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A COMPARATIVE STUDY ON ENERGY USE OF RICE (*Oryza sativa* L.) CULTIVARS UNDER MECHANIZED CROPPING SYSTEMS IN WEST OF TURKEY

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Abstract: The study was performed energy analysis of mechanized rice production for two rice cultivars under a region, named Çanakkale, in West Turkey. The indicators are energy use efficiency, specific energy, energy productivity and net energy. The cultivars of rice commonly grown in the region are listed in two groups: native and high yield hybrid. Primary data were obtained through field survey with farmer's interviews face to face with a questionnaire in Biga, Ezine and centre districts, commonly rice cultivation areas in the region. Secondary data and energy equivalents were obtained from available literature using collected data of the production period of 2020–2021. Analysis of data showed that averagely diesel had the highest share within the total energy inputs as 46.46% and 45.72% for native and hybrid, respectively, followed by chemical fertilizers with 24.19%, and 23.80%, especially nitrogen. Water input was the third highest share with 11.29% and 11.60% for native and hybrid, respectively. Machinery input had fourth share in total, but it showed similar percentage with around 8.00% in both cultivars because of receiving similar machinery operations. Another high input was pesticides with around 4.00% because herbicides using is very high, especially for annual and perennial sedges and broadleaf weeds. Labour is the optimum level because of cultivation practices are usually performed by mechanical power. Net energy was found higher in hybrid cultivar with 101.41MJ ha^{-1} due to higher grain and straw yield than native with 84.01 MJ ha^{-1}. The energy use efficiency and energy productivity of nature cultivar were 2.3 and 0.12 kg·MJ^{-1}, respectively, corresponding to increases of 2.5 and 0.13 kg·MJ^{-1}in hybrid. With appropriate agronomic measures in rice production in the study area, higher yield of hybrid cultivar would necessarily lead to an increase in energy productivity and gain.

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Key words: *Energy analysis, energy indicators, rice cultivars*

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the important principal food crops that feeds more than half of world's population. Rice production areas in world cover around 162 million hectares comprising about 11% of all arable lands which annually produces approximately 758 million ton [1]. The main producer countries are Chin, India, and other Asian countries while Turkey is ranked at thirty-seven.

China is the largest rice producer in the world with 211 million tons production volume per year, and India comes second with 159 million tons yearly production.

Although, worldwide agriculture production has defeated the population growth [2], still there is a challenge to providing feed for huge population with sustainability and so, it felt urgent need of find mitigation and adaptation practices to minimize the impact of crop cultivation on climate change, especially rice provides food a half of the world population, particularly in developing countries subjected to intense demographic growth [3].

In Turkey, due to the low of subsidies, farmers have taken on more costs for fuel as well as chemical fertilizer and electricity for irrigation, particularly for rice production which is one of the important crops among cereals. Meanwhile, rice consumption and then its production has steadily been increasing in the country although wheat is the main crop. In annual, rice production in the country was reported to be more than 920 thousand tons [4] with 116 thousand hectares with 7930 kg ha^{-1} on average yield depending on cultivar. Marmara Region, one of the considerable rice production areas of the country, produces more than 71 percentage of total rice production. Osmancık-97 and Baldo are the well-known nature cultivars among farmers and consumers and have dominated the region for many years. However, new hybrid cultivars such as Cammeo, Galileo, Ronaldo, and Luna are catching farmers' attention in term of high yield and milling rates. Nonetheless, the country still has rice importing with more than 225 thousand tons per year. Therefore, efforts are required to increase the production of rice sustainably, but effective energy use is needed to reduce production costs and preserving fossil resources and decreasing environmental pollution. South of the Marmara Region of the country, especially Çanakkale, is one suitable region for rice production in terms of favourable climate and abundant water resources according to many other parts. The region keeps fourth rank with 11348 hectares (9.3%) in rice production at national level. The mechanization degree is showing high level in the application of farm machinery for rice production, but it varies due to variations in climate, culture, technology adaptation, cropping systems, crop season, farming conditions and seed cultivars. Optimal use of improved farm machinery coupled with optimal use of other recommended resources allow an increase in rice yield up to potential levels.

Energy is used in every stage of the crop production process agriculture, from soil tillage to harvesting as well as drying and storage stage. Therefore, identifying sustainable rice cultivation methods using cultivar with different yields is crucial to ensure food security for a growing population. Energy is also a key input of agriculture and agriculture production positively correlated with energy input. In recent years, energy input in agriculture, like fuel and electricity, has been highly affected by changes in country energy policy.

The energy analysis of agricultural ecosystems is a promising approach to assess the energy efficiency, and their impact on environment [5].

On the other hand, the countries like Turkey, energy consumption in agriculture is much lower than the other sectors, energy use as both input and output of agricultural sector is a very important issue due to its large agricultural potential and rural area. Also, energy consumption in such areas based on farm conditions (size of crop area), farmer's social considerations such as level of education, and energy inputs including fertilizer, water, etc. Studies on this aspect help in identifying or developing more energy efficient technologies, with low adverse environmental impacts and improvement in natural resource conservation. So, many studies were devoted on exploring yield performance and nitrogen use efficiency of different methods of rice production under rainfed and controlled irrigation. Nonetheless, few studies have been conducted to determine energy efficiency of rice cultivation with different cultivars in similar or different agro-ecologies conditions. But very few studies compared different rice cultivar due to yield. In this study, we hypothesized that rice production with hybrid cultivar reduces the energy use and increase net energy comparing and nature. The objective of this study was to identify a cultivar with optimum energy consumption that had maximum productivity, energy use efficiency and low environmental impacts.

