Tikrit Journal for Agricultural Sciences (2024) 24 (2): 115-130
DOI: https://doi.org/10.25130/tjas.24.2.10

IRAQI Academic Scientific Journals

ISSN:1813-1646 (Print); 2664-0597 (Online)
Tikrit Journal for Agricultural Sciences
Journal Homepage: http://www.tjas.org
E-mail: tjas@tu.edu.iq

TJAS
Tikrit Journal for Agricultural Sciences

Sustainable Energy Use for Mechanized Wheat Production Systems in Iraq

Abdulla Azawi, Thaer Turky, and Momtaz Isaak *

Agricultural Machinery and Equipment Department, College of Agriculture, Tikrit University, Iraq

**Correspondence email*: momtaz.isaak@tu.edu.iq

KEY WORDS:
renewable energy; machinery energy; energy use efficiency

Received: 03/01/2024
Revision : 10/03/2024
Proofreading: 20/04/2024
Accepted: 30/05/2024
Available online: 30/06/2024

ABSTRACT

The utilization of agricultural machinery was fully mechanized for wheat production in Iraq. This study essentially aimed to inspect inputs and outputs of energy for wheat production in Salah Al-Deen, Iraq. The data were obtained from 45 wheat farms by using the face-to-face questionnaire method in 2022. The findings from this study were determined for five basic operations (i.e., tillage, sowing, fertilizing. spraying, and harvesting). Direct energy sources (fuel and humans) accounted for about 51.39% of the total energy used in cultivation. Energy exemplified in fuel recorded the highest rate of the total expenditure of energy, with 51.09 % (6091.01 MJ/ha). Farmers utilized nearly 879.11 MJ/ha of machinery energy, the highest rate of expenditure of machinery energy was in harvesting, which recorded 38.38 % (337.42 MJ/ha) of the total energy of machinery used in the study. Results of analyzing the energy of fuel that farmers utilized indicated that operations of tillage were about 25.98 % (1582.29 MJ/ha) of the total energy of fuel. This rate denotes the highest operation of fuel consumption. Harvesting operations followed it. These operations were implemented through the use of engines powered with diesel, which accounted for about 23.43% (1427.05 MJ/ha). The average energy input/output ratio was 4.40 for the wheat crop, while the energy intensity was 1.79 MJ/kg for the wheat crop.

استخدام الطاقة المستدامة في أنظمة إنتاج القمح الميكانيكية في العراق

عبد الله عزاوي، ثائر تركي، ممتاز اسحق

قسم المكائن والآلات الزراعية، كلية الزراعة، جامعة تكريت، العراق

الخلاصة

تمت ميكنة استخدام الآلات الزراعية بشكل كامل لإنتاج القمح في العراق. كانت هذه الدراسة تهدف في الأساس إلى فحص مدخلات الطاقة والمخرجات لإنتاج القمح في صلاح الدين، العراق. تم الحصول على البيانات من 45 مزرعة قمح باستخدام طريقة استبيان وجهًا لوجه في عام 2022. تم تحديد النتائج من هذه الدراسة في خمس عمليات أساسية (أي الحراثة، البذار، التسميد، الرش، والحصاد). كانت مصادر الطاقة المباشرة (الوقود والبشر) تشكل حوالي 51.39٪ من إجمالي الطاقة المستخدمة في الزراعة. سجلت الطاقة المستهلكة في الوقود أعلى نسبة للإنفاق الإجمالي للطاقة، بنسبة 51.09٪ (6091.01 ميجاجول/هكتار). استخدم المزارعون ما يقرب من 879.11 ميجاجول/هكتار من طاقة الآلات، وكانت أعلى نسبة لإنفاق طاقة الآلات في عملية الحصاد، حيث بلغت 38.38٪ (337.42 ميجاجول/هكتار) من إجمالي طاقة الآلات المستخدمة في الدراسة. أظهرت نتائج تحليل طاقة الوقود التي استخدمها المزارعون أن عمليات الحراثة كانت حوالي 25.98٪ (1582.29 ميجاجول/هكتار) من إجمالي طاقة الوقود. هذه النسبة كانت أعلى نسبة لاستهلاك الوقود. تلتها عمليات الحصاد، حيث تم تنفيذ هذه العمليات باستخدام محركات تعمل بالديزل بنسبة حوالي 23.43٪ (1427.05 ميجاجول/هكتار). كان متوسط نسبة مدخلات الطاقة إلى الإنتاج كان 4.40 لمحصول القمح، بينما كانت كثافة الطاقة 1.79 ميجاجول/كغم لمحصول القمح.

كلمات مفتاحية: الطاقة المتجددة، طاقة الآلات، كفاءة استخدام الطاقة، تحليل الطاقة، محصول القمح.

INTRODUCTION

Excessive energy usage in developed and developing nations has resulted in several environmental, commercial, technological, and even societal issues that require further research to offset the negative consequences. To minimize energy use and its environmental consequences, all relevant information must be analyzed (Safa and Samarasinghe, 2011). Agriculture, a high-energy input sector, yields vital energy for human survival. Wheat, a cereal crop, serves as a staple food worldwide, meeting heightened demand due to people growth through modern, energy-intensive farming practices (Ashraf *et al.,*, 2020; Imran *et al.,* 2021). Farmers have ramped up the use of input energy in wheat production to keep up with rising demand. This heightened energy usage has far-reaching implications for both energy security and environmental sustainability (Imran & Özçatalbaş, 2020). The Iraqi government is working to enhance agriculture to increase food production. This is a crucial step in stabilizing the country's economy and reducing food imports in favor of domestic production and procurement to source the Public Distribution System's (PDS) food supply (CFSVA 2016). This is due to the importance of wheat production and its various uses through human consumption of grains as well as animal consumption as fodder, adding to the entry of this crop in industrial uses. These operations are managed using energy from various sources, including human labor, machinery, fuel, fertilizer, chemical applications, and seeds. Essentially, the production capacity of crops is directly consumed in the operation of machinery and equipment and indirectly through the application of fertilizers and chemicals used in agriculture. The timely availability of adequate energy is a prerequisite for the timely completion of wheat production, which is essential to ensuring maximum yield (Sami, 2014; Muazu *et al.,,* 2015). Most of the researchers collected data on energy expenditures in fields using the questionnaire method (Soltani *et al.,* 2013; Ajabshirchi, 2013; Bilalis *et al.,,* 2013; Yousefi *et al.,* 2014; Khoshnevisan *et al.,* 2014; Nabavi-Pelesaraei *et al.,* 2014; Nabavi-Pelesaraei *et al.,* 2016; Barak *et al.,* 2016; Singh *et al.,,* 2021; Alwan and Hassan, 2023). To maximize benefits, farmers must have the right energy mix in time. Much of the energy input indicates non-economic production and thus waste, which may lead to a reduction or loss of utility, an increase in global warming, and some stress on the environment. Very little energy is required to make it difficult to reach the maximum level of productivity to ensure the required level of food sufficiency (Muazu *et al.,* 2015; Al-jughaify and Alobaidy, 2023).

