Energy Consumption in Wheat Crop Production in Central Region of Uttar Pradesh, India

Abstract

The research investigated energy usage in the production of wheat crops in the central region of Uttar Pradesh, India among different groups of farmers. The study involved surveying a total of 250 farmers from 59 villages, gathering data about various inputs utilized in wheat crop cultivation during the period of 2020-22. Using standard energy equivalents, the inputs required for wheat production were quantified in terms of energy. The findings indicated that the overall energy input for wheat production in the region amounted to 20497.1 MJ/ha, with fertilizers, fuel, and seeds contributing to 85% of this energy consumption. Specifically, fertilizers represented 50.2% of the total energy, followed by fuel at 22.6%. The study also revealed that larger and medium-scale farmers utilized more energy compared to those with smaller landholdings, but they also achieved higher grain yields. Among different farming operations, energy usage was highest in fertilizer application, followed by tillage. The average output-to-input energy ratio was calculated at 3.02. Additionally, this ratio differed among farmer categories: 3.26 for large farmers, 3.15 for medium farmers, 3.14 for semi-medium farmers, 3.11 for small farmers, and 2.95 for marginal category farmers. In conclusion, the research established a positive correlation between energy consumption and crop yield.

Keywords: Energy, Wheat, Tillage

1. Introduction

Contemporary agricultural crop cultivation necessitates a substantial amount of fossil energy inputs, both in the form of "direct energy" and "indirect energy" (which includes energy expended off the farm for producing fertilizers, plant protection agents, machinery, etc)(Sharma et al 2020, Hülsbergen 2001).The global need for food security compels an increase in agricultural output due to the diminishing availability of cultivable land and the growing world population (Mandal et al. 2022, Azad et al 2023 Mandal et al.2023)· Broadly, strategies to enhance agricultural production involve expanding land use, increasing yield per unit area, and elevating cropping intensity (Sharma et al 2023, Pahlayan R 2014). Given the limitations on expanding arable land, the primary means of significantly boosting production involves intensifying the use of input resources(Mandal et al. 2023, Singh et al 2023). The production of wheat crops is intricately linked to factors like high-yielding varieties, chemical inputs, fertilizers, mechanization, and other energy resources. The relationship between energy input, crop yield, and efficiency varies with each input (Singh et al 2004). The escalated utilization of resources like fertilizers, irrigation water, diesel, pesticides, and electricity necessitates higher energy consumption from human, animal, and mechanical sources (Lal 2004). The utilization of commercial energy in Indian agriculture exhibited a growth rate of 11.8% between 1980-81 and 2000(Singh and Singh 1992). Rice and wheat constitute over 75% of India's total cereal production (Singh et al 2021). The introduction of improved rice and wheat varieties during the 1960s triggered a series of technological advancements that facilitated a remarkable 50% increase in food production (Pathak and Bining 1985).The majority of these technological shifts require extra energy inputs, particularly from commercial energy sources. The rise in energy and natural resource consumption is attributed to farmers' limited awareness about employing more energy-efficient approaches (Esengun et al 2007)

The energy usage in the process of cultivating a specific crop within agricultural production differs due to factors such as the agro-climatic conditions, crop management strategies, farm machinery accessibility, mechanization level, utilization of various forms of direct and indirect energy, and other inputs[1]. In India, farmers are classified based on their land ownership into categories like small, marginal, medium, and large. This distribution of land holdings significantly influences the consumption of input energy within the crop production system, owing to the variations in management practices(Pishgar et al 2011).The way energy is utilized and the efficiency of energy usage for a specific crop differ based on the agro-climatic circumstances and the degree of mechanization in agriculture. Furthermore, it is essential to examine how farm size influences the energy consumption pattern in crop production.

Hence, this research was conducted to comprehensively analyze the energy utilization among various groups of farmers. This information is valuable for determining the overall energy consumption of the region and pinpointing the energy-demanding tasks within the wheat production system.