MATERIALS AND METHODS

Study area and climate

The study was carried out in Çanakkale region, South of the Marmara Region of west Turkey (Figure 1). The region is located between 39°27′-40°45′ Lat. N and between 25°40′-27°30′ Lon. E, covering a total area of 993318 hectares, cropping area of 331633 hectares and a rice cropping area of 383367 decare, which is a total of 7.52% of the rice areas in the country. Topographic elevations vary between 0 and 100 metre above sea level (Figure 1). Agriculture in the region is intensively irrigated, mechanized and input-intensive (Figure 1). Rice is usually cultivated under continuous flooding irrigation with full water control, despite the introduction of drip irrigation in recent years. The climate of the study area is semiarid subtropical with extreme summers and severe cold winters. The northern parts of the region experience cold weather, whereas the southern parts experience tropical weather. Summer is from May to September, and winter is from October to April. Annual mean of maximum summer temperature is about 28°C (in August) according to the long-term period, and annual mean of minimum winter temperature is 6 °C (in January) (Figure 2). The annual total rainfall is varying from 460 mm to 715 mm according to years, and about 65% of annual rainfall events occur from December to May (Figure 3).

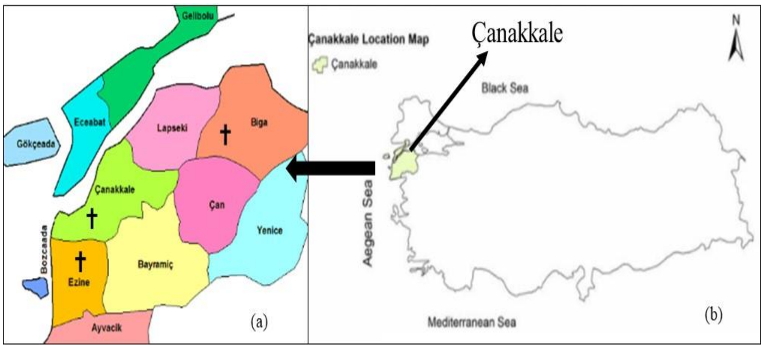

Fig. 1. Location of the study area in the country (b).,
farms in surveyed three-district (a).

In this area, rice is usually grown under mechanized system, but human labour is still using in some cultivation practices. In general, the average farm size is very small in the area. The most of rice farmers have 20 to 30 decare (1 decare =1000 m^2), area for the rice production. Only a few farmers have 1000 to 2000 decare size. The cultivars of rice commonly grown in the region are listed in two groups as native (*Baldo, Osmancık-97, Yatkın*) and hybrid (*Cameo*, *Vasco*, *Luna*) cultivars. Farmers usually prefer hybrid cultivars which open new options and flexibility under prevailing weather conditions. They may also enhance land use efficiency following winter season because crops stay for short duration in field and leaving enough time for the succeeding crops during autumn and winter season. These cultivars also are increasing crop productivity and probability per unit area because cost is one of the major goals of agriculture farming. The study was conducted from only three districts of the region, named is Biga, Ezine and center (Figure 1). Data were collected from 65 farmers in three districts by a questionnaire. Observations and surveys were performed face to face with farmers during production season of 2020-2021. Farms were determined by using Neyman method by Yamane [6] with following equation.

$$n = \frac{N^2 \ x \ s^2 \ x \ t^2}{(N-1)\, d^2 + (s^2 \ x \ t^2)} \tag{1}$$

Where, n, the required sample size; N, the number of rice farmers in the target population; s, the standard deviation; t, the t-value at 95% confidence limit (1.96); d, the acceptable error. In addition to the data collected by the questionnaire, the secondary data used in the study were collected from the previous studies [7] and publications by some institutions such as TUIK (Turkish Statistical Institute), and other government agencies, Çanakkale Directorate of Provincial Agriculture and Forestry. the questionnaire included all kinds of inputs such as seed, fertilizer, pesticides, fuel, and water, supplied to the crop and use of different power sources such as human and agricultural machinery as well as output of farms as the yield of main product (grain) and by-product (straw).

The first, all inputs and outputs for rice production were determined, quantified and entered into Microsoft Excel spreadsheets, and then transformed into energy units and expressed in MJ ha^{-1}.

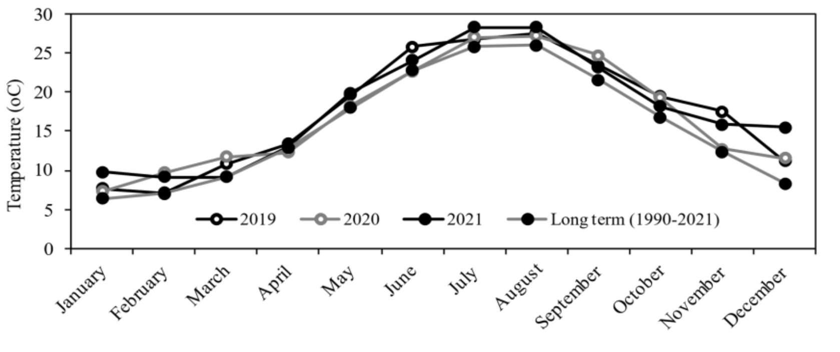

Fig. 2. Average temperature according to months for three years and long-term

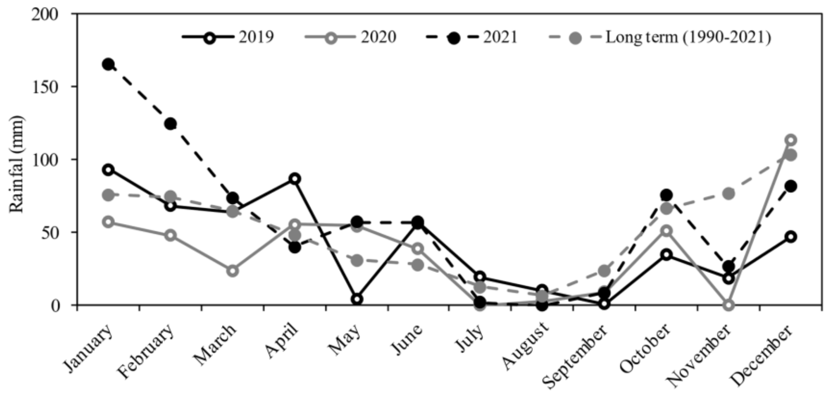

Fig. 3. Rainfall distribution according to months for three years and long-term period

