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Energy use pattern in wheat crop production system among different farmer groups of the Himalayan Tarai region

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This study examines the energy use pattern in wheat crop cultivation in the Himalayan Tarai region of India among different farmer groups. A total of 250 farmers from 59 villages were interviewed and information on various inputs in wheat crop production was collected during 2015–16. Based on the information, all the inputs in wheat crop production were identified and converted into energy using standard energy equivalents. Results showed that the total energy expenditure in wheat crop production in the region was 20497.1 MJ/ha in which fertilizer, fuel and seed shared 85% of the total energy. Fertilizer alone accounted for 50.2% of total energy followed by fuel (22.6%). It was estimated that farmers of the large and medium category used more energy compared to those having small landholding, but also produced more grains. Operation-wise, fertilizer application consumed maximum energy followed by tillage operation. The average value estimated for output-to-unit input energy ratio was 3.02, whereas it was 3.26, 3.15, 3.14, 3.11 and 2.95 for large, medium, semi-medium, small and marginal category farmers respectively. It can be concluded from the present study that energy consumption has a positive relationship with yield.

Keywords: Agriculture, energy use pattern, farmer groups, wheat crop.

MODERN-DAY agriculture crop production requires high input of fossil energy, which is consumed as ‘direct energy and indirect energy (energy expended beyond the farm for the manufacture of fertilizers, plant protection agents, machines, etc.)¹. Global food security demands an increase in agriculture production as total cultivable land is decreasing and the world population is increasing day by day². In general, various alternatives for increasing agricultural production can be characterized in the form of additional land use, increase in yield per unit area and increased cropping intensity. As it is not possible to increase cultivable land for agriculture production, the substantial change in production may be increased by increasing the use of input resources³. Production of wheat crop directly depends on high-yielding varieties,

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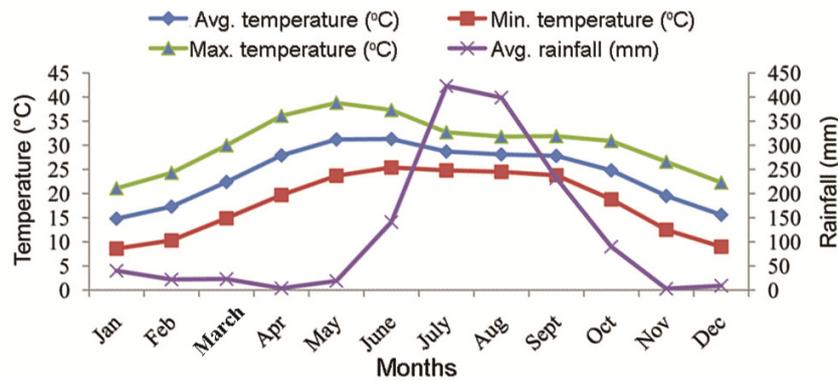


Figure 1. Average weather conditions of the Himalayan Tarai region.

agrochemicals, fertilizers, mechanization as well as on other energy inputs. Energy expenditure and crop yield in crop production vary with each input, influencing energy use efficiency⁴. The excessive use of inputs like fertilizers, water, fuel, agrochemicals, nutrients, electricity, etc. demands more energy in the form of human energy, animals and machinery^{5,6}. The commercial energy consumed in Indian farming rose by 11.8% between 1980 and 2000. Paddy and wheat make up about 75% of India's overall cereal production. The emergence of high-yielding varieties of paddy and wheat in the 1960s sparked a chain of agricultural developments that made it viable to increase food production by well over 50% (ref. 7). Most of these agricultural changes require additional crop inputs, in particular, fossil fuel, electricity, fertilizers, agrochemicals and commercial energy. The consumption of energy and natural resources has increased because farmers have little knowledge of using more energy-efficient methods⁸. Use of chemical fertilizers needs to be drastically reduced. It is now well established that inorganic nitrogen fertilizer production by combining nitrogen and hydrogen at high pressure has already upset the balance between nitrates accumulating on land and aquifers, and the atmospheric nitrogen. It is affecting the planet as a whole and is therefore a serious concern.