The energy analysis in crop production is executed to identify energy uses. The obtained information is then used to improve performance by increasing yield, decreasing production costs, and minimizing greenhouse gas emissions, which are accountable for an alteration in the environment. Energy use is an important necessity for the sustainability of agricultural production, as it reduces costs, restricts fossil fuels, and lowers air pollution levels (Ghorbani *et al.,* 2011; Shaaban and Omer, 2023). When analyzing energy, the farm's inputs utilized in production and the outputs produced from it are recognized using a boundary defined for the system. A clear definition of the study boundary is a cardinal issue in assessing agricultural systems (Dixon *et al.,* 2001). The inputs and outputs are evaluated and then translated into energy values using proper energy conversion coefficients. Classical mathematical equations are then used to provide an estimation of the energy flow into the system. The number of inputs and outputs incorporated in the analysis, along with the conversion coefficients adopted, have a tremendous effect on the estimated energy flow. Most variations in the results of energy studies are hinged on these factors. Therefore, for effective comparison among different energy studies, these variations need to be recognized and addressed properly (Isaak *et al.,,* 2020).

An energy equivalent, otherwise called an energy conversion coefficient, is a value that expresses the energy input expended in the production and distribution of a unit physical material (e.g., pesticides, fuel, fertilizers, seeds, etc.) used as input in crop production. The value is not fixed for any given material input but varies widely from place to place. It reflects the level of technological development associated with the production or manufacture of the given material input. In other words, using lower-energy coefficients denotes improvements in the efficiency of production (Rathke *et al.,,* 2007; Tabatabaie *et al.,,* 2013).

Based on the literature, no study has been conducted or reported on energy use analysis in wheat cultivation in Iraq. Thus, this study was conducted on energy input in wheat cultivation to understand when, where, and how much energy inputs are consumed, and finally to identify the opportunities for saving energy input for individual operations. The objectives of the present study were to assess energy use analysis in mechanized wheat cultivation in Iraq.

MATERIALS AND METHODS

In this study, 45 farms of wheat production were surveyed in Salah Al-Deen province, Iraq, located at 34°27′N 43°35′E, by using the face-to-face questionnaire method in 2022. The collection of data was conducted by randomly selected farms. The size of the sample was determined using the simple random sampling method. This method is expressed as below: (Kizilaslan, 2009):

$$n = \frac{N(s \times t)^2}{(N-1)d^2 + (s \times t)^2} \quad (1)$$

where n is the required sample size; s, is the standard deviation; t is the value at 95% confidence limit (1.96); N, is the number of holding in the target population and d, is the acceptable error (permissible error 5%). Consequently, the calculated sample size in this study was 45. For the calculation of sample size, criteria of 5% deviation from the population mean and 95% confidence level was used.

The recorded farm inputs from the six sources (namely human labor, machinery, fuel, fertilizer application, chemical and seed) used by the wheat farmers and wheat yield from each were converted into equivalent energy values using appropriate conversion coefficients shown in Table 1.

Table 1 Energy conversion coefficients used to compute energy value for the farm inputs and outputs

Material	conversion coefficients	Unit	Source
Human labor	1.96	MJ/h	(Mohammadi *et al.*, 2010)
Tractor	93.61	MJ/kg	(Canakci *et al.*, 2005)
Machinery	62.7	MJ/kg	(Ozkan *et al.*, 2004)
Diesel	56.31	MJ/l	(Mohammadi *et al.*, 2010)
Nitrogen	78.1	MJ/kg	(Khoshnevisan *et al.*, 2014)
Phosphorus	17.4	MJ/kg	(Khoshnevisan *et al.*, 2014)
Potassium	13.7	MJ/kg	(Khoshnevisan *et al.*, 2014)
Chemicals	120	MJ/kg	(Mohammadi *et al.*, 2010)
Pesticides	315	MJ/kg	(Safa and Samarasinghe 2011)
Herbicides	310	MJ/kg	(Safa and Samarasinghe 2011)
Fungicides	210	MJ/kg	(Safa and Samarasinghe 2011)
wheat seed	13	MJ/kg	(Khoshnevisan *et al.*, 2014)

The source-wise energy budget in megajoules per hectare (MJ/ha) is evaluated using the classical equation for every one of the farm inputs used by farmers in the cultivation operations of wheat. The evaluation utilized energy conversion factors as specified in Table 1, because of their popular applications in similar studies by previous researchers in the Philippines (Flores *et al.*, 2016), Iran (Lorzadeh, 2012; Taki et al, 2012), India (Yadav *et al.*, 2013 ; Mani *et al.*, 2007), and Pakistan (Shafique *et al.*, 2015) Machinery energy, fuel energy, human energy, seed energy, chemical energy and fertilizer energy were calculated using the following equation:

$$ME = \frac{Cf * W}{Fc * L} \quad (2)$$

Where *ME* refers to the energy of machinery (MJ/ha), *CF* refers to the conversion factor of energy for the used machinery (MJ/kg), *W* refers to the machinery weight (kg), *Fc* refers to the capacity of effective field (ha/h) and *L* refers to the economic life of the machinery (h).

