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Status of Energy Used Efficiency and Farm Mechanization Level for Wheat Production in District Jaunpur, Uttar Pradesh

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Abstract

To meet the rising demand for food, wheat production, which accounts for about 25% of the world's cereal crop area, must be increased. Since wheat yield is directly correlated with energy inputs, the current study aims to investigate and optimize energy use patterns in wheat production throughout the Jaunpur district of Uttar Pradesh in order to achieve greater productivity. The study included six tehsils: Jaunpur (Sadar), Badlapur, Kerakat, Machhlishahar, Mariahu, and Shahganj. The energy output from grain and straw as well as the energy used for land preparation, sowing, irrigation, fertilizer application, harvesting, and threshing were among the many energy and mechanization indicators that were taken into account. In the district under study, the total energy input for wheat cultivation was estimated to be 16,658.58 MJ/ha, while the energy output was 98,181.3 MJ/ha. At 8,257.27 MJ/ha, chemical fertilizers accounted for the largest share of energy inputs. Of these, nitrogen shared roughly 7,415.99 MJ/ha, followed by phosphorus. Harvesting and threshing operations used 1,877.23 MJ/ha of energy, whereas irrigation used 3,313.12 MJ/ha. The region's wheat production had an EUE of 5.89, which further indicates that energy output is nearly six times greater than energy input. EUE was greatly impacted by farm size. Large farms had the highest value (6.36), medium-sized farms ranged from 5.66 to 5.96, and small farms had the lowest value (5.64), indicating a declining trend with smaller landholdings. The overall mechanization level was noted at 5.99 kW/ha in the region. Improvement in energy management and better mechanization would definitely increase wheat productivity in Jaunpur District, specifically among small and medium farmers.

Keywords Energy used efficiency: Farm power availability: Mechanization level.

Introduction

Since the middle of the 1960s, technological developments in Indian agriculture have resulted in a dramatic rise in agricultural output. Production of food grains, especially rice and wheat, has continuously increased at a faster rate than population growth. After experiencing acute food shortages until the 1980s, India is now self-sufficient and a net exporter of food grains. The creation of high-yielding crop varieties, more chemical fertilizer application, irrigation facility expansion, plant protection measures, and efficient price support policies for agricultural commodities have all contributed to this change. In addition to these interventions, increased reliance on purchased inputs has made it necessary to improve resource-use efficiency, which is greatly aided by farm mechanization. The argument for mechanized agriculture labor has been further reinforced by rising labour costs and the higher costs of maintaining bullock power. The technological leap in Indian agriculture since the mid-1960s has resulted in a revolutionary improvement in agricultural output. Food grain production of wheat and rice particularly has been growing consistently faster than population. Indeed, India's food supply shortages, which were acute until the 1980s, have been transformed with the country now emerging as a net exporter of food grains. This impressive growth has been singularly made possible by development of high-yielding varieties of crops, improved application of chemical fertilizers, expansion of irrigation facilities, the practice of plant protection, and an efficient price support policy for agricultural produce. The use of purchased inputs on a greater scale brought about the associated need for increased resource-use efficiency, to which farm mechanization had contributed in no small measure. Rising labour costs and increased expenditure on maintaining bullock power further reinforced the argument for mechanized agriculture.

By guaranteeing accuracy and timeliness in critical field operations like land preparation, irrigation, sowing and planting, fertilizer application, crop protection, harvesting, and threshing, farm mechanization has significantly increased agricultural productivity. Even though India's agricultural sector has grown at a moderate rate over the last ten years roughly 3% annually there have been significant structural changes. Commercialization, diversification, and increased use of contemporary machinery and inputs are characteristics of the industry that are becoming more prevalent. The energy consumption of agriculture is significantly impacted by these developments. Significant commercial energy inputs are needed for modern production technologies, especially when managing perishable commodities.

Energy is produced and consumed by agriculture. In addition to commercial energy sources like diesel, electricity, chemical fertilizers, irrigation water, pesticides, and machinery, it makes extensive use of non-commercial energy sources like seeds, organic manure, and animate power. Crop productivity, financial returns, sustainability, and competitiveness are all improved by efficient use of energy resources. Due to the country's abundant agricultural resources and rural population base, energy use in agriculture continues to be a crucial area of focus even though its share of the nation's total energy consumption is smaller than that of other sectors. Judicious use of agricultural energy contributes to environmental sustainability by reducing greenhouse gas emissions and minimizing ecological degradation (Schroll 1994; Dalgaard et al. 2001; Nasso et al. 2011). Excessive or inefficient energy use increases the cost of production and reduces the profitability of farms, hence a policy challenge. In technologically advanced agricultural systems, gains in productivity are closely linked to increased energy inputs through mechanization and adoption of high yielding crop varieties. In developing economies where agriculture is the primary livelihood for a significant share of the population, mechanization plays an imperative role in lessening human drudgery, ensuring timely farm operations and enhancing productivity. Besides expansion of arable land, improvements in production efficiency through mechanized operations and efficient water, fertilizer, and weed management practices remain critical (Faidley 1992). Understanding the energy input–output relationship in agriculture is hence an essential step in optimizing energy use, thereby minimizing costs and environmental impacts (Jones 1989).

