmers. It can also be seen that the sum of elasticities ($\sum bi$ = 2.98) was not deviating from unity significantly, indicating increasing return to scale. It showed that for pearl millet production, sowing had the highest impact (0.94) among other inputs. The elasticity for interculture is 0.94 implying that a given 1% change in human energy will result 0.80% increase in yield. The other important inputs were preparatory tillage, interculture, irrigation, harvesting and Pesticide Application with elasticities of 0.84, 0.44, 0.04 and 0.02, respectively.The sum of the regression coefficients of the energy inputs was calculated as 2.98. The sum of the regression coefficients implies that a 1% increase in the total energy inputs would lead to 2.98% increase in the pearl millet yield.

This indicated that the production function exhibited an increasing return to scale which implied that if all the inputs specified in the function were increased by 100%, then income would increase by about 98%. The results are similar to the findings of (Wongnaa and Ofori 2012, Akighir and Shabu 2011, Goni 2007) who had observed increasing return to scale on cashew production, tank command farming system and rice production, respectively in Ghana, India and Nigeria.

DISCUSSION

Source-wise energy use pattern in rainfed region

It can be seen from Fig. 1 that the medium farmers used more human energy as compared to marginal and small farmers so less time was needed to complete one operation, because two operations of interculture and harvesting were totally done manually using human labor. So as the farm size increased number of labor was also increased for performing these operations. Animal energy was not used by any category of farmers in rainfed region. Diesel energy consumed by small, medium and large farmers were 1252.09 MJ/ha, 1330 MJ/ha and 1449.85 MJ/ha, respectively which showed that as the size of farm increased, use of machinery also increased. Maximum amount of seed energy was consumed by marginal farmers because marginal farmers used more amounts hybrid seeds of private company amounts of seed as compared to small and medium farmers. Almost all category of farmers used hybrid variety (PRO-AGRO, PIONEER) at the rate of 4.5-6 kg/ha, had yield of 30-45 q/ha. Among the total energy, fertilizer application was found to be the major source of energy for all category of farmers because all of them applied high dose of fertilizer (urea) at the rate of 150-170 kg/ha. Application of pesticide (Atrazine) was done by all farmers at the rate of 2.5 kg/ha.This is similar with research reported by Ozturk (2016).

Operation–wise energy use pattern in rainfed region

Table 4 show the operation wise energy consumption of marginal, small and medium farmers in rainfed area. The energy consumption depends on farm size and level of production activities.

Energy used by fertilizer was highest among all the operation in all categories of farmers followed by preparatory tillage. It was maximum in case of medium farmers followed by small and small farmers. As the farm size increased fertilizer application also increased followed by preparatory tillage. Energy consumption in preparatory tillage was more in case of medium farmers because as the size of land holding increased, fuel consumption and manual energy also increased. Sowing was found to be the third energy consuming operation in case of marginal and small farmers but fourth in large farmers. Since large farmers were low seed rate as compared to them. Interculture was found to be third largest energy consuming operation in case of medium farmers because they are using less number of labor and so more time was consumed in performing this operation. Pesticide application was not done by many of the small farmers so their energy use was low as compared to marginal and medium farmers. Energy consumption of medium farmers is low as compared to marginal and small farmers because they used more number of labor which took less time to perform the operation. Harvesting is the higher energy consuming operation in case of small farmers as compared to marginal and medium farmers because small farmers used less human labor and took more time. Transportation energy was nil for marginal farmers because they kept all the pearl millet for personal consumption. Energy consumed in threshing and harvesting was less in case of medium farmers because they used efficient thresher and more number of labor so performed these operations in lesser time and thus energy consumed was less in both these operations.

CONCLUSION

The energy input of marginal,small and medium farmers were 4689.11, 4933.11and 6128.95, respectively. The energy output of marginal, small and medium farmers were observed to be 13377.00 MJ/ha, 29988.00MJ/ha and 47040.00 MJ/ha, respectively. The energy ratio was found to be 2.85, 6.07 and 6.67 of marginal, small and medium farmers, respectively. The energy productivity of farmers was obtained as 0.19 kg/ MJ (small), 0.41 kg/MJ (medium) and 0.57 kg/MJ (large). Manual energy increased with the size of land holding indicating the use of more number of labors by marginal farmers as compared to medium ones. This indicated that medium farmers used less labor for performing different operations which took more time and more energy. On the basis of source wise energy use pattern, fertilizer application was found to be the highest energy consuming source. Application of fertilizer increased with the size of land holding. Diesel fuel consumption increased with the size of land holdings. Fertilizer application was found to be the major energy consuming operation in case of all farmers followed by preparatory tillage. On the basis of source wise energy use pattern, fertilizer application was found to be the highest energy consuming source. Application of fertilizer increased with the size of land holding.

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