The energy expenditure in production agriculture to raise a particular crop varies because of agro-climatic location, crop production and management practices, farm power availability, mechanization status, consumption pattern of energy inputs in different forms and other agricultural inputs¹. In India, farmers are categorized as small, marginal, medium and large according to their land holding. Land-holding pattern also has significant effect on input energy use in the crop production system as management practices are different⁹.

Energy use pattern and energy efficiency for a particular crop vary with agro-climatic condition and mechanization status of agriculture³. Also, there is a need to study the effect of farm size on energy use pattern for crop production.

Therefore, this study was undertaken to examine the energy use of different farmer groups, which will be helpful to decide energy consumption of the region as a whole, identify the energy-intensive operations in wheat production system and provide pathways of reducing it.

The study was conducted in Udham Singh Nagar district of Uttarakhand and adjacent area of Uttar Pradesh located in the Tarai region. Figure 1 shows the average weather conditions of the growing season. Agro-ecologically, the region is classified as Zone 1: Western Himalayan Region. Tarai region in India is situated at the outer foothills of the Siwalik Hills and north of the Indo-Gangetic Plains. It starts from Chandigarh (foothills of the Himachal hills), and lies in Doon Valley, Bijnore, Udham Singh Nagar, Rampur, Pilibhit and Gonda districts. The Tarai belt is 15–25 km wide from north to south. In Uttarakhand, the Tarai region is bounded by 28°53' and 29°20' N lat., 78°53' and 80°0' E long., covering a total geographical area of 2908 sq. km. The common crop rotations followed are continuous rice–wheat, rice–wheat–rice, sugarcane–ratoon–wheat, rice–rapeseed–sugarcane–ratoon–wheat and rice–rice–peas¹⁰. This region is considered important for wheat crop due to its higher productivity of 5–5.5 tonnes ha⁻¹ compared to the Indian average of 3.0 tonnes/ha. Figure 2 shows demographic details of the study area.

The farmers were categorized into five groups according to their land holding (Table 1). A total of 250 farmers from 59 villages in different categories (50 from each category) were interviewed during *rabi* season of 2016. The information on various aspects of wheat crop production was collected by personal interviews with each selected farmer using a pre-designed questionnaire. The questionnaire was designed in such a way that it contained information about all unit operations in crop production as well as details about inventory of all resources. It included information on fertilizers, agrochemicals and farm yard manure (FYM), details of power sources (human and prime movers) and agricultural machinery as well as per hectare yield of wheat. Every crop input was

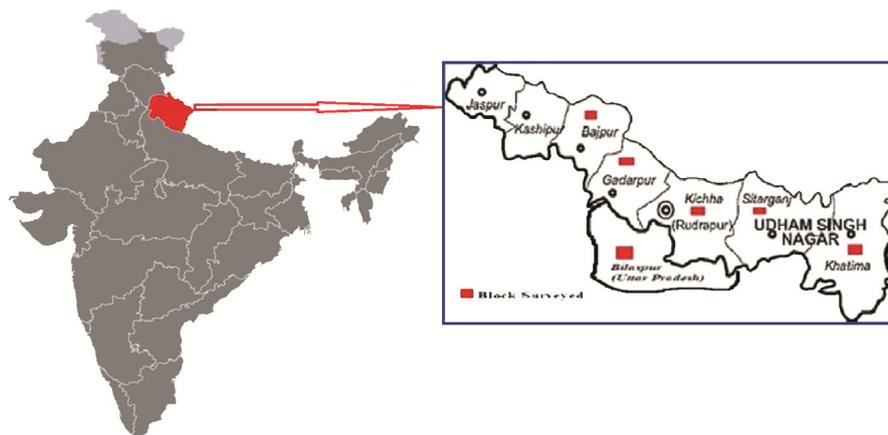


Figure 2. Map of Indian showing the study area.