The derivation of the economic life of farm machinery implemented by farmers was from the management standard of farm machinery, as shown in Table 2.

Table 2 The economic life of farm machinery used by farmers in the study area

Machine	Economic life/ h	Source
Tractor 2WD	12000	
Self-propelled combine harvester	3000	
Chisel plow	2000	(ASABE standard D497. 2006)
Sprayer	1500	
Spreader	1200	

In computing the machinery energy for tillage operation which involves the use of a tractor and chisel plow having different weight, energy conversion coefficient and economic life, the total machinery energy was obtained as the summation of machinery energies due to the tractor and chisel plow used in operating, as shown in Equation 3.

$$ME = \frac{1}{Fc} * \left[\frac{Cf_t * W_t}{L_t} + \frac{Cf_r * W_r}{L_r}\right] \qquad (3)$$

Where Cf_t is 93.61 MJ/kg the energy conversion factor for tractor, W_t is 2311 kg the weight of the tractor, L_t is 12000 h the economic life of tractor, Cf_r is 62.70 MJ/kg the energy conversion factor for chisel plow, W_r is 325 kg the weight of chisel plow, L_r is 2000 h the economic life of chisel plow. *Fc* is the effective field capacity for the tillage operation (ha/h). The general formula for computing machinery energy expenditure per area basis (MJ/ha) is expressed in Equation 4.

$$ME = \frac{Cf * W}{Fc * L} \qquad (4)$$

Where *ME* refers to the energy of machinery (MJ/ha), *Cf* refers to the conversion factor of energy for the machinery used (MJ/kg), *W* refers to the machinery weight (kg), *Fc* refers to the capacity of effective field (ha/h) and *L* refers to the machinery economic life (h).

$$FE = \frac{fcon * fc}{A} \qquad (5)$$

Where *FE* is fuel energy (MJ/ha), *fcon* is the fuel consumed quantity (L), *fc* refers to the conversion factor of fuel energy (MJ/L), and *A* refers to the covered area of the farm (ha). The energy conversion coefficients adopted for diesel, as shown in Table 1, are 56.31 MJ/l . Therefore, based on what fuel type is used the prime movers engaged in an operation, appropriate fuel energy conversion factor (fc) is used in Equation 5.

$$HE = \frac{n * H * lc}{A} \quad (6)$$

Where *HE* is human energy (MJ/ha), *n* is the number of workers engaged in an operation, *H* is the time taken for the operation (h), *lc* refers to the conversion factor of energy for human labor (1.96 MJ/h) and A is the farm area covered (ha). The average human energy expenditure in the block was calculated as the total energy of human expended in the cultivation in all farms.

$$SE = \frac{Sq * sc}{A} \quad (7)$$

Where *SE* refers to the energy of seed (MJ/ha), *Sq* refers to the weight of the seeds used in the study (kg), *sc* refers to the conversion factor of seed energy (13 MJ/kg) and *A* refers to the area of the farm under study (ha). The average seed energy in the block was computed as the summation of seed energy in all farms under study.

$$CE = \frac{Cq * Cc}{A} \quad (8)$$

Where *CE* is chemical energy (MJ/ha), *Cq* refers to the chemical weight used in the study (kg), *Cc* refers to the conversion factor of chemical energy (MJ/kg) and *A* is the farm area covered (ha). The average chemical energy in the block was computed as the total chemical energy in the block.

$$FTE = \frac{FTq * \sum_{i=1}^{n} FTi * FTci}{A} \quad (9)$$

Where *FTE* refers to the energy of fertilizer (MJ/ha), *FTq* refers to the fertilizer weight used in the study (kg), *FTi* refers to the i^{th} element percent composition (decimal), *FTci* refers to the conversion factor of energy for the i^{th} fertilizer element (MJ/kg) and *A* is the farm area covered (ha). The average fertilizer energy in the block was computed as the summation of fertilizer energy in all farms.

$$TEI = ME + FE + HE + SE + CE + FTE \quad (10)$$

Where *TEI* refers to total input of energy (MJ/ha) and ME, FE, HE, SE, CE and FTE are as defined earlier.
The average overall energy input in the block was then obtained as the total energy inputs in all farms.

$$TOE = Y * mc \quad (11)$$

Where *TOE* is total energy output wheat (MJ/ha), *Y* is the harvested wheat yield (kg/ha) and *mc* refers to the conversion factor of energy for wheat (MJ/kg).

The block's average energy output was determined as the ratio of energy output sum from all farms. The energy ratios determined in this study were computed as follows:

$$EE = \frac{TEO}{TEI} \quad (12)$$

Where EE is energy use efficiency (dimensionless), *TEO* is the total energy output (MJ/ha) and *TEI* is the total energy input (MJ/ha). The average energy use efficiency in the block was established as the total energy use efficiencies in all farms.

$$EI = \frac{TEI}{Y} \quad (13)$$

Where *El* = Energy intensity for wheat (MJ/kg), *TEI* Total energy input (MJ/ha) and *Y* = Harvested wheat yield (kg/ha).

$$EP = \frac{Y}{TEI} \quad (14)$$

Where *EP* = Energy productivity for wheat (kg/MJ), *Yc* = Harvested wheat yield (kg/ha) and *TEI* = Total energy input (MJ/ha).

$$NEG = TEO - TEI \quad (15)$$

Where *NEG* = Net energy gain (MJ/ha), *TEO* = Total energy output (MJ/ha) and *TEI* = Total energy input (MJ/ha).

$$PERi = \frac{EIi}{TEI} * 100 \quad (16)$$

Where PERi = Percent energy use for the i^{th} source of energy input *Eli* = Energy input from an i^{th} source (MJ/ha) and *TEI* = Total energy input (MJ/ha).