2. Materials and methods

2.1 Study area

The research was carried out to assess the energy requirements for wheat and paddy crop production in the LakhimpurKheri, Sitapur, Hardoi and Shahjahanpur districts of Uttar Pradesh.. The average weather conditions during the growing season are illustrated in Figure 1. The Central region in India is positioned on the outer foothills of the Siwalik hills and lies in the Indo-Gangetic plains. The central region of Uttar Pradesh is situated at the outer foothills of the Siwalik hills and lie in the Indo-Gangetic plains. The central region is positioned between 27° and 29° north latitude and 78°53' and 81° east longitude. These district lies at an average elevation of 383.39 meters above mean sea level and encompasses a total geographical area of 23797 square kilometers. The primary crops cultivated in this region include rice, wheat, sugarcane, mustard, and peas. Common crop rotations practiced in the this region of Uttar Pradesh include continuous rice-wheat, rice-wheat-rice, sugarcane-ratoon-wheat or rice, rice-rapeseed-sugarcane-ratoon-wheat, and rice-rice-peas. Figure 2 provides the demographic specifics of the studied area.

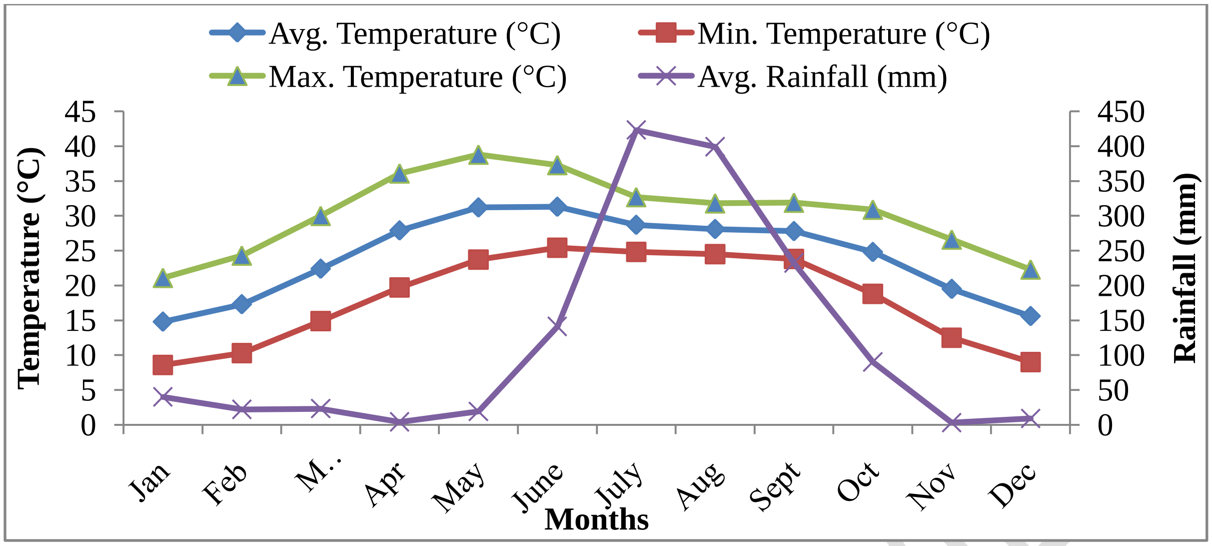

Fig. 1 Average Weather Condition of Central Region of Uttar Pradesh

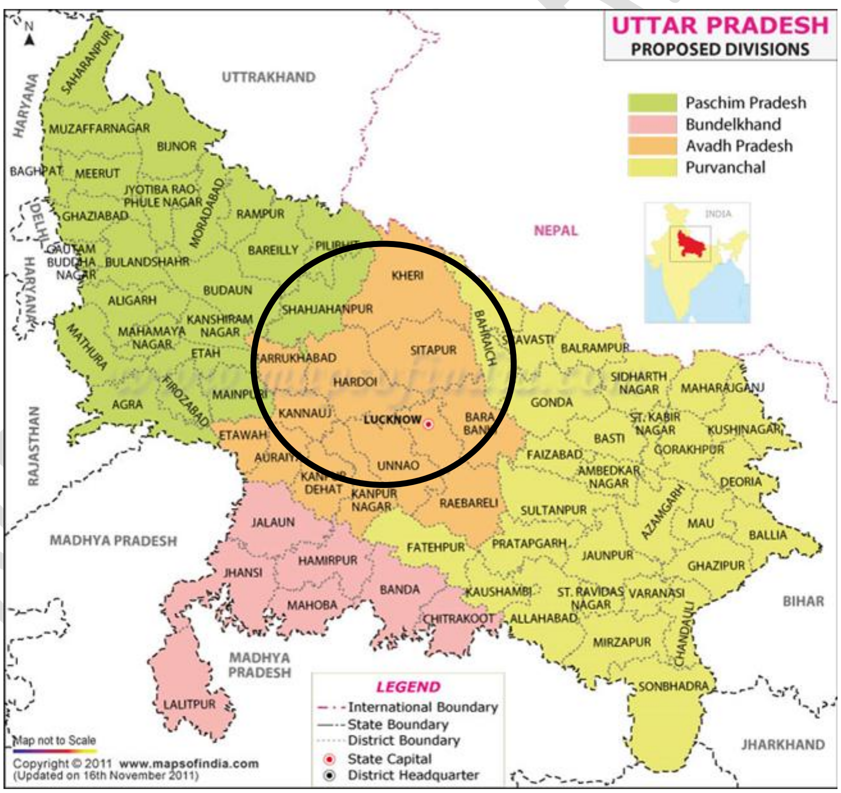

Fig 2. Map of surveyed area

2.2 Data collection

We conducted surveys involving a total of 250 farmers across 59 villages from the four districts of the selected region as depicted in Figure 2. The distribution of surveyed farmers in each block was as follows: 65 from Sitapur district, 62 from Lakhimpur Kheri district, 65 from Hardoi district and 58 from Shahjahanpur district, in Uttar Pradesh. The selection of farmers in various districts within the selected region was done through a random process, ensuring that each farmer in the population had an equal chance of being included in the study. The equal number of farmers were selected from each category of farmers as depicted in Table 1. Information regarding various aspects of wheat crop cultivation was gathered through personal interviews with each selected farmer, utilizing a predetermined questionnaire. The questionnaire was meticulously constructed to encompass comprehensive details about all stages of crop production and comprehensive resource