Table 1. Land holding-wise category of farmers

Farmer category	Land holding (ha)
Large	More than 10
Medium	4–10
Semi-medium	2–4
Small	1–2
Marginal	0–1

Table 2. Energy coefficient for different energy inputs

Source	Energy equivalent (MJ)	Reference
Human (Man-hour)	1.96 1 adult women = 0.8 adult man	22
Animal (pair-hour)	10.10	22
Diesel (litre)	56.31	22
Electricity (kWh)	16.93	22
Seed (kg)	14.7	22
Farm yard manure (kg)	0.3	
Fertilizer		
Nitrogen (kg)	60.6	23
Phosphorus (kg)	11.1	23
Potash (kg)	6.7	23
Agrochemicals (kg)	120	23
Inferior chemicals machinery (kg)	100	23
Electric motors (kg)	64.80	22
Prime mover (kg)	68.40	22
Farm machinery (kg)	62.10	22

categorized into direct and indirect energy source. Direct energy sources are human energy, fuel energy and electricity, while the indirect energy sources include seeds of high-yielding varieties, fertilizers and chemicals used in the production process, FYM and energy invested to manufacture agricultural machineries. The indirect energy sources do not have their own energy, but some energy has been invested to produce these sources. In order to

estimate energy use in a particular unit operation, information on duration, amount and frequency of the unit operations and energy inputs was collected and quantified using the energy coefficient (Table 2).

The methodology adopted for the study was cradle to gate assessment, wherein some operations of the life cycle of the product such as transport and disposal of agro residue were not considered in the assessment. Therefore, the total energy expenditure assessed is that applied to the crop production system prior to the post-harvest process. The study assessed the energy inputs used in the production of wheat crop only for a season without taking into account the natural sources like annual rainfall, wind, sun radiation, etc.¹¹.

Human energy use was estimated by taking into consideration the time of labour-intensive activity and the total number of people engaged in that particular operation. The total human energy expenditure was assessed by multiplying the energy coefficient of the human power for unit man-hour by the total number of hours of human activity in the particular unit operation.

The main fuel input in wheat production was high-speed diesel (HSD), used in tractors and irrigation pump sets. In order to estimate reliable data on fuel consumption of tractors and pump sets as used by different categories of farmers, the following relationship was used¹².

$$F = \frac{LCF \times RHP \times SFC}{1000}, \quad (1)$$

where F is the time rate of consumption of fuel (l/h), LCF is the load coefficient factor (ratio of actual load on tractor to maximum load for an operation; Table 3), RHP is the rated horsepower of the source (kW) and SFC is the brake specific fuel consumption (ml/kWh).

The values of specific fuel consumption and rated horsepower of various tractors and combine harvesters used by farmers of the region were taken from the engine

Table 3. Load coefficient factor (LCF) for different unit operations

Power source	Type of work	LCF
Stationary diesel engine	Water-lifting	0.6
	Threshing, etc.	0.8
Tractor	Light work, e.g. transport, water-lifting etc.	0.4
	Medium work, e.g. secondary tillage, sowing intercultural operations, etc.	0.5
	Heavy work, e.g. primary tillage	0.6

test report of the respective tractor/combine harvester published by Central Farm Machinery Training and Testing Institute (CFMTTI) Budni, MP, India. Table 3 shows the values of load coefficient factor for various power sources¹².

Electricity was mainly used for pumping and irrigation. Electric motors of different ratings were found to be used by different categories of farmers for irrigation purpose. The electricity consumption by electric motor was estimated by the following relationship¹³.

$$E = \text{RHP} \times T, \quad (2)$$

where E is the total electricity expenditure (kWh), RHP the rated horsepower of the motor (kW) and T is the total time of irrigation (h).

The most commonly used fertilizers in India are urea, diammonium phosphate as well as super phosphate for providing nutrients like nitrogen (N), phosphate (P_2O_5) and potash (K_2O) respectively, to the plants. In this study the amount of fertilizers applied on wheat crop was recorded by farmers' observations and therefore total N, P and K contents were estimated. The total energy expenditure was estimated by N, P and K contents of the fertilizers by the respective energy equivalents.

Similarly, energy involved in the production, packaging and transportation of agrochemicals was examined. The methodology adopted in this study to examine the agrochemical energy expenditure was to assess the amount of herbicides, insecticides and fungicides that have been applied on the wheat farms. The total chemical energy expenditure was estimated by accumulating the energy coefficient of a particular agrochemical by the total amount of that particular agrochemical applied²⁰.