Sustainable agricultural mechanization depends on the obtainability of modern and efficient machinery supported by correctness technologies. In Uttar Pradesh, farm power availability has improved from 1.75 kW/ha in 2001 to 2.84 kW/ha in 2017. Though, future production targets require further increases, with projected needs of 3.49 kW/ha by 2022 and 6.12 kW/ha by 2030. Although mechanical power has largely replaced human and animal labour, concerns persist regarding its socio-economic implications, particularly the displacement of traditional labour systems. In this regard, quantification and analyses of energy-use pattern in various major cropping systems will become imperative to identify operations which are intensive in energy use and finding suitable low-input and efficient energy alternatives for sustainable agricultural development. Hatirli (2006) pointed out that though there are a number of studies estimating energy performance in some cropping systems of the Upper Indo-Gangetic Plains (Nassiri and Singh, 2009), a few research studies have been conducted related to the middle Indo-Gangetic region (Mittal et al., 1992).

Some researchers have discussed the role of farm mechanization in evaluating energy-use efficiency during wheat production (Shen et al., 2018) and overall issues of sustainability and mechanization in the agricultural sector (Nikhade et al., 2020; Mehta et al., 2021; Yadav et al., 2023; Aiswarya et al., 2024). In the backdrop of these gaps, the present study estimates the energy inputs and outputs related to wheat production in the Jaunpur district of Uttar Pradesh and assesses energy-use efficiency and mechanization levels across marginal, small, and medium farms. This analysis would help in identifying avenues for enhancement in energy efficiency, profitability, and overall sustainability in wheat cultivation in the region.

Materials and Methods

Study Area Description

Jaunpur district forms the north-western part of the former province and lies within the present Varanasi Division. The district extends between latitudes 25°24′ N and 26°12′ N, and longitudes 82°07′ E and 83°05′ E. It is bound on the west by the districts of Pratapgarh and Prayagraj, on the south by Sant Kabir Nagar, east by Ghazipur, Azamgarh, and on the north by the Sultanpur district. The study area has a perfect length of 85 km from north to south and an extreme breadth from east to west of 90km. The total area of the Jaunpur district is 4038 km2. Jaunpur District is administratively divided into 6 Subdivisions or tehsils to streamline governance and ensure efficient management. Each tehsil is overseen by a Tehsildar, who manages revenue administration and maintains law and order within the subdivision. The soil is mainly sandy and Loamy. District is often affected by the floods during rainy seasons. The climate of Uttar Pradesh is the tropical monsoon type, with warm weather year-round. Data collection.

Data Collection and Analysis

Field surveys and in-person interviews with farmers using questionnaires were used to gather the primary data for energy input resources. The information found in literature and other sources was used to gather secondary data for energy input resources and energy outputs. On- and off-farm energy input were used to estimate the mechanical energy lost in mechanical operations and the energy used in other activities, such as transportation, irrigation, and other inputs. Based on the findings of a survey conducted in the target area, the actual values of all the inputs used were computed. Through direct, in-person interviews with the farmers in the four blocks Badlapur, Jaunpur, Kerakat Machhlishahr Mariahu, and Shahganj data was gathered at random between March and April of 2019. About 250 farmers completed the survey, which was divided into three groups according to the size of their land, the amount of input power they used, and their yield. In addition to other economic factors in the various blocks of the Jaunpur district of the state of Uttar Pradesh, such as the cost of cultivation, the cost of machinery, the cost of human and animal labor, etc. Information gathered from published reports or trade or industry statistics is referred to as secondary data.