RESULTS AND DISSCUSION

Farmers in the study area conduct tillage operation using two-wheel drive made of medium size with ratings of engine power ranging between 65 and 120 hp as a prime mover. The energy inputs used in performing the tillage operations are human labor, machinery and fuel consumed by the prime movers, essentially during the data collection for tillage operations. All tillage data were collected and analyzed. At first energy, analysis was made regarding the share contribution of each or the three energy sources (human labor, machinery, and fuel) used in conducting the tillage operations. The energy expenditures due to tillage operations are presented in Table 3. Mean total energy of 1701.31 MJ/ha was expended in performing the tillage operation. Fuel constitutes the bulk of the energy expenditure accounting for 93 % (1582.29 MJ/ha) of the total energy expenditure (Turky *et al.*, 2023). The contributions of machinery and human labor were rather low, pegged at 6.38 and 0.62 %, respectively.

The energy data for sowing operations covers four farm inputs: humans, fuel, machinery, and seeds. The energy expenditure data for the sowing operation is presented in Table 3. A mean total energy of 3114.92 MJ/ha was used by the farmers in the study area. The energy embodied in wheat seeds constitutes about 49.64% (1546.15 MJ/ha) of the total budget of energy due to the planting operation. The large confidence interval was recorded in seed energy, highlighting the wide variation in the seeding rate adopted by the farmers. The highest and lowest seed energies were 1760.27 and 912.00 MJ/ha, representing a seeding rate of about 115.81 and 60 kg/ha, respectively. The combined contributions of human labor, fuel, and machinery energy to the total energy accruing to the planting operation were 0.20%, 41.55%, and 8.61%, respectively.

Farmers in the study area applied different types of fertilizers, both organic and inorganic, at different rates and intervals. A total number of 1 to 3 fertilizer applications were made by all farmers in the study area during the season in which the research was conducted. The average fertilizer application frequency per farm was two. The fertilizer application was done mechanically using the collected data. Essentially, the data collection exercise for fertilizing operations covers four energy sources, including human labor, fuel, machinery, and fertilizer applied. The detailed results for energy fertilizer application are given in Table 3. Summary for the average total expended in performing wheat fertilizing application as indicated in Table 3 demonstrates that energy contained in fertilizer used by the farmers accounted for 34.66% (or 4132.06 MJ/ha) of the average total energy expenditure of 4132.06 MJ/ha, which accrued to fertilizing operations. The operational energy due to human labor, fuel, and machinery together recorded 22.34% of the total energy used in fertilizing operations. Analysis of the result further shows that human labor energy is not only the least contributor, with 5.24 MJ/ha, but also lags behind machinery energy expenditure by about 16.15 times. Thus, this indicates the high level of mechanization for the fertilizing operation, which is fully mechanized in Iraq. The recorded large confidence interval in fertilizer energy of 47.36 MJ/ha is indicative of huge variation in the use of fertilizer among the farmers.

Chemical application is intended to offer much-needed protection to wheat plants against disease, insect pests, and weed infestations that could hamper yield. In the area under study, farmers used about 15 types of assorted chemical pesticides on their wheat farms. Generally, the farmers used tractor-mounted sprayers when applying pesticides to their farms. The results for the distributed energy expenditure in pesticide applications are illustrated in Table 3. Analysis of the results presented in Table 3 shows that about 13.50%, representing 162.11 MJ/ha of the total average energy expended (1201.04 MJ/ha) in conducting pesticide application by the farmers, is from embodied energy in the pesticides used.

The harvesting operation of wheat is done mechanically in Iraq. The energy data for the harvesting operation comprises three inputs, namely human labor, fuel, and machinery, used in executing the operation. The results for the energy expenditures due to the three energy sources used in harvesting operations are presented in Table 3. Analysis of the results shown in Table 3 indicates that farmers utilized an average total expenditure of energy of 1773.87 MJ/ha in carrying out harvesting operations. The highest contribution of 1427.05 MJ/ha, representing 80.45% of the total average energy budget, came from fuel energy. The share contributions were for human energy at 0.53% (9.40 MJ/ha), which is the least significant contributor.

Table 3 Operations – wise energy expenditure wheat

Operations	HE MJ/ha	FE MJ/ha	ME MJ/ha	FE MJ/ha	CE MJ/ha	SE MJ/ha	Total MJ/ha
Tillage	10.5 ± 0.05	1582.29 ± 39.43	108.52± 3.27	Nil	nil	nil	1701.31 ± 42.75
Sowing	6.37 ± 0.12	1294.11 ± 33.72	268.29± 9.61	Nil	nil	1546.15 ± 49.95	3114.92 ± 93.4
Fertilizing	5.24 ± 0.20	833.27 ± 27.25	84.61 ± 1.63	3208.94 ± 18.28	nil	nil	4132.06 ± 47.36
Spraying	4.37 ± 0.15	954.29 ± 22.56	80.27± 1.37	Nil	162.11 ± 3.90	nil	1201.04 ± 27.98
Harvesting	9.40 ± 0.13	1427.05 ± 35.68	337.42±2 3.89	Nil	nil	nil	1773.87 ± 59.7
Total MJ/ha	35.88± 0.66	6091.01± 158.64	879.11±3 9.77	3208.94 ± 18.28	162.11 ± 3.90	1546.15 ± 49.95	11923.2 ± 271.19

As outlined earlier, five farm inputs were used by the farmers in wheat cultivation. The summary statistics for the inputs in energy equivalents are presented in Table 3. Direct energy sources (fuel and humans) accounted for about 51.39% of the total energy used in the cultivation, while indirect energy inputs (machinery, fertilizer, chemicals, and seeds) accounted for 48.61% of the total energy input. One of the (5) operations represented by fertilizer application comprised (4) inputs of energy, namely, fuel, machinery, human, and fertilizer energy. This application has contributed the highest share of 34.66% (4132.06 ±47.36 MJ/ha) of the total energy expenditure. The second highest energy expenditure is followed by 26.12% (3114.92 ± 93.4 MJ / ha) for sowing operations. Harvesting operations had a share contribution of 14.88% (1773.87 ± 59.7 MJ / ha). Tillage operations with three energy inputs have a share contribution of 14.27% (1701.31± 42.75 MJ / ha). Moreover, spraying operations were carried out with four inputs of energy, namely, the energy of humans, fuel, machinery, and chemical application, which denoted the least consuming operations of energy. The operation contributed to the overall expenditure of energy by 10.07% (1201.04 ± 27.98 MJ / ha), as revealed in Figure 1.