inventory. It encompassed details related to fertilizers, chemicals, and farmyard manure, the sources of power (both human and mechanical), agricultural equipment, as well as the wheat yield per hectare.Every agricultural input was categorized into either direct or indirect energy sources. Human energy, fuel energy, and electricity fell under the category of direct energy sources, whereas indirect energy sources encompassed high-yielding variety seeds, fertilizers, chemicals utilized in the production process, farmyard manure (FYM), and the energy required to manufacture agricultural machinery. To assess the energy consumption for specific unit operations, data pertaining to the duration, quantity, and frequency of these operations, along with energy inputs, were collected and quantified using energy coefficients outlined in Table 2.

Table 1. Land holding wise category of farmer

Farmer Category	Land Holding (ha)
Large	More than 10 ha
Medium	4-10 ha
Semi Medium	2-4 ha
Small	1-2 ha
Marginal	0-1 ha

Table 2. Energy co-efficient for different energy inputs

Sl.No.	Source	Unit	Energy equivalent (MJ)	References
1.	Human	Man-hour	1.96 1 adult women = 0.8 adult man	Sharma et al. 2020

2.	Animal	Pair-hour	10.10	Sharma et al. 2020
3.	Diesel	Litre	56.31	Sharma et al. 2020
4.	Electricity	k-Wh	16.93	Sharma et al. 2020
5.	Seed	kg	14.7	Sharma et al. 2020
6.	FYM	kg	0.3	Sharma et al. 2020
7.	Fertilizer			Sharma et al. 2020
	N	kg	60.6	Sharma et al. 2020
	P	kg	11.1	Sharma et al. 2020
	K	kg	6.7	Sharma et al. 2020
8.	Agro chemical	kg	120	Sharma et al. 2020
	Inferior chemicals	kg	100	Sharma et al. 2020
9.	Machinery			Sharma et al. 2020
	Electric motors	kg	64.80	Sharma et al. 2020
	Prime mover	kg	68.40	Sharma et al. 2020
	Farm machinery	kg	62.10	Sharma et al. 2020

2.3 Estimation of Energy Inputs

The approach used in this study followed a cradle-to-gate analysis, implying that factors related to transportation and waste disposal in the product's life cycle beyond the farm's boundary were not taken into account. In simpler terms, the energy inputs assessed in this study pertain to the on-farm production processes prior to post-harvest activities. The research exclusively focused on the energy utilized within the production of wheat crops, omitting the consideration of environmental factors like rain, wind, and radiation (Safa et al 2011).