The energy expenditure to manufacture machineries such as tractors and other farm equipment was determined based on their weight, working lifespan and average annual working hours. In this study, the estimated life was used from IS:9164 (1979)²¹. The annual use of different machineries was estimated from the questionnaire, since it is the sum of total energy consumed to manufacture machineries for different unit operations for crop production. The machine energy was determined by the relationship¹¹.

$$\text{ME} = \frac{G \times E}{TC_{\text{ef}}}, \quad (3)$$

where ME is the machine energy (MJ/ha), G the total weight of the machinery (kg), E the total energy consumed in the production of agricultural equipment (MJ/kg), T the total life span of the machine (h) and C_{ef} is the actual field capacity of the machine (ha/h).

After energy input, energy output was calculated based on energy equivalents of the grain. The energy indices for wheat production such as energy use efficiency and energy productivity were calculated using the following equations^{14,15}

$$\begin{aligned} \text{Net energy} &= \text{Energy output (MJ ha}^{-1}) \\ &- \text{energy input (MJ ha}^{-1}), \end{aligned} \quad (4)$$

$$\begin{aligned} \text{Energy use efficiency} &= \text{Energy output (MJ ha}^{-1}) / \\ &\text{energy input (MJ ha}^{-1}), \end{aligned} \quad (5)$$

$$\begin{aligned} \text{Energy productivity} &= \text{Grain yield (kg ha}^{-1}) / \\ &\text{energy input (MJ ha}^{-1}). \end{aligned} \quad (6)$$

Table 4 presents the operation-wise energy consumption among different farmer groups. It includes tillage, sowing, fertilizer, interculture operation, spraying, irrigation, harvesting and threshing. Where machinery is concerned for any operation, large farmers spent much energy such as in tillage and seed-bed preparation. This is because the farmers believe that the higher number of tillage operations would prepare the field better for crop production in comparison to conservation tillage. Large number of farmers also applied higher amount of irrigation water as well as chemicals. For harvesting and threshing, energy input was higher in small land holdings due to the use of small-sized machinery which require specific energy. Table 4 shows that input energy increases with increasing land holding in a linear manner.

Many farmers consider that crop production would only increase with a higher rate of urea application. However, it is now an established fact that only a limited quantity of nitrogen used in crops is consumed by the

Table 4. Operation-wise energy consumption pattern in wheat crop production (MJ/ha)

Operation	Category of farmers					Weighted average
	Large	Medium	Semi-medium	Small	Marginal	
Harrowing	2602.3	2182.4	2020.6	1461.3*	1284.2*	1486.0
Planking	545.0	361.9*	370.3*	300.9*	260.0*	291.0
Sowing	2945.5	2804	2857.9	2895.2	2643.3	2729.9
Irrigation	4192.7	3504.5	2565.9*	2652.8*	2779.2	2784.5
Fertilizer application	11,208.4	11,237.7	10,874.9	9833.1	10,064.5	11,066.8
Plant protection	1170.8	1061.5	504.9*	518.1*	495.6*	543.2
Harvesting and threshing	2217.8	2170.6	2166.6	2545.5	2503.3	2439.7
Total	24,882.4	23,322.7	21,361.1	20,206.9*	20,030.1*	20,497.1

*Significant difference at 5% level of significance.

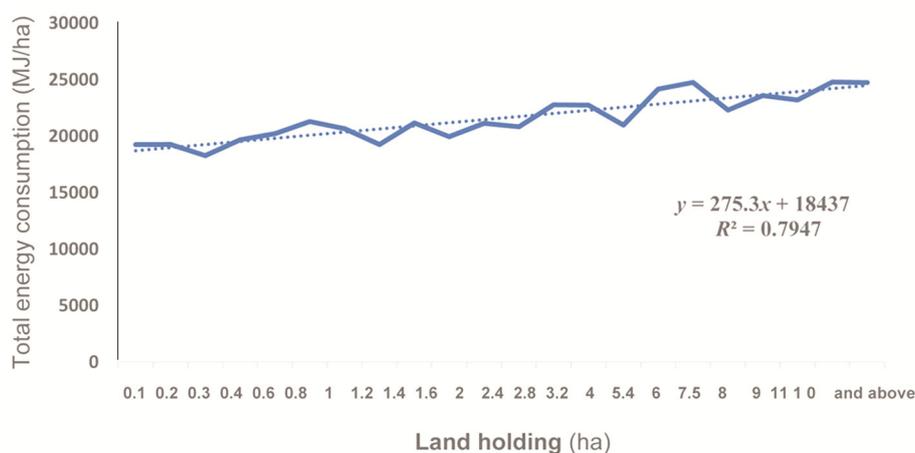


Figure 3. Relationship between energy use pattern and land holding of the farmers.