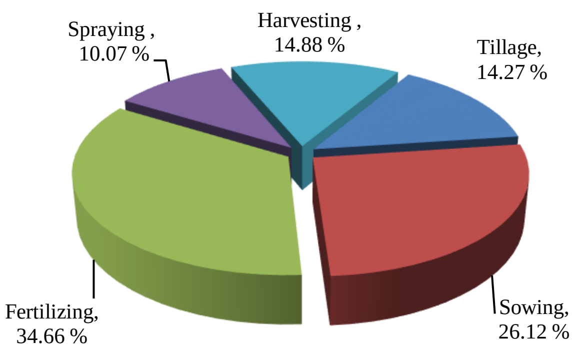

Figure 1 Operations-wise energy distribution

In terms of individual energy sources, the distribution of which is highlighted in Figure 2, energy exemplified in fuel recorded the highest rate of the total expenditure of energy, with 51.09 % (6091.01MJ/ha). The following rates were fertilizer energy, 26.91% (3208.94 MJ/ha), seeds energy, 12.97% (1546.15 MJ/ha), machinery energy, 7.37 % (879.11 MJ/ha), chemical energy, 1.36 % (162.11 MJ/ha) and human energy, 0.30 % (35.88 MJ/ha) .

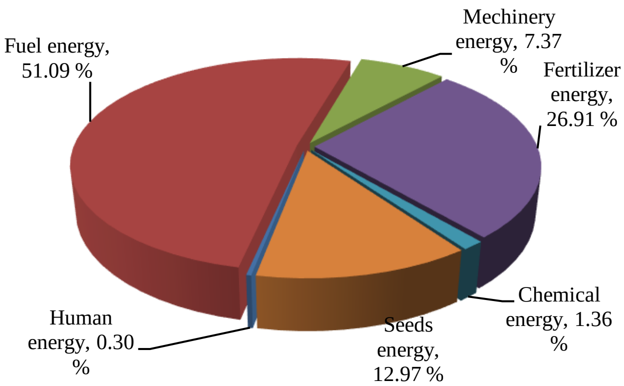

Figure 2 Energy distribution according to source

Results of analyzing expenditures of human energy demonstrated that in the area under study, farmers used nearly 35.88± 0.66 MJ/ha of human energy. However, this value is less than the recorded human energy that farmers used when working in farms of wheat in Gorgan, Iran, of 142 ± 26 MJ/ha (Soltani *et al.*, 2013); similar results (Safa and Samarasinghe 2011) got 6 % of machinery energy higher than human energy. The manual operations recorded about in tillage operation 29.26 %, harvesting 26.20 %, sowing 17.75 %, fertilizing 14.60 %, and spraying 12.18%) of the total human energy used in the season, as shown in

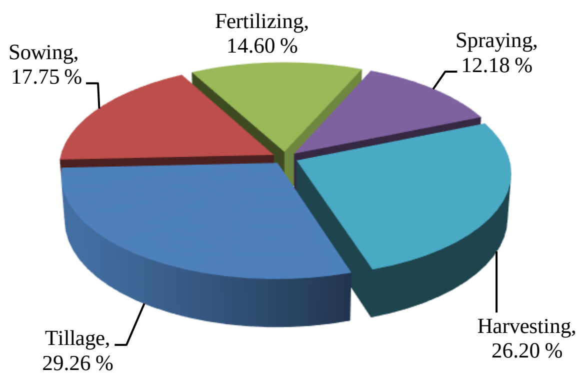

Figure 3 Distribution of human energy based operations

Farmers utilized nearly 879.11±39.77 MJ/ha of machinery energy (see Table 3) in carrying out the entire operations of cultivation. In the covered area, the highest rate of expenditure of machinery energy was in harvesting, which recorded 38.38 % (337.42 ± 23.89 MJ/ha) of the total energy of machinery used in the study. The following rates were recorded for operations of sowing, 30.52% (268.29± 9.61 MJ/ha), tillage operation, 12.34 % (108.52± 3.27 MJ/ha), fertilizing operation, 9.62 % (84.61 ± 1.63 MJ/ha), and spraying operation, 9.13 % (80.27± 1.37 MJ/ha) recorded less energy of machinery that farmers used in the study, as shown in Figure 4.

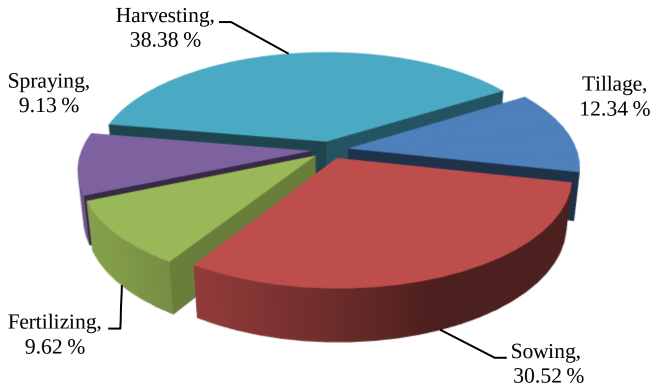

Figure 4 Distribution of machinery energy-based operations

Results of analyzing the energy of fuel that farmers utilized indicated that operations of tillage were about 25.98 % (1582.29 ± 39.43 MJ/ha) of the total energy of fuel. This rate denoted the highest operation of fuel consumption. Harvesting operations followed it. These operations were implemented through the use of engines powered with diesel were about 23.43% (1427.05 ± 35.68 MJ/ha). Sowing operation, 21.25 % (1294.11 ± 33.72 MJ/ha), spraying operation, 15.67 % (954.29 ± 22.56 MJ/ha), and fertilizing operation, 13.68 % (833.27 ± 27.25 MJ/ha) recorded less fuel energy that farmers used in the study, as shown in Figure 5.