Rice production

There are different farming practices in the area for rice production due to seasonal soil tillage and seedbed preparation in autumn following by previous crop harvest time, and in spring season. A brief description of these soil preparation practices is presented in Table 1 and 2 for autumn and spring season, respectively. Field operations began with disposal of the straw by soil incorporation or removal from the field. Tillage may be done in fall or may be postponed until spring under wet conditions, but generally begins as early as possible.

Tillage with mouldboard plough is carried out in 20 to 25 cm depth followed by shallow tillage performed with a disk harrow or a field cultivator, and rotovator. Soil levelling is done with leveller blades after the first ploughing under dry conditions.

The laser is usually used in larger farms and allows a uniform water depth within the basin. Before flooding the field, the fertilizer and pre-emergence herbicide are applied and incorporated into the soil with a spike-tooth harrow followed by pressing of the soil with the leveller to press soil surface before seeding. Seeding is done by seed drill with iron wheel, while some farmers also broadcast pre-soaked seed (ungerminated) with centrifugal fertilizer broadcaster into water.

Seed rate is 200 kg per hectare for long-large grain size cultivars and it is 170-180 kg per hectare for medium grain type and 150 kg for small grain cultivars. Under both season tillage practices, different soil tillage equipment is used for the first deep tillage operation (Table 1, 2), for example mouldboard plough and disc harrow are usually used in autumn where mouldboard plough and chisel are performed in spring season. Other equipment is used in both season with different times such as disc harrow, spring cultivator, rotovator, centrifugal fertilizing broadcaster, soil lever, sprayer, laser, and seed drill. Farmers are preferred autumn time practices because of operation time is very limited in spring to prepare the seedbed on time for seed drill practice. For this reason, in this study, the applications in the autumn model-1 were taken to determine energy input and output. Weed control, one of the major challenges toward rice production in the study area, is often performed by sprayer before seeding. Some characteristics of agricultural machinery such as field speed, field efficiency and working widths required for the effective field capacity were obtained from the equipment commonly used in the study area.

Table 1 Agricultural practices in autumn rice production systems and their estimated fuel consumption, model-1

Time	Machinery	Practice	Fuel (l ha^{-1})
Second week November	Mouldboard plough	Soil tillage at 20-25 cm	40
Second week April	Heavy cultivator	Incorporation crossing soil tillage	10
Third week April	Heavy disc harrow	Breaking soil clods-3 times	30
Fourth week April	Spring cultivator	Incorporation crossing soil tillage-2 times	20
First week May	Vertical rotovator	Breaking soil clods	20
First week May	Laser	Levelling	45
First week May	Centrifugal fertilizer	Applying fertilizer	2
First week May	Spike-tooth harrow	Mixing on soil surface-3 times	12
First week May	Leveller	Pressing soil surface before seeding	2
First week May	Mounted sprayer	Applying the pre-seeding herbicides	2
Second week May	Seed drill with iron wheel	Seeding	2
First week October	Combine	Harvesting	18

Table 2. Agricultural practices in spring rice production systems and their estimated fuel consumption, model-2

Time	Machinery	Practice	Fuel (l ha^{-1})
Second week April	Mouldboard plough	Deep soil tillage	40
Fourth week April	Chisel (curved arm)	Incorporation deep soil	10
Fourth week April	Heavy cultivator	Incorporation crossing soil tillage	10
First week May	Heavy disc harrow	Breaking soil clods-2 times	20
First week May	Laser	Levelling	45
First week May	Centrifugal fertilizer	Applying fertilizer	2
First week May	Spike-tooth harrow	Mixing on soil surface-3 times	12
First week May	Leveller	Pressing soil surface before seeding	2
First week May	Mounted sprayer	Applying the pre-seeding herbicides	2
First week May	Seed drill with iron wheel	Seeding	2
First week October	Combine	Harvesting	18

Nitrogen and phosphorus fertilizer with zinc compound are usually used for rice crop in the country as well as in the region. Soils have enough available potassium, therefore no-potassium application is done for rice crop. Fertilizer rate is $N_{150}P_{80}Zn_{15}$ per hectare. Nitrogen is applied in three times; the first, second, third parts are at the pre-planting, tillering, panicle initiation, respectively. Under irrigation with continuous flooding, nitrogen is applied in the form of ammonium sulphate or urea. All phosphorus and zinc are used at the pre-planting. Rice harvesting time varies from September 15 to October 30 in the study area at 45 to 50 days after flowering. Early harvesting may reduce the head yield of rice owing to the presence of immature kernels as well as grain yield in unit area. Late harvesting may also reduce grain yield in unit area because of grain shattering and lodging. Rice is directly harvested with combine and the crop is dried to a storable moisture of 13 to 14 percent.