plant itself, depending on the soil type, temperature and rainfall¹⁶.

Average operational energy consumption was observed 20,497.1 MJ/ha. It was much higher in the case of large and medium category farmers compared to small and marginal category farmers. The major difference is due to high fuel consumption and higher fertilizer application. Fertilizer application consumed maximum energy in all categories of farmers followed by harvesting and threshing. It incurred 54% of total energy consumption, which is in conformity with previous studies⁶.

The present study also indicates that total energy consumption has a positive relationship with land holding of the farmers (Figure 3). This may be due to the fact that farmers with larger farm size have better resources and a more mechanized agriculture production system. More mechanized agriculture system requires more fuel and electricity compared to the less mechanized system.

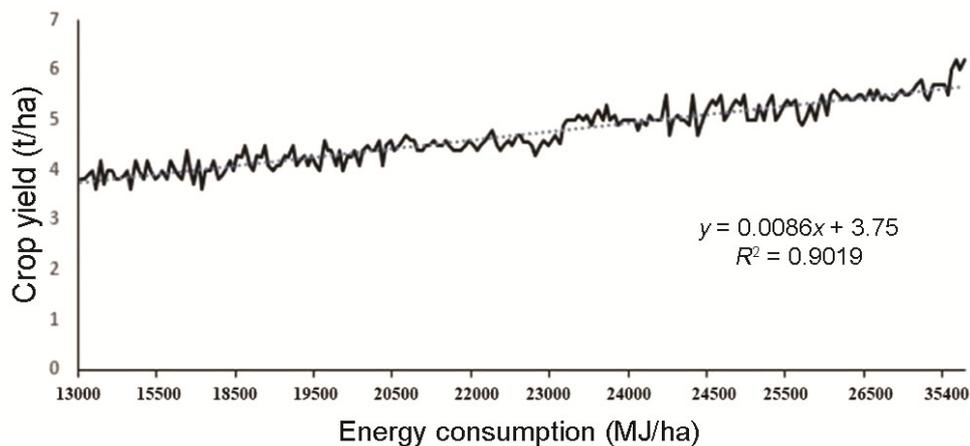
The total energy expenditure for wheat crop production was assessed and is presented source-wise (Table 5). As discussed above, maximum energy was consumed in fertilizer application, which accounts for 10,295 MJ/ha (50.22%). It was observed that farmers from large and

medium categories applied more fertilizers. By far, fertilizers and agro nutrients (especially urea) are the important sources of energy, followed by fuel and electricity in wheat crop production in the region. The present study and regional agronomical recommendations suggest that it is feasible to optimize energy expenditure in crop production, particularly in fertilizer application by employing improved fertilizer management system and more efficient sowing methods, such as band placement. The slow-rate fertilizers can also be an efficient method of fertilizer application. The agronomical recommended dose of fertilizers for wheat crop production in the region is 150, 60 and 40 kg/ha of N, P and K respectively, whereas average fertilizer application by farmers is 187.5, 40 and 20 kg/ha respectively. This indicates that farmers in the region are applying 25% more N fertilizer than recommended. Nitrogen fertilizer being the most energy-intensive in the production process naturally increases the energy input in wheat production. This excessive energy consumption can be checked by applying recommended dose of N fertilizer. Adopting improved crop management practices such as adequate rates, appropriate sources, efficient methods of application, and application timing when crops

Table 5. Source-wise energy consumption pattern in wheat crop production (MJ/ha)