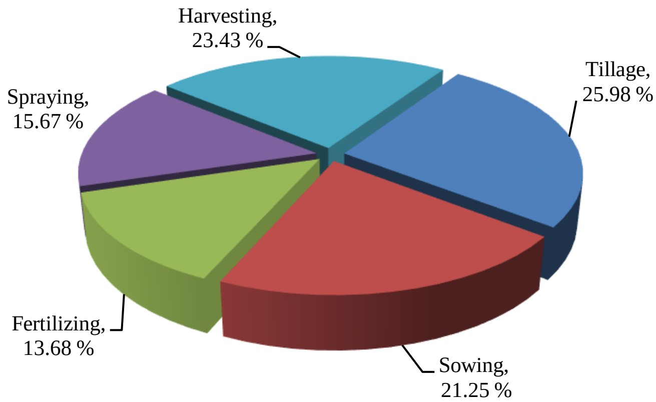

Figure 5 Distribution of fuel energy based operations

In the area under study, farmers were using an average of about 180.94 kg/ha of assorted fertilizers. Figure 6 demonstrates the distribution percentage for the three main mineral elements of fertilizer (Nitrogen, Potassium and Phosphorus), which were used by farmers. Results analysis indicated that the highest share was for nitrogen use (NUR) by

77.07 %, demonstrating an application rate of 24.73 kg/ha. Whereas, phosphorus (PUR) and potassium (KUR), respectively accounted for 15.21 % and 7.73 % of the total rate of using fertilizer. The rates of respective application for these two elements of fertilizer are 4.88 and 2.48kg/ha.

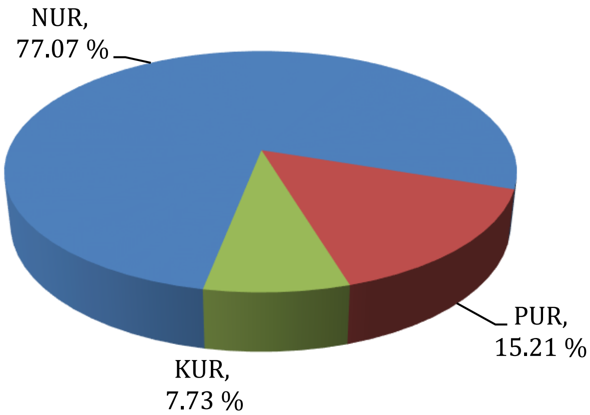

Figure 6 Distribution of NPK use rate by the farmers

Generally, nearly 2.19 kg/ha (162.11 MJ/ha) of assorted chemical applications were used by farmers in the area under study. This application comprised pesticides, fungicides, and herbicides. The energy content of herbicides takes the highest share, accounting for 60.65% (1.33 kg/ha) of the total chemical energy that the farmers used, as indicated in Figure 7. This is indicative of the high prevalence of weeds in comparison to infestation by fungal diseases and insects on the wheat farms in the covered area. The share contributions for pesticides and fungicides used in the study were about 30.66 % (0.67 kg/ha) and 8.69 % (0.19 kg/ha), respectively. In the study area, the least common chemical pesticides used by farmers were fungicides.

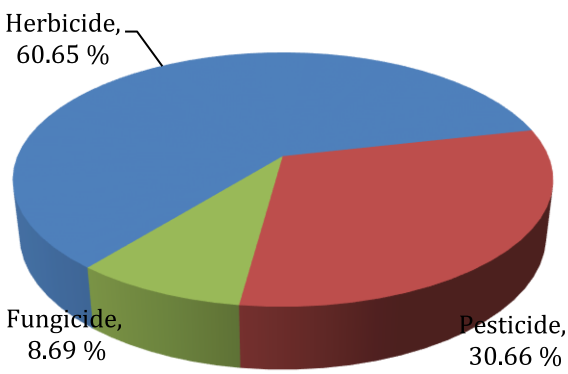

Figure 7 Distribution of chemical use rate by type

Accordingly, the energy ratio analysis for the cultivation of one hectare of wheat in the study area is summarized in Table 4. From the table, the average level of wheat yield in the covered area was found to be 4033.96 kg/ha. The average energy productivity of wheat crops was 0.56 kg/MJ. This means that 0.56 units of wheat crop output were obtained per unit of energy. The net energy gain and energy intensity of wheat crops were 45,238.30 MJ/ha and 1.79 MJ/kg respectively. Net energy is positive. Therefore, it can be concluded that in wheat crop production, energy is being acquired. The total mean input of energy in direct, indirect, renewable, and non-renewable forms is shown in Table 4. The total consumed energy of input could be categorized into direct energy (51.39 %), indirect energy (48.51%), renewable energy (13.27 %), and non-renewable energy (86.73%). Based on Table 4, in the area under study, farmers reaped nearly 7.28 times the energy they invested. Farmers produced one kg of wheat by using 1.79 MJ of one of the five sources of energy input utilized in the current study. In other words, farmers produce 560 g of wheat from 1 MJ of energy.