Energy analysis procedures

The energetic efficiency of the agricultural system has been evaluated by the energy rate between output and input. Human labour, machinery, diesel fuel, chemical fertilizers and pesticides, seed, water, electricity, etc., and output values such as rice grain and straw yield have been used to estimate the energy rate. Energy equivalents shown in Table 3 were used for estimating the input and output energy. Agricultural energy consumption may be divided into four energy categories: direct, indirect, renewable, and non-renewable. Direct energy is defined as the energy used to power (diesel fuel as thermal) the agricultural machines used in the soil tillage and preparation or harvesting stages [8], and manual. Indirect energy comprises of energy inputs in manufacturing of machinery and raw materials such as chemical fertilizers, pesticides, seed and transportation. Non-renewable energy includes machinery, chemical fertilizers, pesticides, and diesel fuel while renewable energy includes seed, water, and human labour. A complete inventory of all inputs (fuels, fertilizers, seed, pesticides, human labour, irrigation water and, machinery power) and outputs of both rice grain and straw yields were recorded from the surveyed forms. Energy inputs in different studies were computed by multiplying the inputs with the corresponding energy coefficients and summation of all these components. For this study, the energy coefficients were taken from the literature (Table 3), but they varied in different studies due to differences in calculations and spatial and temporal system boundaries.

Due to this, the results of different studies are not comparable. So, the energy coefficient values from different studies conducted in similar environments were used in the present study (Table 3).

Manual energy input was determined by multiplying the number of persons engaged in an operation by the man hour requirement [9].

The energy contribution from male (E_m) and female (E_f) labour were estimated using equation (1) and (2), respectively.

$$E_m = 3.6\ (0.075 \text{ x N x T}) \quad (1)$$
$$E_f = 3.6\ (0.065 \text{ x N x T}) \quad (2)$$

Where, T is the useful time spent by the person per unit operation.

N shows the number of persons involved in an operation at the maximum continuous energy consumption rate of 0.30 kW and conversion efficiency of 25%, respectively.

Table 3 Energy coefficients of different agricultural inputs and outputs

Particulars	EC (MJ unit^{-1})*		Reference
A. Inputs			
1.Human labour	1.96	MJ man h^{-1}	[10]
2.Machinery**	62.70	MJ kg^{-1}	[11]
2.1. Tractor	138	MJ kg^{-1}	[12]
2.2. Chisel plough	149	MJ kg^{-1}	[12]
2.3 Mouldboard Plough	180	MJ kg^{-1}	[12]
2.4. Disc harrow (heavy)	149	MJ kg^{-1}	[12]
2.5. Spring cultivator	148	MJ kg^{-1}	
2.6. Seed drill	133	MJ kg^{-1}	[12]
2.7. Centrifugal fertilizer	129	MJ kg^{-1}	[12]
2.8. Mounted sprayer	116	MJ kg^{-1}	[12]
2.9. Combine	116	MJ kg^{-1}	[12]
3.Diesel***	56.31	MJ l^{-1}	[12]
4.Chemical fertilizer			
4.1. Nitrogen (N)⸸	78.1	MJ kg^{-1}	[12]
4.2. Phosphate (P_2O_5)⸸⸸	17.4	MJ kg^{-1}	[12]
4.3. Zinc (Zn)	8.40	MJ kg^{-1}	[13]
5.Pesticide			
5.1. Insecticides	184.63	MJ kg^{-1}	[14]
5.2. Herbicides	255	MJ kg^{-1}	[14]
5.3. Fungicides	115	MJ kg^{-1}	[12]
6.Water for irrigation	1.02	MJ m^{-3}	[11]
7.Seed	14.57	MJ kg^{-1}	[12]
8.Electricity	11.93	MJ kWh^{-1}	[12]
B. Outputs			
1.Grain (rice)	14.57	MJ kg^{-1}	[14]
2.Straw (rice)	12.50	MJ kg^{-1}	[14]

*Energy coefficients; **excluding self-propelled machines; ***including cost of lubricants; ⸸,production (69.5) and PTA (packaging, transportation, application, 8.6); ⸸⸸production (7.6) and PTA (packaging, transportation, application, 9.8); ⸸⸸⸸,production (6.4) and PTA (packaging, transportation, application, 7.3).

Diesel (thermal) energy (E_d) was estimated by multiplying the quantity of total fuel used in different farm operations by its lower heating value for rice crop production [9]. The diesel energy input was determined using the following equation (3):

$$E_d = 47.8 \times D \tag{3}$$

Where,

E_d, the diesel energy consumed (MJ);

47.8, the calorific (lower heating) value of diesel fuel (MJ l^{-1});

D, the quantity of diesel fuel consumed per unit operation (l).

The machinery input energy (indirect) was calculated by computing the production energy of tractors and agricultural machines per unit area using the following equation (4).

$$E_m = \frac{\text{M x E}}{\text{L x C}_e} \tag{4}$$

Where,
E_m, total machinery input energy for agricultural machinery in the lifetime allocated to one hectare (MJ ha^{-1});
M, the mass of tractor and machinery (kg);
E, the energy coefficient to manufacture, transport and repair (for tractor, 76 MJ kg^{-1} and farm machinery, 111 MJ kg^{-1}) (transport and repair) (Table 3);
L, the economic life of tractor and machinery (h);
Ce, the effective field capacity of farm machinery (ha h^{-1}).

Fuel consumption in different tillage operations depends on depth and width of ploughing, soil type, moisture content, tractor size, and the equipment used (Table 1, 2). So, fuel consumptions in different tillage operations, which were done with different tillage implements drawn by a 45 HP two-wheel drive tractor, were estimated.

$$C_e = \frac{\text{V x W x E}_f}{10} \tag{5}$$

Where,
W, the working width (m);
V, the working speed (km h^{-1});
E_f, the field efficiency. Chemical energy input was obtained from the quantity of fertilizer and herbicides (kg) used.