Human energy consumption was computed by considering the hours spent on labor-intensive tasks and the count of laborers engaged in those tasks. The calculation involved multiplying the energy coefficient corresponding to the workers by the overall hours dedicated to human activities across various unit operations.

The primary fuel source utilized in wheat production was high-speed diesel (HSD), employed for tractors and irrigation pump sets. To accurately gauge fuel consumption for tractors and pump sets across different farmer categories, the subsequent equation was employed(De 2005)

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

Where, F = fuel consumption, l/h,

LCF = load coefficient factor, (It is the ratio of actual load on tractor to maximum load for an operation, Table 3)

RHP = rated horsepower of source, kW

SFC = specific fuel consumption, ml/kWh.

The data regarding the specific fuel consumption and rated horsepower of different brands of tractors and combine harvesters used by local farmers were acquired from the official test reports of these machinery models published by CFMTTI Budni, Madhya Pradesh, India. The load coefficient factors corresponding to various power levels, as suggested by De (2005), are presented in Table 3.

Electricity primarily served the purpose of irrigation and pumping. Farmers of varying categories utilized electric motors with varying power ratings for their irrigation needs. The calculation of electricity consumption for an electric motor employed by a farmer followed the formula introduced by De (2006).

$$E = RHP \times T \qquad \ldots (2)$$

Where, E= Electrical energy consumption, kWh, RHP= Rated power of electric motor, kW, T=Number of hours required for a particular operation, h.

The dominant fertilizers used in India include urea, ammonium phosphate, and super phosphate. These fertilizers are utilized to supply plants with nitrogen (N), phosphate (P2O5), and potash (K2O) respectively. Within this research, the amount of fertilizer applied was documented through a survey, and the NPK levels were subsequently calculated.

The primary source of energy consumption in agricultural chemicals primarily stems from their production, packaging, and transportation processes. The approach employed in this research for evaluating the energy usage of pesticides has involved estimating the quantities of herbicides, insecticides, and fungicides applied across various farms. Energy consumption was calculated by multiplying the energy factors of these pesticides by the total quantities of the corresponding herbicides, insecticides, and fungicides used.

The energy required by tractors and additional machinery was calculated using parameters such as weight, operational lifespan, and average annual working hours. This research utilized the estimated lifespan as outlined in IS:9164 (1979), while the annual usage of various machinery was gauged through a questionnaire. This summation encompasses the overall energy expended in producing machinery for distinct unit processes in crop cultivation. Machine-related energy was assessed using the approach put forth by Safa et al. (2011),

$$ME = \frac{G.xE}{T\ C_{ef}} \qquad \ldots (3)$$

Where, ME = Machine energy, MJ/ha,

G = Weight of the machinery, kg,

E= Energy sequestered of agricultural machinery MJ/kg,

T = Machine economic life, h,

Cef = Effective filed capacity of machine, ha/h.

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

2.4 Energy indices

Following the computation of energy input, the determination of energy output relied on the energy values associated with grains. Energy metrics pertaining to the production of wheat, such as energy utilization efficiency and energy yield, were assessed using the subsequent equations as described by Mandal et al 2014 and Singh et al 1997.

Net energy = Energy output (MJ ha^{-1}) − Energy input (MJ ha^{-1}) …(4)

Energy Use Efficiency = Energy output (MJ ha^{-1})/Energy input (MJ ha^{-1}) …(5)

Energy productivity = Grain yield (kg ha^{-1})/Energy input (MJ ha^{-1}) …(6)

3. Results and Discussion

3.1 Operation wise energy consumption

The operational energy across diverse groups of farmers is displayed in Table 4. This encompasses activities like plowing, planting, fertilizing, spraying, watering, harvesting, and threshing. Several noteworthy observations can be drawn from Table 4. In instances involving mechanized operations, considerable energy was expended by larger-scale farmers, especially evident in tasks like plowing and preparing the seedbed. This is due to a higher frequency of plowing activities and the utilization of equipment designed for seedbed preparation. Moreover, significant quantities of irrigation water and chemicals were applied by larger farmers. Conversely, in the context of harvesting and threshing, smaller landholders recorded higher energy input, attributed to the use of smaller machinery that demands greater specific energy.

The data in Table 4 indicates a linear rise in input energy corresponding to the increase in landholding size.