Table 4 Energy ratio analysis

Items	Unit	Value	Percentage (%)
Energy output	MJ/ha	52441.42	-
Energy input	MJ/ha	11923.20	100.00
Direct energy	MJ/ha	6126.89	51.39
Indirect energy	MJ/ha	5796.31	48.61
Renewable energy	MJ/ha	1582.03	13.27
Non-renewable energy	MJ/ha	10341.17	86.73
Energy use efficiency	-	4.40	-
Energy intensity	MJ/kg	1.79	-
Energy productivity	Kg/MJ	0.56	-
Net energy	MJ/ha	40518.22	-

CONCLUSION

The study aimed to assess the energy inputs and outputs of mechanized wheat production systems in Salah Al-Deen, Iraq, by collecting data from 45 wheat farms through face-to-face questionnaires in 2022. It analyzed five main operations: tillage, sowing, fertilizing, spraying, and harvesting. Direct energy sources, primarily fuel and human labor, accounted for 51.39% of the total energy input, with fuel being the largest contributor. Machinery energy was predominantly utilized in harvesting, while fuel energy was highest during tillage operations. The average yield for wheat cultivation in the study area was 4,033.96 kg/ha, with a total energy input of 12,539.57 MJ/ha. The energy use efficiency for wheat crops was determined to be 7.28, while the energy intensity remained at 1.79 MJ/kg. Approximately 37.61% of the total energy input for wheat cultivation originated from fossil-based, non-renewable resources, with fuel, machinery, fertilizer, and chemicals contributing about 22.15%, 3.20%, 11.67%, and 0.59%, respectively. Notably, fertilizer application exhibited high mechanization, with machinery energy surpassing human labor significantly. Overall, the study revealed a positive net energy gain, indicating the efficiency and sustainability of mechanized wheat production in the region.

CONFLICT OF INTEREST

The authors declare no conflicts of interest associated with this manuscript.

ACKNOWLEDGMENTS

The authors wish thank to the staff of the College of Agriculture, Tikrit University, for their technical and general support.

REFRANCES

Alwan, J. A., & Hassan, A. M. (2023). Evaluating the suitability of the lands of magnoon area (west of al anbar governorate) for the purpose of growing wheat crops using storie index. *Anbar Journal of Agricultural Sciences*, *21*(2), 575-589.

Ajabshirchi, Yahya. 2013. "Energy Input-Output , Optimization of Energy Consumption with DEA Approach for Corn Silage Production in Iran." *International Journal of Agriculture and Crop Sciences* 5:80–88.

Al-jughaify , S. F., A., & Sh. J. Alobaidy, B. (2023). Effect Of Osmo-Hardening Seed On K And Na Concentration And Some Growth Properties Of Wheat Under Salt Stress. *Anbar Journal Of Agricultural Sciences*, *21*(1), 32-43. doi: 10.32649/ajas.2023.179713

ASABE standard D497. 2006. "Agricultural Machinery Management Data American Society of Agricultural Engineers." 373–80.

Ashraf, Muhammad N., Mahmood, Muhammad H., Sultan, M., Banaeian, N., Usman, M., Ibrahim, Sobhy M., Butt, Muhammad U. B. U., Waseem, M., Ali, I., Shakoor, A., Khan, Zahid M., (2020). Investigation of Input and Output Energy for Wheat Production: A Comprehensive Study for Tehsil Mailsi (Pakistan). *Sustainability*. 12(17); 6884. https://doi.org/10.3390/su12176884

Barak, Sasan, Marziye Yousefi, Hamidreza Maghsoudlou, and Sanaz Jahangiri. 2016. "Energy and GHG Emissions Management of Agricultural Systems Using Multi Objective Particle Swarm Optimization Algorithm: A Case Study." *Stochastic Environmental Research and Risk Assessment* 30(4):1167–1187. doi: 10.1007/s00477-015-1098-1.

Bilalis, Dimitrios, Panoraia Eirini Kamariari, Anestis Karkanis, Aspasia Efthimiadou, Antonis Zorpas, and Ioanna KAkabouki. 2013. "Energy Inputs, Output and Productivity in Organic and Conventional Maize and Tomato Production, under Mediterranean Conditions." *Notulae Botanicae Horti Agrobotanici Cluj-Napoca* 41(1):190–94.

Canakci, M., M. Topakci, I. Akinci, and A. Ozmerzi. 2005. "Energy Use Pattern of Some Field Crops and Vegetable Production: Case Study for Antalya Region, Turkey." *Energy Conversion and Management* 46(4):655–66. doi: 10.1016/j.enconman.2004.04.008.

CFSVA. 2016. "Comprehensive Food Security and Vulnerability Analysis (CFSVA)." *World Food Programme* 1–480.

Dixon, J., a Gulliver, and D. Gibbon. 2001. "Chapter 2: Global Factors Influencing the Evolution of Farming Systems." *Global Farming Systems Study: Challenges and Priorites to 2030*. 10–17.

Flores, Edgar D., Renita S. M. Dela Cruz, and Ma Cecilia R. Antolin. 2016. "Environmental Performance of Farmer-Level Corn Production Systems in the Philippines." *Agricultural Engineering International: CIGR Journal* 18(2):133–43.

Ghorbani, Reza, Farzad Mondani, Shahram Amirmoradi, Hassan Feizi, Surror Khorramdel, Mozhgan Teimouri, Sara Sanjani, Sepideh Anvarkhah, and Hassan Aghel. 2011. "A Case Study of Energy Use and Economical Analysis of Irrigated and Dryland Wheat Production Systems." *Applied Energy* 88(1):283–88. doi: 10.1016/j.apenergy.2010.04.028.

Imran, M., & Ozcatalbas, O. (2020). Energy Use Efficiency in Irrigated and Rainfed Wheat in Pakistan. *Current Trends in Wheat Research*. Book chapter. doi: http://dx.doi.org/10.5772/intechopen.95284

Imran, M., ul Haq, S., & Ozcatalbas, O. (2021). Comparative analysis of energy use efficiency among Pakistani and Turkish wheat growers. *Renewable Agriculture and Food Systems*. 37(1): 83-91. doi.org/10.1017/S1742170521000351

Isaak, M., A. Yahya, M. Razif, and N. Mat. 2020. "Mechanization Status Based on Machinery Utilization and Workers' Workload in Sweet Corn Cultivation in Malaysia." *Computers and Electronics in Agriculture* 169. doi: 10.1016/j.compag.2019.105208.

Khoshnevisan, Benyamin, Shahin Rafiee, Mahmoud Omid, and Hossein Mousazadeh. 2014. *Development of an Intelligent System Based on ANFIS for Predicting Wheat Grain Yield on the Basis of Energy Inputs*. Vol. 1. China Agricultural University.