The NPK 20:20:0 fertilizer was the most widely used in the study area, and sometimes combined with Zn. The energy equivalent for a kilogram of NPK fertilizer was obtained from the rate of its elements (N P K) in a 50 kg bag of the fertilizer. The total chemical energy input was calculated by multiplying the quantity of fertilizer used by its energy equivalent value as shown in equation (6). Also, the chemical energy input from pesticides (especially herbicides) was obtained using equation (7).

$$E_{fert} = \sum_{n=1}^{n} \left(\frac{Nx\text{N}_{eqv}}{AP} + \frac{\text{P}_2O_5x\text{P}_{eqv}}{AP} + \frac{\text{K}_2O\text{xK}_{eqv}}{AP} \right) \tag{6}$$

Where,
E_{fert}, the chemical energy fertilizer;
N_{eqv}, the energy equivalent value of N;
P_{eqv}, the energy equivalent value of P_2O_5;
K_{eqv}, the energy equivalent value of K_2O; N, the compound fertilizer rate applied percentage of N ingredient (kg); P_2O_5, the compound fertilizer rate applied percentage of P_2O_5 ingredient (kg); K_2O, the compound fertilizer rate applied percentage of K_2O ingredient (kg);
AP, the planted area (ha); n, the compound fertilizer for applied time nth.

$$E_{herb} = H_{herb} \times H_{eqv} \quad (7)$$

Where,
E_{herb}, the chemical energy herbicide;
H_{herb}, the quantity of herbicide used (kg);
H_{eqv}, the energy equivalent value of herbicide.

Biochemical energy sources are the amount of energy stored in the rice seed. The biological energy input in rice production was calculated using equation (8).

$$E_{bio} = Q_{seed} \times Q_{eqv} \quad (8)$$

Where, Q_{seed}, the quantity of seed planted (kg ha^{-1}) and
Q_{eqv}, the energy equivalent of rice (MJ kg^{-1}).

Canal water is not used in any of the studied farms, therefore, only well water was calculated. The energy required for pumping water (E_{ir}) from a well was calculated using the following equation (9).

$$E_{ir} = r \times g \times H \times \frac{Q}{Ep} \times Eq \quad (9)$$

Where,
r, water density (1000 kg m^{-3});
g, the acceleration due to gravity (9.80 m s^{-2});
H, total depth of dynamic head (m);
Q, the volume of water required for one season (m^3 ha^{-1});
Ep, the pump efficiency (80%);
Eq, total power conservation efficiency (20%).

Transmission and production efficiencies were also considered for estimation of irrigation energy. Transportation to storage facilities was done with tractor and trailer. The energy input in transportation consists of thermal, manual, and mechanical energy. Energy required (MJ) in transportation (E_{trans}) was estimated by measuring the time involved in the operation which include time spent on loading and off-loading the rice in equation (10).

$$E_{trans} = 4.8 \times D + 3.6\ (0.075 \times N \times T) + \frac{M \times E}{L \times C_e} \quad (10)$$

Land preparation, planting, weeding, fertilizer application and harvesting were done mechanically in all the farms questioned. For land preparation, the amount of fuel consumed by the tractor in litres per hectare and the time taken by the operator to perform the operation were recorded.
The energy required (MJ) for each field practice (land preparation, planting, weeding, fertilizer application, harvesting, transportation) was obtained from equation (11). The technical properties of all farm equipment were presented in Table 3

$$E_{field-practice}=3.6\ (4.8 \times D) + 3.6\ (0.075 \times N \times T) + \frac{M \times E}{L \times C_e} \quad (11)$$

The amount of output energy (MJ ha^{-1}) is estimated by multiplying the rice and straw yield (kg ha^{-1}) by rice and straw energy equivalent (MJ kg^{-1}) as mentioned in Table 3). Total output energy of rice was estimated as a sum of the total energy from grain and straw yield in equation (12).

$$E_{output} = Q_{grain\text{-}yield} \times Q_{grain-eqv} + Q_{straw\text{-}yield} \times Q_{straw-eqv} \quad (12)$$

Where,
$Q_{grain\text{-}yield}$ is the quantity of grain yield (kg ha^{-1});
$Q_{grain\text{-}eqv}$ is the energy equivalent of rice grain (MJ kg^{-1});
$Q_{straw\text{-}yield}$ is the quantity of straw yield (kg ha^{-1});
$Q_{straw\text{-}eqv}$ is the energy equivalent of rice straw (MJ kg^{-1}).

Based on the total energy equivalents of the inputs and outputs, energy use efficiency, energy productivity, specific energy and net energy were used to evaluate the performance of energy usage in rice farms They were calculated using the following equations (13-17) as suggested in literature [15, 16]. Net energy refers to the difference between the energy consumed in producing a product and the sum of energy gain from the product. The energy rate describes the relationship in a production process between energy outputs and inputs. Energy productivity is also an important indicator for evaluating the energy use efficiency, and the amount of economic output for each unit of energy consumed. Specific energy is the energy consumed to produce a unit mass of a product.

$$\text{Net energy (MJ ha}^{-1}) = \text{Total energy output} - \text{Total energy input} \quad (13)$$

$$\text{Energy use efficiency (energy rate)} = \frac{\text{Total energy output (MJ ha}^{-1})}{\text{Total energy input (MJ ha}^{-1})} \quad (14)$$

$$\text{Energy productivity (kg MJ}^{-1}) = \frac{\text{Grain and straw yield (kg ha}^{-1})}{\text{Total energy input (MJ ha}^{-1})} \quad (15)$$

$$\text{Specific energy (MJ kg}^{-1}) = \frac{\text{Total energy input (MJ ha}^{-1})}{\text{Grain and straw yield (kg ha}^{-1})} \quad (16)$$

$$\text{Energy profitability} = \frac{\text{Net energy (MJ ha}^{-1})}{\text{Total energy input (MJ ha}^{-1})} \quad (17)$$

RESULTS AND DISCUSSION

Energy consumption is one of the important indicators of crop performance and environment sustainability; higher energy use efficiency with less input is required for improving livelihood security of millions of rural household practicing rice cultivation.