Energy Use

To determine the energy equivalencies in the study, the number of inputs (chemicals, human labor, machinery, seed, manure, fertilizers, fuel, electricity, and irrigation water) used in the production of wheat crops was specified. After calculating the input amounts per hectare, the coefficient of energy equivalent was multiplied by the input data. The energy equivalents coefficients were calculated using the earlier research (Nassiri and Singh, 2009). The Mega Joule (MJ) unit is used to calculate the energy equivalencies of unit inputs. To determine the energy equivalencies in the study, the wheat crop's output (grain and straw as byproducts) was specified. The quantities of output were calculated per hectare and then, these output data were reproduced with the coefficient of energy equivalent (Soni et al.,2013; Taewichit, 2012; Nassiri and Singh, 2009; Chaudhary et al., 2009; Kizilaslan, 2009; Hatirli, 2006).

Energy Input (MJ) = Use of Input (unit) × Energy Equivalent (MJ/unit)

Energy output (MJ/ha) = grain production in (kg/ha) × Energy Equivalent (MJ/kg) + by product production (kg/ha) × Energy Equivalent (MJ/kg)

Energy Use Efficiency (EUE)

EUE measures the energy input and output efficiency of a crop production system, where the output is determined by the production of the primary product and its byproducts. The inefficiency of an agricultural production system has been expressed using the EUE ratio, one of the energy indices that shows the efficient use of energy in agriculture. Any increase in EUE signifies effective use of available energy for farming, and vice versa.

EUE= Total Output Energy (MJ/ ha)/Total Input Energy (MJ/ha)

A pre-made questionnaire was used to interview 250 farmers in total. The total amount of farm power available from both mechanical and animate power sources per hectare of operational land holding was used to calculate farm power availability. The following formula was used to calculate the districts' average farm power availability.

{(Number of agricultural Worker × 0.05) + (Number of

Tractors × 26.1) + (Number of electric motor ×3.7) + (Number of diesel engine × 5.6)} / Available cultivated land in ha.

Results and Discussion

Fuel energy accounted for 943.138 MJ/ha (≈87.36%), followed by the tractor (75.212 MJ/ha; 6.97%), implement (47.492 MJ/ha; 4.40%), and human labor (13.745 MJ/ha; 1.27%) in the land preparation operation's total consumption of 1079.586 MJ/ha. The tractor, man, fuel, and implement energy use standard deviations were 2.062, 0.377, 26.976, and 1.430 MJ/ha, respectively. The total standard deviation was 30.455 MJ/ha, indicating a consistent field operation and a low coefficient of variation (~2.8%). As fuel contributes the bulk of energy and also accounts for most of the observed variability, improvements in fuel efficiency through better field traffic management, optimum tyre pressure and ballast, timely soil preparation at optimum moisture, operator skill, and proper machine maintenance will yield the largest reduction in overall energy consumption for land preparation.

The total energy consumption for sowing operations was 2120.79 MJ/ha, with the largest energy input coming from seed (1785.02 MJ/ha), followed by fuel (306.03 MJ/ha), tractor (29.74 MJ/ha), implement (19.53 MJ/ha), and human labor (8.89 MJ/ha). This shows that fuel accounted for 14.44% of the total energy, seed input alone contributed over 84%, and the combined contribution of all other components was less than 2%. The implement, man, tractor, fuel, and seed energy standard deviation values were 5.89, 4.74, 2.58, 26.59, and 79.13 MJ/ha, respectively. The total standard deviation was 85.30 MJ/ha, indicating moderate variability across operations, with fuel and seed energy being the main causes of variation (Fig. 1).

The total energy consumption in irrigation was 3313.12 MJ/ha, with fuel accounting for 2662.61 MJ/ha (≈80.37%), followed by smaller shares from manpower (252.56 MJ/ha (7.62%), electricity (234.32 MJ/ha (7.07%), centrifugal pump (110.51 MJ/ha (3.34%), diesel engine (31.58 MJ/ha (0.95%), and electricity (SD 59). Chemical and fertilizer application consumed 8257.27 MJ/ha, with nitrogen alone contributing 7415.99 MJ/ha (≈89.8%), followed by phosphorus (626.66 MJ/ha; 7.6%) and herbicides (159.03 MJ/ha; 1.9%), while sprayer and labour energy was marginal. The total disparity was SD 1250.55 MJ/ha, mainly driven by nitrogen input variability (Fig. 2)

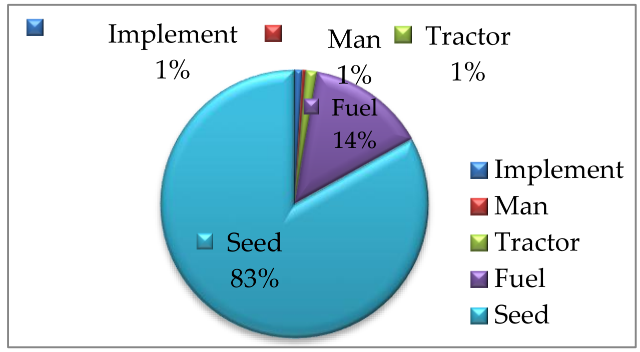

Fig. 1 Energy consumption in sowing MJ/ha.