Source	Category of farmers					Weighted average
	Large	Medium	Semi-medium	Small	Marginal	
Human energy	369.6	290.6	284.2	384.6	299.0	239.6
Fuel	5970.2	5171.1	4711.7*	5009.9	4421.9*	4624.9
Electricity	4114.8	3420.5	2202.2*	1693.4*	1914.1*	2030.1
Seed	2435.0	2440.1	2519.5	2504.6	2577.5	2546.5
Fertilizer	11,208.4	11,237.7	10,874.9	9833.1*	10,064.5*	10,295.0
Agrochemicals	491.2	482.1	482.4	483.0	482.6	482.7
Machinery	293.2	280.6	286.2	298.3	270.5	278.4
Total energy input	24,882.4	23,322.7	21,361.1	20,206.9*	20,030.1*	20,497.1
Direct	10,226	8760.1	7121	7021.4	6569.2	6894.6
Indirect	14,656.6	14,562.6	14,240.1	13,185.5	13,460.9	13,602.5
Yield (tonnes/ha)	5.52	5.00	4.57	4.27	4.02	4.22
Energy output	81,144	73,500	67,179	62,769	59,094	62,034
Energy productivity (kg/MJ)	0.222	0.214	0.214	0.211	0.201	0.210
Energy use efficiency	3.26	3.15	3.14	3.11	2.95	3.02

*Significant difference at 5% level of significance.

**Figure 4.** Effect of energy consumption on crop yield.

absorb maximum amount can increase nitrogen use efficiency in crops. Nitrogen can be applied based on field trials that determine crop responses to various rates of fertilizer application. These methods are highly efficient and effective. Further, practices such as the use of organic manure, appropriate crop rotations and conservation tillage systems also enhance crop productivity¹⁷. There is a need to reduce excessive use of fertilizers (especially urea) by large and medium farmers, and to improve the method of fertilizer application like band placement in place of broadcasting.

In comparison with other operations, tillage, and harvesting and threshing operations have the maximum proportion of fuel energy (3960 MJ/ha). These operations share 62.5% of total fuel expenditure in wheat crop production. The way to reduce fuel consumption in wheat crop production is efficient tillage methods^{18,19}. It is an established fact that a significant amount of energy could

be saved by using zero tillage or minimum tillage methods without affecting the crop yield. Energy efficiency can be achieved by adopting zero tillage or minimum tillage method¹³. It is obvious from the study that fuel is a major input in wheat crop production. It was observed that farmers do not adopt these tillage methods due to the problem of accumulation of standing paddy stubbles.

There is a tendency for higher energy uses to be associated with higher yield. Figure 4 shows the relationship between energy consumption and crop yield. One can observe from the figure that energy has a positive relationship with crop yield. Maximum yield was observed in the case of large and medium category farmers as they were consuming maximum energy. The results are also in agreement with previous studies⁴. Table 5 also shows energy ratio and energy productivity. Maximum energy ratio and energy productivity was observed in case of

large and medium category farmers, who were consuming more energy. It appears that to boost crop yield, extra energy should be spent. Though it is obvious from the study that energy consumption has a positive relationship with crop yield, but the effect is insignificant statistically.

Energy use efficiency in wheat crop production system varied from 3.26 to 2.95 in the region. The study shows that large and medium category farmers are more efficient than small and marginal category farmers. The energy output of large and medium category farmers was higher than other farmer categories. This may be due to the fact that the mechanization level of agriculture of large and medium category farmers is high compared to other categories, which results in better grain yield.

In this study, energy consumption in wheat crop production for each category of farmers in Himalayan Tarai region was analysed. The study showed that with increase in land holding, the energy consumption in wheat crop production increases. However, large and medium category farmers are more energy-efficient. The gap in energy use efficiency recommends increasing agriculture mechanization level for small and marginal category farmers. In wheat crop production, fertilizer is the most significant energy input followed by fuel and electricity. Therefore, we need to focus more on fertilizers, electricity and fuel consumption to reduce energy expenditure in crop cultivation compared to other factors. Special crop management practices and application procedures should be followed to increase nitrogen use efficiency. The large and medium category farmers need to be more aware of this. Also, there is a need to educate farmers about the zero tillage system by which a significant amount of energy can be saved. Proper management of these resources can reduce energy use on farms and can improve energy efficiency.

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