Energy requirement and its production potential largely depend on inputs used, it is also affected by crop the cropping systems, cultivation practices, and type. The total energy requirement of the system was significantly varied with the methods of establishment and rice cultivars (Table 4). Good levelling of the soil to be cultivated rice seed germination of seedlings, healthy growth, weed control and weed enhancement of the effectiveness of pesticides is very important. Soil levelling is done in small parcels with levelling blades, in larger parcels with lightweight graders, or with a laser machine. With the use of laser, a 20% increase in yield is achieved. During the studies in the farms, the amount of rice produced per hectare during the 2020-2021 production season was calculated as an average of 8990 and 8000 kg for hybrid and nature, respectively. Grain energy output was directly related to the productivity. Hence, the highest grain energy output was observed in the hybrid cultivar (130,830 MJ ha^{-1}) compared to nature (117,600 MJ ha^{-1}) (Table 4). This was mainly because of higher yield in hybrid cultivar (8990 kg ha^{-1}) than that of nature (8000 kg ha^{-1}). This was also expressed by the farmers participated questionnaire that they cleared particularly the hybrid cultivars provided more rice grain yield as well as high profits. In addition, hybrid cultivars have higher grain yields per unit area due to their higher resistance to pests than natural cultivars. Similar results were observed in total energy output including crop straw. The total energy output for hybrid and nature cultivars were calculated as 168,330 and 148,850 MJ ha^{-1}, respectively (Table 4). However, it is stated that generally the farmers do not collect the crop residues at the end of a crop season since these were returned to the soil. The energy equivalents were same for both the cultivars, which imply that there was no effect on the grain energy returns. The weight of straw harvested is 1.2 times higher (3000 kg ha^{-1}) in hybrid cultivar than nature (2500 kg ha^{-1}), therefore the straw contains large amount of energy, which is much higher (37,500 MJ ha^{-1}) than the energy of nature cultivar (31,250 MJ ha^{-1}) straw. The energy output for straw increased by 6250 MJ with using hybrid cultivars while correspond value was 13,230 MJ for grain (Table 4).

The highest energy inputs for both type cultivars were the fuel around 45%, but it was higher with 46.46% in nature compared to hybrid with 45.72% (Table 4). The results of study indicated that fuel input plays an important role in energy input for rice production. In particular, fuel consumption in tillage and harvesting is more than in other operations in rice production. In general, there is a considerable reason for high diesel consumption in the study area due to old machineries and irrigation pumps. One of the main reasons for high consumption of diesel fuel is a temporal depreciation of machinery particularly in the tractors and tillage equipment.

In order to improve the energy consumption as well as reduction of diesel fuel in rice producing system, it is powerfully suggested that the machinery's efficiency is increased with new machineries and equipment such as tractor, tillage and irrigation pumps.

The total energy equivalent of the chemical fertilizer consumption was ordered as second component among energy inputs and constituted 15,928 MJ ha^{-1} of the total energy input for both cultivars with 23.80% and 24.19% rate for hybrid and nature cultivar, respectively. Analysis of data showed that energy input of nitrogen fertilizer has the highest share (around 91%) within all chemical fertilizers. It has been reported that the energy input of chemical fertilizer has the biggest share of the total energy input in crop production while machinery had the most significant impact on rice production.

Similarly, several researchers reported that the energy used by fertilizers represented a major part of the total input energy around 40-70% of total compared with other input requirements [14, 17].

In most previous rice production studies, fertilizer accounted for the largest share of total energy input, with the energy input of nitrogen ranking top among all fertilizers[9], which agrees with the findings of the present study (Table 4). Fertilizer, fuel, and water were the three highest energy inputs and accounted for 81.78% of total energy input, regardless the cultivar. Hence, to reduce total energy input for rice production, it is essential to control fertilizer, fuel, and water inputs. Consume energy for irrigation water was the same in both rice cultivars and consist of approximately 12.00% (Table 4). Irrigation water and its operation consumed the maximum energy on rice farm due to the higher water requirement of rice crop and the electrical energy is mainly utilized by motor pumps to run irrigation pump set. Similarly, Pimentel and Pimentel [18] reported that irrigation energy requirement for rice production in the United States of America is 8949.6 MJ ha^{-1} (18.10%) of the total energy requirement. However, Alipour. et al. [19] found that in rice study the irrigation energy had the highest share with 38.84% which is higher than what was obtained in this study. Since fertilizer and fuel are closely related to the profitability of rice production, farmers are highly receptive to integrated machinery and nitrogen-saving technologies that can achieve high energy-use efficiency. In general, reducing diesel fuel and fertilizer consumption, mainly nitrogen, is important for energy management in this study area. Reducing chemical fertilizer use on rice fields, it does not only provide financial benefits to farmers, but it also can reduce environmental pollutions. Consequently, farmers pay less attention to water-efficiency measures, resulting in negative environmental impacts [20]. Therefore, it is essential to adopt water-saving irrigation methods to reduce irrigation water input and ultimately total energy input. Fertilization management, integrating a legume into the crop rotation, chopped residues and other soil managements can reduce the chemical fertilizer energy requirements [21, 22]. Therefore, it is necessary to focus more on fertilizer, fuel consumption than other factors to effectively reduce energy consumption in rice production.