Harvesting was almost entirely labor-driven, requiring 400.77 MJ/ha, with labor contributing 393.53 MJ/ha (Men 100.54 + Women 292.99 MJ/ha) and sickle use adding 7.24 MJ/ha. With additional contributions from the tractor (77.23 MJ/ha), thresher (53.10 MJ/ha), and labor (84.69 MJ/ha), threshing consumed 1191.96 MJ/ha of diesel, suggesting that fuel was the primary source of energy consumption. The outcome demonstrated that fertilizer use contributed the most to the overall input in the wheat cropping system. In the fertilizer section, nitrogen in particular contributed the most, followed by phosphorus. The consumption of diesel fuel in the various on-farm agricultural activities was ranked as the second most important input in wheat cropping, while seeds were ranked as the third most important. The next major component of the total input energy was electricity. The primary use of electricity was for irrigation.

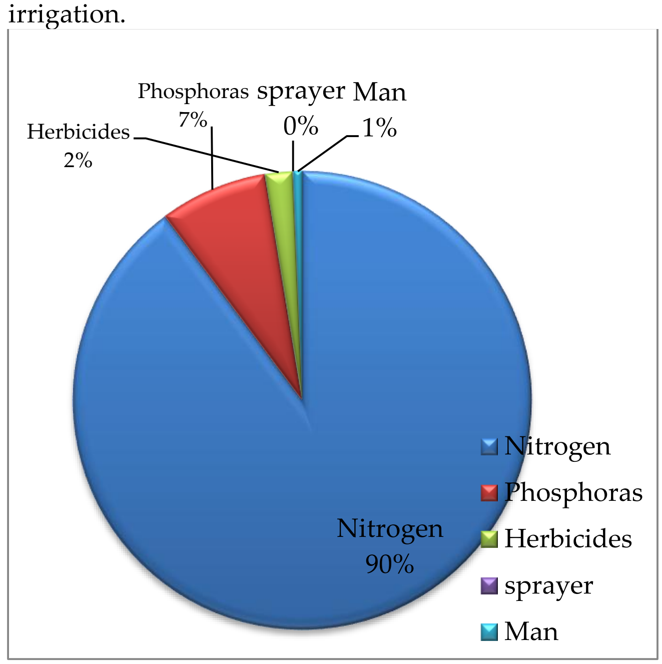

Fig. 2 Energy consumption in chemical and fertilizer

MJ/ha

Energy Output from Wheat Production

It was discovered that the wheat crop produced 98181.3 MJ/ha of energy in the form of grain and biomass. Energy use patterns across farm sizes reveal that chemicals and fertilizers account for the largest portion of total energy, followed by irrigation, with comparatively less variation in land preparation and sowing. Large farmers used the least amount of fertilizer-chemical energy (7486.93 MJ/ha), whereas marginal farmers used the most (8880.34 MJ/ha), suggesting that marginal farmers use more inputs. Large farmers had slightly higher irrigation energy due to higher pumping intensity, but overall irrigation energy was similar across categories (≈3280–3420 MJ/ha).

There was little variation in land preparation and sowing energy between farm sizes (≈1070–2120 MJ/ha). The amount of energy used for harvesting and threshing decreased with farm size, with small farmers using the most (2021.38 MJ/ha) and large farmers using the least (1527.83 MJ/ha). This suggests that larger holdings have lower labor dependence or better mechanization efficiency (Fig. 3). Large farmers use relatively energy-efficient farming methods, while marginal farmers use more energy overall per hectare, primarily due to fertilizer inputs.

The findings showed that the biggest energy input in wheat production was fertilizer use, with nitrogen accounting for the largest share, followed by phosphorus. Due mostly to the use of diesel in field operations, fuel was ranked as the second most important energy source. The production of all biomass, including grain and straw, was the source of the energy output in wheat farming. Examining the impact of farm size on energy use efficiency (EUE), it was found that larger farms had the highest EUE (average 6.36) and that efficiency dropped as farm size decreased, reaching 5.96 for medium, 5.66 for marginal, and 5.64 for small farmers. With an average EUE of 5.94 and a standard deviation of ±0.80, the wheat crop demonstrated higher efficiency in larger landholdings.