Certain farmers hold the belief that crop yield can only be enhanced through elevated nitrogen application. Nevertheless, it's important to note that only a fraction of the nitrogen applied to crops is actually taken up by the plant. This uptake is influenced by factors such as soil composition, temperature, and precipitation(Hirel et al 2011).

An average operational energy usage of 20497.1 MJ/ha was recorded. This was notably more pronounced among farmers categorized as large and medium, in contrast to their counterparts categorized as small and marginal. This disparity primarily stems from elevated fuel consumption and increased fertilizer usage. Across all farmer categories, the most substantial energy consumption was attributed to fertilizer application, followed by the tasks of harvesting and threshing. Notably, fertilizer application accounted for the largest share of total energy consumption, representing 54%, a finding that aligns with the observations made by Singh and Singh in 1992 .

The research findings also suggest a direct correlation between total energy consumption and farmers' land holdings, as illustrated in Figure 3. This could be attributed to the reality that farmers with larger land holdings tend to possess enhanced resources, often leading to the adoption of more advanced mechanized agricultural production methods. Such heightened mechanization demands greater quantities of fuel and electricity in comparison to less mechanized systems.

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

Particulars	**Categories of Farmer**					**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	11208.4	11237.7	10874.9	9833.1	10064.5	11066.8
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	**24882.4**	**23322.7**	**21361.1**	**20206.9***	**20030.1***	**20497.1**

*Significant difference at 5% level of significance

3.2 Source wise energy consumption

The composition of both direct and indirect energy sources for wheat crop cultivation was established, as outlined in Table 5. As discussed earlier, the foremost contributor to energy consumption was fertilizer usage, accounting for 10295 MJ/ha (50.22%). Notably, larger and medium-scale farmers were observed to employ more fertilizers. Predominantly, fertilizer, particularly Urea, emerges as the primary energy source, trailed by fuel and electricity in the context of wheat crop production within the region. There is an opportunity to curtail energy usage, particularly that of fertilizers, by adopting improved management practices and employing more efficient techniques like band placement.

In the region, the recommended fertilizer dosage for wheat cultivation is 150 kg/ha of nitrogen (N), 60 kg/ha of phosphorus (P), and 40 kg/ha of potassium (K). In contrast, farmers on average apply 187.5 kg/ha of N, 40 kg/ha of P, and 20 kg/ha of K. This highlights that farmers in the region are using 25% more nitrogen fertilizer than the recommended amount. Given that nitrogen fertilizer holds the highest energy-intensive profile in the production process, this surplus usage inherently drives up the energy input in wheat cultivation. This excessive energy consumption can be effectively curbed by adhering to the recommended nitrogen fertilizer dosage. Addressing the excessive utilization of fertilizers, particularly urea, among larger and medium-sized farmers, as well as adopting improved fertilizer application techniques like band placement over broadcasting, is imperative.

Amongst the various operations, plowing, and the harvesting and threshing processes constitute the most substantial portion of fuel energy consumption, amounting to 3960 MJ/ha. Collectively, these activities contribute to 62.5% of the total fuel consumption in wheat crop production. One effective strategy to mitigate fuel consumption in wheat crop cultivation involves the implementation of more efficient tillage techniques (Aghapour and Masihi 2014, Baishya and Sharma 1990). De (2006) concluded that considerable energy savings can be achieved through the adoption of zero tillage or minimum tillage methods, all the while maintaining crop yield. The adoption of such practices can lead to enhanced energy efficiency. The research underscores the fact that fuel plays a pivotal role in the energy input of wheat crop production. Notably, farmers tend to avoid the adoption of these innovative tillage methods due to concerns related to the accumulation of standing paddy stubbles.

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

Particulars	**Category of Farmers**					
	Large	**Medium**	**Semi Medium**	**Small**	**Marginal**	**Weighted Average**
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	11208.4	11237.7	10874.9	9833.1*	10064.5*	10295.0
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	**24882.4**	**23322.7**	**21361.1**	**20206.9***	**20030.1***	**20497.1**
Direct	10226	8760.1	7121	7021.4	6569.2	6894.6
Indirect	14656.6	14562.6	14240.1	13185.5	13460.9	13602.5
Yield, t/ha	5.52	5.00	4.57	4.27	4.02	4.22
Energy Output	**81144**	**73500**	**67179**	**62769**	**59094**	**62034**
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

Energy consumption and Yield

There exists a trend wherein increased energy usage tends to correlate with higher crop yields. The relationship between energy consumption and crop yield is illustrated in Figure 3. As seen in Figure 4, a positive correlation is evident between energy consumption and crop yield. Larger and medium-scale farmers, who consumed greater energy, achieved the highest yields. These findings align with the conclusions drawn by Singh et al. in 2007. Energy ratios and energy productivity, as indicated in Table 5, also display their peak values among larger and medium-scale farmers, reflecting their heightened energy consumption. It is apparent that a higher energy expenditure is linked to improved yields. However, while the study demonstrates a positive association between energy consumption and crop yield, this effect lacks statistical significance.