Table 4 Energy (MJ ha^{-1}) input-output analysis for two cultivars of the rice production

Input	Hybrid		Nature	
	(MJ ha^{-1})	Percentage (%)	(MJ ha^{-1})	Percentage (%)
Human labour	997.96	1.49	997.96	1.52
Diesel fuel	30592	45.72	30592	46.46
Machinery	5575	8.33	5575	8.47
Chemical fertilizer	15928	23.80	15928	24.19
Pesticides	2220	3.32	2220	3.37
Electricity	900	1.34	900	1.37
Seed	2940	4.39	1864	2.83
Water	7764	11.60	7764	11.79
Total energy input	66916	100.00	64842	100.00
Output	168330		148850	
Rice	130830	77.72	117600	79.01
Straw	37500	22.28	31250	20.99

According to the data collected from all questioner farms, pesticides consumption was 2220 MJ ha^{-1}, especially comes from herbicide use to control common weeds such as watergrass (*Echinocloa spp*.) which is the most competitive and difficult weed to control in rice fields in the area. Annual and perennial sedges and broadleaf weeds are also the most important infested weeds in the rice production fields. Regardless of the cultivar, labour consumed around 2% energy, whereas least energy was utilized for labour. Energy share from human labour for rice fields of the study area was as 1.49% and 1.52% of related total energy inputs for hybrid and nature cultivar, respectively. Most of the human labour in rice production was used in the soil seedbed preparation, irrigation and harvesting although most of the machine power was used in the seedbed preparation, harvesting (in many farms) and irrigation operation. The source of human labour in the questioned farms is either from family members or hired labours. In contrast, [23] reported that the contribution of human labour in rice production was approximately 46% of the total in Sikkim State of India because many agricultural practices were performed by human. The energy input of electricity was calculated 900 MJ ha^{-1} (Table 4). In this study, due to water being pumped from deep wells, water channel and supply need for consumption of the electricity energy was very high. A high percent of this energy in the studied area could be attributed to use of irrigation pumps of low efficiency despite the low electricity price in the country where electric energy used in agriculture is produced mainly from renewable sources, especially water which highly considers energy consumption for both cultivar production (Table 4). This input is in line with others [24] who show generally account for a considerable share of total energy input. Seed only represented 4.39% and 2.83% of total energy requirement in studied area, for hybrid and nature cultivar, respectively. There was a significant difference among two seed cultivars in respect to energy consumption of seeds due to higher cost of purchase for hybrid, although it has high quality. However, the required quantity of seed will reduce by using high quality seeds. In addition, qualified seed will help to reduce the eventuality of pests and weeds infestation, reduce the energy needed in for weeding and chemical application and increase yield.

The key indicators to compare the efficiency of energy resources in a cropping system are net energy, energy use efficiency (energy rate), energy productivity and specific energy. Energy use efficiency (energy rate), specific energy, energy productivity, and net energy in the study are presented in Table 5. Energy use efficiency or energy rate represents energy output per 1 MJ energy input, which is an important indicator of crop production efficiency. The energy use efficiency above 1.0 showed energy being used efficiently, high energy use efficiency is attributed to lower input usage. Reducing the quantity of agrochemical inputs with high energy costs and effective use of energy resources are critical for energy saving in modern crop production. Additionally, increasing crop yield by using improved seed cultivars such as hybrid is also required. With respect to the data analysis, the energy use efficiency varied from 2.3 for nature cultivar to 2.5 for hybrid with greater yield.

In contrast, others [25] reported that the energy use efficiency of rice cultivated predominantly through manual was lower with 1.72 and decreased to 1.63 following greater mechanization.

However, the lower inputs of resources such as fertilizer and machinery use in Iran rice production led to lower rice yields, which was the most significant difference between the rice production systems of Iran and this region of western Turkey. Similarly, different rice cultivars have been found to respond differently to energy use efficiency [15], while some rice cultivar yielded more grain than the others [26]. This could be also due to differences in agricultural and climatic conditions, and rice cultivar between the studies. Similarly reported that different rice cultivars responded differently to the growing methods [27]. Similar to the present study, [28] obtained energy use efficiency of 2.8 in energy consumption analysis for selected crops in different regions of Thailand despite the low grain yield with 2593 kg ha^{-1} as compared to 8000 and 8990 kg ha^{-1} obtained from this study for nature and hybrid cultivars, respectively. Low efficiency of rice production in the present study comparable to Kosemani and Bamgboye [9] in Nigeria (6.6) and Khan et al. [5] in Australia (6.7) was a result of low grain and straw yield of rice in the study area. They reported that high energy use efficiency was due to low input energy with 14,813 MJha^{-1} because of many practices are performed bay human. In this study, results demonstrated that energy use in rice production is not efficient and on the other hand is detrimental to the environment due to mainly excess input use. Therefore, reducing inputs would be helpful to optimize rice fields by more efficient fertilizer application and diesel in rice production. By increasing the annual yield of rice production and/or decreasing the energy consumption, especially diesel fuel energy, rice production in this area will be efficient. Management systems with a legume as a previous crop have been reported as having a greater energy use efficiency than those with a cereal as the preceding crop [21].