Kizilaslan, Halil. 2009. "Input-Output Energy Analysis of Cherries Production in Tokat Province of Turkey." *Applied Energy* 86(7–8):1354–58. doi: 10.1016/j.apenergy.2008.07.009.

Lorzadeh, Sh. A. Mahdavidamghan., Enayatgholizadeh M.R., and Yousefi M. 2012. "Reasearch of Energy Use Efficiency for Maize Production Systems in Izeh, Iran." *Acta Agriculturae Slovenica* 99(2):137–42. doi: 10.2478/v10014-012-0013-4.

Mani, Indra, Pradeep Kumar, J. S. Panwar, and Kamal Kant. 2007. "Variation in Energy Consumption in Production of Wheat-Maize with Varying Altitudes in Hilly Regions of Himachal Pradesh, India." *Energy* 32(12):2336–39. doi: 10.1016/j.energy.2007.07.004.

Mohammadi, Ali, Shahin Rafiee, Seyed Saeid, and Hamed Rafiee. 2010. "Energy Inputs – Yield Relationship and Cost Analysis of Kiwifruit Production in Iran." *Renewable Energy* 35(5):1071–75. doi: 10.1016/j.renene.2009.09.004.

Muazu, A., A. Yahya, and W. I. W. Ishak. 2015. "Energy Audit for Sustainable Wetland Paddy Cultivation in Malaysia." *Energy* 87:182–91. doi: 10.1016/j.energy.2015.04.066.

Nabavi-Pelesaraei, Ashkan, Reza Abdi, and Shahin Rafiee. 2016. "Neural Network Modeling of Energy Use and Greenhouse Gas Emissions of Watermelon Production Systems." *Journal of the Saudi Society of Agricultural Sciences* 15(1):38–47. doi: 10.1016/j.jssas.2014.05.001.

Nabavi-Pelesaraei, Ashkan, Reza Abdi, Shahin Rafiee, and Hassan Ghasemi Mobtaker. 2014. "Optimization of Energy Required and Greenhouse Gas Emissions Analysis for Orange Producers Using Data Envelopment Analysis Approach." *Journal of Cleaner Production Journal* 65(August):311–17. doi: 10.1016/j.jclepro.2013.08.019.

Ozkan, Burhan, Handan Akcaoz, and Feyza Karadeniz. 2004. "Energy Requirement and Economic Analysis of Citrus Production in Turkey." *Energy Conversion and Management* 45(11–12):1821–30. doi: 10.1016/j.enconman.2003.10.002.

Rathke, G. W., B. J. Wienhold, W. W. Wilhelm, and W. Diepenbrock. 2007. "Tillage and Rotation Effect on Corn-Soybean Energy Balances in Eastern Nebraska." *Soil and Tillage Research* 97(1):60–70. doi: 10.1016/j.still.2007.08.008.

Safa, M., and S. Samarasinghe. 2011. "Determination and Modelling of Energy Consumption in Wheat Production Using Neural Networks: 'A Case Study in Canterbury Province, New Zealand.'" *Energy* 36(8):5140–47. doi: 10.1016/j.energy.2011.06.016.

Sami M., M. Javad &. M. Almassi. 2014. "Analysis of Energy and Greenhouse Gas Balance as Indexes for Environmental Assessment of Wheat and Maize Farming: A Case Study." *Acta Agriculturae Slovenica* 103(2):191–201. doi: 10.14720/aas.2014.103.2.4.

Shafique Q. M., N. Amjad, R. A. Dayo &. G. Jarwar. 2015. "Energy Requirement and Energy Efficiency for Production of Maize Crop." II(11):14609–14.

Shaaban, H., W., & Omer, A. F. (2023). Evaluation of bread wheat cultivars in terms of spike and yield properties under various concentrations of soil and foliar fertilization. *Anbar*

Journal of Agricultural Sciences, *21*(2), 261-275.

Singh, Gurdeep, Singh, Pritpal, Sodhi, G.P.S. and Devinder, Tiwari, (2021). Energy auditing and data envelopment analysis (DEA) based optimization for increased energy use efficiency in wheat cultivation (Triticum aestium L.) in north-western India. *Sustainable Energy Technologies and Assessments*. 47(1); 101453. https://doi.org/10.1016/j.seta.2021.101453

Soltani, Afshin, M. H. Rajabi, E. Zeinali, and Elias Soltani. 2013. *Energy Inputs and Greenhouse Gases Emissions in Wheat Production in Gorgan, Iran*. Vol. 50. Elsevier Ltd.

Tabatabaie, Seyed Mohammad Hossein, Shahin Rafiee, Alireza Keyhani, and Amirhossein Ebrahimi. 2013. "Energy and Economic Assessment of Prune Production in Tehran Province of Iran." *Journal of Cleaner Production* 39:280–84. doi: 10.1016/j.jclepro.2012.07.052.

Taki, M., H.G.Mobtaker, and N. Monjezi. 2012. "Energy Input – Output Modeling and Economical Analyze for Corn Grain Production in Iran." 52:11500–505.

Turky, Thaer, Momtaz Isaak, Naseem A. Hassan, and Khalid Sabah. 2023. "Mechanization Status and Its Technical Indicators and Its Impact on the Production of the Wheat Crop." *Agricultural Engineering* 1(1):75–85.

Yadav S.N., R. Chandra, T. K. Khura &. N. S. Chauhan. 2013. "Energy Input-Output Analysis and Mechanization Status for Cultivation of Rice and Maize Crops in Sikkim." *Agricultural Engineering International: CIGR Journal* 15(3):108–16.

Yousefi, Mohammad, Abdolmajid Mahdavi Damghani, and Mahmud Khoramivafa. 2014. "Energy Consumption, Greenhouse Gas Emissions and Assessment of Sustainability Index in Corn Agroecosystems of Iran." *Science of the Total Environment* 493:330–35. doi: 10.1016/j.scitotenv.2014.06.004.