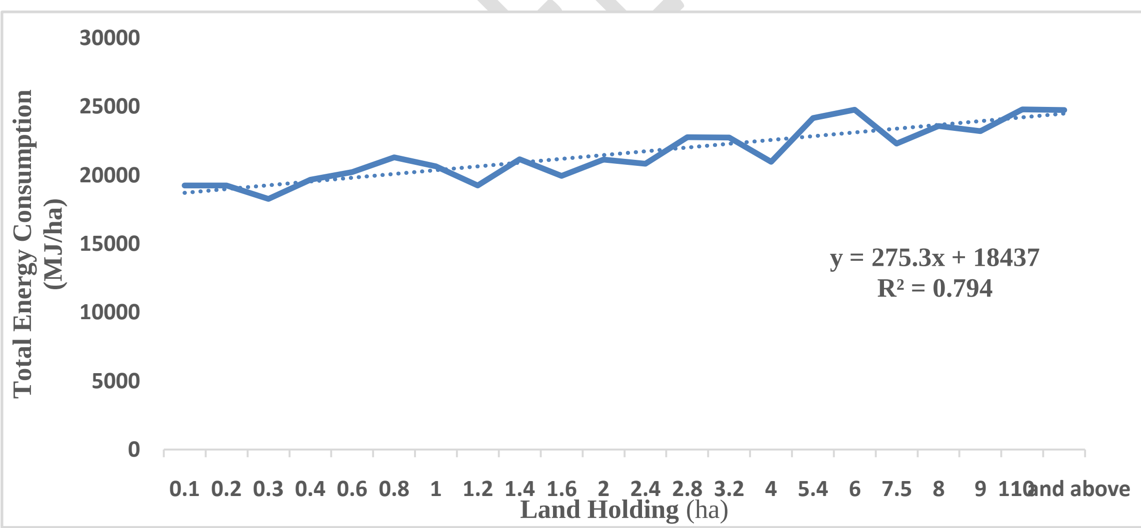

Fig. 3 Energy use pattern with land holding

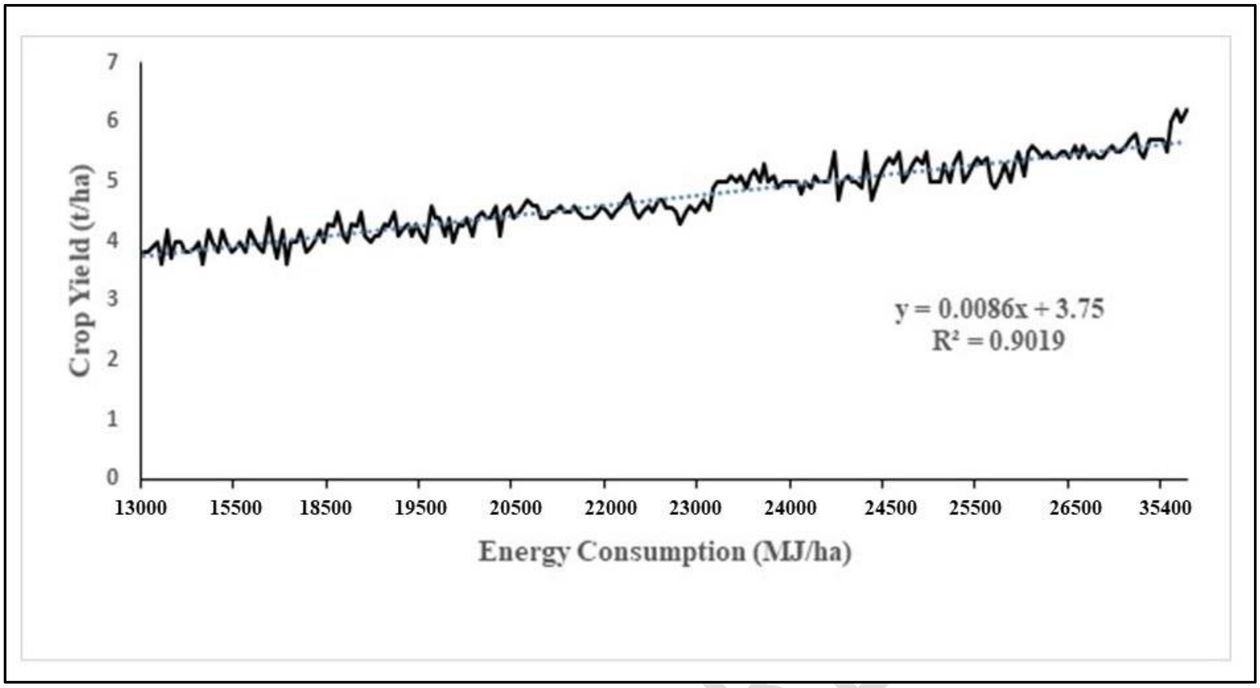

Fig. 4 Effect of Energy Consumption on Crop Yield

Energy Use efficiency

The energy use efficiency within the wheat crop production system ranged between 3.26 and 2.95 across the region. The research highlights that efficiency is greater among farmers categorized as large and medium, compared to those falling under the small and marginal categories. The energy output of larger and medium-scale farmers exceeded that of their counterparts. This phenomenon can be attributed to the higher degree of mechanization present in the agricultural practices of larger and medium-scale farmers, resulting in enhanced grain yields, as evident from the outcomes.

Conclusion

This research undertook an analysis of energy consumption in wheat crop production across various farmer categories in central region of Uttar Pradesh. The findings reveal that as land holdings increase, the energy consumption in wheat crop production follows suit. However, it's noteworthy that large and medium-scale farmers exhibit superior energy efficiency. The disparities in energy use efficiency underscore the necessity to elevate the level of agricultural mechanization among small and marginal category farmers. Within the context of wheat crop production, fertilizer emerges as the foremost energy input, succeeded by fuel and electricity. Consequently, there exists a need to emphasize greater attention on the consumption of fertilizers, electricity, and fuel, as compared to other factors. Raising awareness among large and medium-scale farmers about these aspects is crucial. Furthermore, promoting the adoption of zero tillage practices could result in substantial energy savings. The judicious management of these resources holds the potential to curtail energy usage on farms and enhance overall energy efficiency.