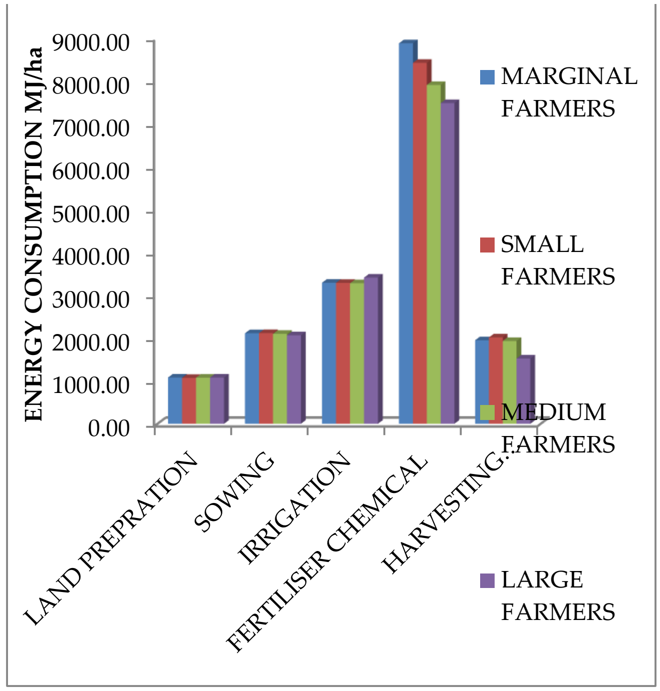

Fig. 3 Energy consumption in different farmer field (MJ/ha.)

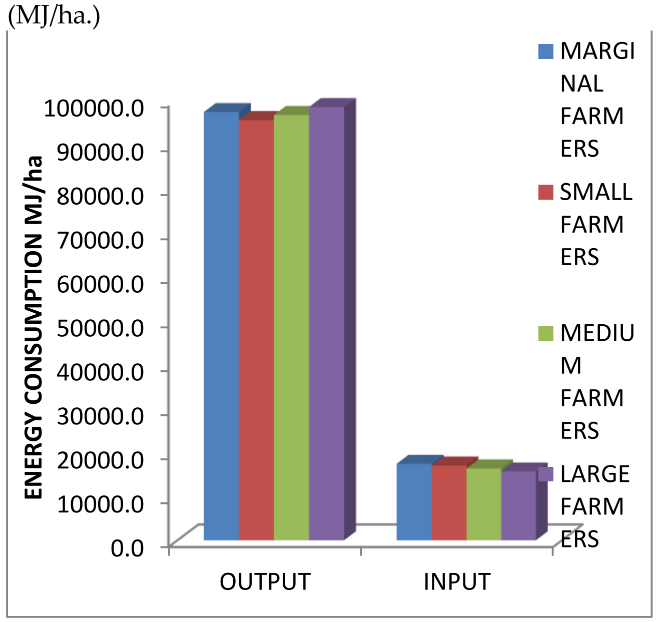

Fig. 4 Energy input and output in different type of farmer field MJ/ha

Conclusions

Jaunpur district of Uttar Pradesh is mainly agrarian, and wheat is the major crop grown in the district. This paper presents the energy-use pattern and mechanization level in wheat production assessed through data collected from 250 farmers through a structured face-to-face survey. The total input energy for wheat cultivation was 16,658.58 MJ/ha, while the total output energy reached 98,181.3 MJ/ha, indicating that wheat is a highly energy-efficient cropping system. Chemical fertilizers accounted for the largest share of energy input at 8,257.27 MJ/ha, with dominant nitrogen inputs followed by phosphorus. Irrigation accounted for a major share at 3,313.12 MJ/ha, and energy use during harvesting–threshing operations was 1,877.23 MJ/ha, reflecting a considerable amount of energy use during post-harvest operations. Energy use efficiency, as a whole, came out to be 5.89, which again confirms efficient energy use in wheat production. Farm size significantly influenced energy performance. Medium and large farms recorded the highest efficiency of 6.36, with efficiency falling as landholding size was reduced, indicating clear economies of scale in mechanization and energy use. Mechanical farm power availability in the district was only 1.90 kW/ha, which is far below the state average of 5.83 kW/ha.

Power availability varied across farms depending on land size, income level, cropping choices, and access to irrigation. A clear trend toward increased mechanical power has also been noted in the study, with the use of animal power almost disappearing. However, overall mechanization remains insufficient, thus constraining productivity gains. The findings suggest that wheat cultivation in Jaunpur is energy-efficient, but wider access to improved machinery and inputs especially for small and marginal farmers goes a long way to enhancing productivity and sustainability, and improving the overall farm power balance of the district.

Data Availability Statement

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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