Table 5. Energy indicators of two rice cultivars produced in the study area

	Unit	Hybrid	Nature
Energy use efficiency (energy rate)	-	2.5	2.3
Energy productivity	kg MJ^{-1}	0.13	0.12
Specific energy	MJ kg^{-1}	7.4	8.1
Net Energy	MJ ha^{-1}	101,414	84,008

The energy productivity indicates the amount of rice produced per MJ of energy consumed and it is a measure of the environmental effects associated with the production of crops. The energy productivity is calculated as 0.13 kg MJ^{-1} and 0.12 kg MJ^{-1} for hybrid and nature cultivar, respectively. These values suggested that 0.13, and 0.12 kg of rice were produced when 1 MJ of energy was used for hybrid and nature cultivars, respectively. There was an increase in energy productivity from hybrid to nature cultivars, indicating that more kilograms of rice were produced per unit energy (1 MJ) input in hybrid cultivar. These are lower than the value of energy productivity of 0.45 kg MJ^{-1} reported by [9]; the low productivity in this study was due to the use of high input energy. They reported that the high energy productivity was due to low energy input by 14813 MJ ha^{-1} as compared to this study 66,916 MJ ha^{-1} and 64,842 MJ ha^{-1} for hydride and nature cultivars.

Specific energy is an indicator which shows how much energy was used to produce one unit of disposable product (Table 5). The specific energy of rice production was 7.4 and 8.1 MJ kg^{-1} for hybrid and nature cultivar, respectively. For producing 1 kg of rice, 7.4 and 8.1 MJ of energy was spent in hybrid and nature cultivar, respectively.
This means that each kg of rice produced with hybrid cultivar will save approximately 0.7 MJ compared with the nature cultivar of rice production. Specific energy decreased in nature than hybrid cultivar, indicating that more energy was used in the production of rice in hybrid than nature one.

Similar to the output energy, the same trend was followed in net energy. The net energy for rice production was approximately 17% greater in hybrid (101,414 MJ ha^{-1}) than nature (84,008 MJ ha^{-1}). Considering this indicator, a considerable difference was recorded between hybrid and natural cultivars. This indicator, which was determined for both cultivars, was found to be lower than the net energy obtained in Nigeria of 82,733 MJ ha^{-1} in small farms [9]. Low net energy values obtained from this study was attributed to low grain and straw yields of rice.

CONCLUSIONS

It is possible to conclude that the energy rate can be increased by raising the crop yield and by decreasing energy input consumption. The results of the study confirmed the importance of diesel fuel and chemical fertilizer consumption on total energy input in the study area. It seems to be possible to reduce energy use, especially fuel and fertilizer, by using better management and more efficient methods such as legume crop rotation. For improving energy efficiency in the study area, the farmers should be educated regarding the optimal use of inputs such as fertilizers, chemicals, and irrigation water as well as technologies. In addition, local agricultural institutes have an important role to inform the farmers with respect to more efficient use of energy resources and providing more sustainable agricultural production systems in the region. Further, results of this study revealed that hybrid cultivar had higher grain and straw yield than nature, and increased output energy. Analysing all impacts, hybrid rice cultivar is a sustainable and very feasible alternative to nature in the region, as it increases energy use efficiency, and net energy due to higher grain and straw yield, which is directly to the productivity, and requires low specific energy used to produce one unit of the product.

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KOMPARATIVNA STUDIJA ENERGETSKOG KORIŠĆENJA KULTIVATORA ZA PIRINAČ (*Oriza sativa* L.) KOD MEHANIZOVANOG SISTEMA GAJENJA NA ZAPADU TURSKE

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Apstrakt: U prikazanom istraživanju je izvršena energetska analiza mehanizovane proizvodnje pirinča (*Oriza Sativa* L.) za dve sorte pirinča u regionu pod nazivom Çanakkale, u zapadnoj Turskoj.
Indikatori su efikasnost korišćenja energije, specifična energija, energetska produktivnost i neto energija. Sorte pirinča koje se obično uzgajaju u regionu navedene su u dve grupe, kao: autohtoni i hibrid visokog prinosa.

Primarni podaci su dobijeni putem terenske ankete sa farmerima licem u lice i upitnikom u okruzima Biga, Ezine i centralnim okruzima, obično u oblastima za uzgoj pirinča u regionu. Sekundarni podaci i energetski ekvivalenti dobijeni su iz dostupne literature korišćenjem prikupljenih podataka za period proizvodnje 2020–2021.

Analiza podataka pokazala je da dizel gorivo ima prosečno najveće učešće u ukupnim uloženim energentima sa 46,46% i 45,72% za autohtoni i hibridni uzorak pirinča, a zatim slede hemijska đubriva sa 24,19% i 23,80%, posebno azot (N).

Unos vode je bio treći najveći uticajni parametar sa 11,29% i 11,60% za autohtone i hibridne uzorke pirinča, respektivno.

Mašinski input je ukupno imao uticaj na četvrtom mestu, ali je pokazao sličan procenat sa oko 8,00% kod obe sorte pirinča zbog upotrebe sličnih mašinskih operacija.

Drugi visok uticaj na rezultate je primena pesticida od približno 4,00% jer je upotreba herbicida veoma visoka, posebno zbog jednogodišnjih i višegodišnjih i širokolisnih korova.

Upotrebljena količina energije ima optimalan nivo jer se kultivacija obično izvodi mehaničkom elementima.

Utvrđeno je da je neto utrošena energija veća kod hibridnih sorti pirinča sa 101,41 MJ ha^{-1} zbog većeg prinosa zrna i slame nego kod authotone sorte sa 84,01 MJ ha^{-1}. Efikasnost korišćenja energije i energetska produktivnost autohtone sorte iznosile su 2,3 i 0,12 $kg \cdot MJ^{-1}$, respektivno, što odgovara porastu od 2,5 i 0,13 $kg \cdot MJ^{-1}$ kod hibridne sorte.

Uz odgovarajuće agronomske mere u proizvodnji pirinča na istraživanom području, veći prinos hibridne sorte trebai nužno da dovede do povećanja energetske produktivnosti i prinosa.

Ključne reči: *Energetska analiza, energetski indikatori, sorte pirinča*

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