.

References

1. Aghapour, M.S. &Masihi, S. Examination of the relationship between energy consumption and performance of potato crop in cultivation under plastic in Dezful City. *IJFAS*, (2014) 4(53), 383-389.

2. Azad, D., Pateriya, R.N. & Sharma, R.K. Chemical activation of pine needle and coconut shell biochar: production, characterization and process optimization. Int. J. Environ. Sci. Technol. (2023). https://doi.org/10.1007/s13762-023-04913-w

3. Baishya, A. & Sharma, G.L., Energy budgeting of rice-wheat cropping system. Indian J Agron; (1990) 35:167–77

4. De, D. Energy Use in Crop Production System in India. (2005) Central Institute of Agricultural Engineering, Bhopal.

5. De, D. Energy use pattern and future energy requirement for crop production by 2020. *Journal of Agril. Engg*. (2006)43(3), 32-41.

6. Esengun, K., Gunduz, O. and Erdal, G. Input-output energy analysis in dry apricot production of Turkey, Energy Conversion and Management. (2007) 48: 592-598

7. Hirel, B., Thierry,T., Lea, P. and Dubois, F., Improving Nitrogen Use Efficiency in Crops for Sustainable Agriculture. Sustainability (2011), 3, 1452-1485

8. Hülsbergen,K.J., Feil, B., Biermann, S., Rathke, G.-W.,Kalk, W.-D.& Diepenbrock, W., A method of energy balancing in crop production and its application in a long-term fertilizer trial, Agriculture, Ecosystems & Environment, (2001) Volume 86, Issue 3, Pages 303-321,

9. Indian Standard IS:9164 (1979) Guide for estimating cost of farm machinery operation

10. Kitani, O., Energy and Biomass Engineering. CIGR Handbook of Agricultural Engineering, Vol (V). (1999) ST Joseph, MI, USA: ASAE publication

11. Lal, R., Soil carbon sequestration impacts on global climate change and food security. Science (2004) 304: 1623–1627.

12. Mandal S., Jena P.C., Gangil S., Haydary J., Sharma R.K., Ni-Supported Pigeon Pea Stalk Biochar as a Catalyst for Ex-situ Tar Cracking Biomass Gasification Biomass Conversion and Biorefinery. https://doi.org/10.1007/s13399-023-04974-4

13. Mandal, S., Sharma, R.K., Bhattacharya, T.K. et al. Charring of pine needles using a portable drum reactor. Chem. Pap. 76, 1239–1252 (2022). https://doi.org/10.1007/s11696-021-01893-4

14. Mandal, S., Sharma, R.K; Bhattacharya, T. K (2023) Deriving fuel from pine needles through pyrolysis, charring and briquetting and their GHG emission potential. Current Science 124 (10)

15. Mandal,S., Roy,S., Das,A., Ramkrushna,G.I., Lal, R., Verma,B.C.,Kumar, A.,Singh,R.K.&Layek,J Energy efficiency and economics of rice cultivation systems under subtropical Eastern Himalaya. Energy for Sustainable Development (2014) 28, 115–121

16. Mittal, J.P., Dhawan,K.C., Research manual on energy requirements in agricultural sector. New Delhi: ICAR; (1988) p. 20–33

17. Pahlavan,R., Omid,M., Akram,A., Energy input–output analysis and application of artificial neural networks for predicting greenhouse basil production Energy (2014) 37 (1), 171-176

18. Pathak, B.S., Bining, A.S.. Energy use pattern and potential for energy saving in rice-wheat cultivation. (1985). Energy in Agriculture (1985) 4. 271-278. 10.1016/0167-582690022-1.

19. Pishgar, K.S.H., Keyhani, A., Rafiee, Sh., Sefeedpary, P.,Energy use and economic analysis of corn silage production under three cultivated area levels in Tehran province of Iran.. Energy (2011)36(5):3335-3341

20. Safa, M., Samarasinghe, S., Mohsen, M., A field study of energy consumption in wheat production in Canterbury, New Zealand. Energy Conversion and Management. (2011) 52, 778 2526–2536

21. Sharma, R.K., Bhattacharya, T.K., Kumain, A., Chand, P. and Mandal, S., (2020) Energy Use Pattern in Wheat Crop Production System among different Farmer's Group of Himalayan Tarai Region. Current Science 118 (2) (SCIE)

22. Sharma, R.K.; Nazari, M.A.; Haydary, J.; Singh, T.P.; Mandal, S. A Review on Advanced Processes of Biohydrogen Generation from Lignocellulosic Biomass with Special Emphasis on Thermochemical Conversion. Energies 2023, 16, 6349. https://doi.org/10.3390/en16176349 (SCIE)

23. Singh P., Singh T.P., Sharma R.K., Negi Y.K., Pal R., (2021) Potential of Pine Needle Biomass as an Alternative Fuel to Mitigate Forest Fire in Uttarakhand Himalayas - A Review. Journal of Agricultural Engineering Vol. 58 (2)

24. Singh, H., Singh, A.K., Kushwaha, H.L.&Singh,A., Energy consumption pattern of wheat production in India.) Energy; (2007) 32: 1848-54

25. Singh, M.K., Pal,S.K., Thakur,R., Verma,U.N., Energy input–output relationship of cropping systems. Indian J Agron; (1997) 67:262–4

26. Singh, S.& Singh. G., Energy input versus crop yield relationship for four major crops of Northern India. Agri Mech Asia Africa Latin AM (AMA) (1992); 23(2): 57-62

27. Singh, V.; Pant, N.; Sharma, R.K.; et al. Adsorption Studies of Pb(II) and Cd(II) Heavy Metal Ions from Aqueous Solutions Using a Magnetic Biochar Composite Material. Separations 2023, 10, 389. https:// doi.org/10.3390/separations10070389

28. Srivastava, N.S.L., Long-term strategies and programmes for mechanization of agriculture in agro climatic zone–V: Upper Gangetic Plains region (2002). www.farmech.gov.in

29. Uttar Pradesh, Directorate of Economics and Statistics Planning Department. Statistical Diary of Uttar Pradesh. 2020 pp. 46-61.