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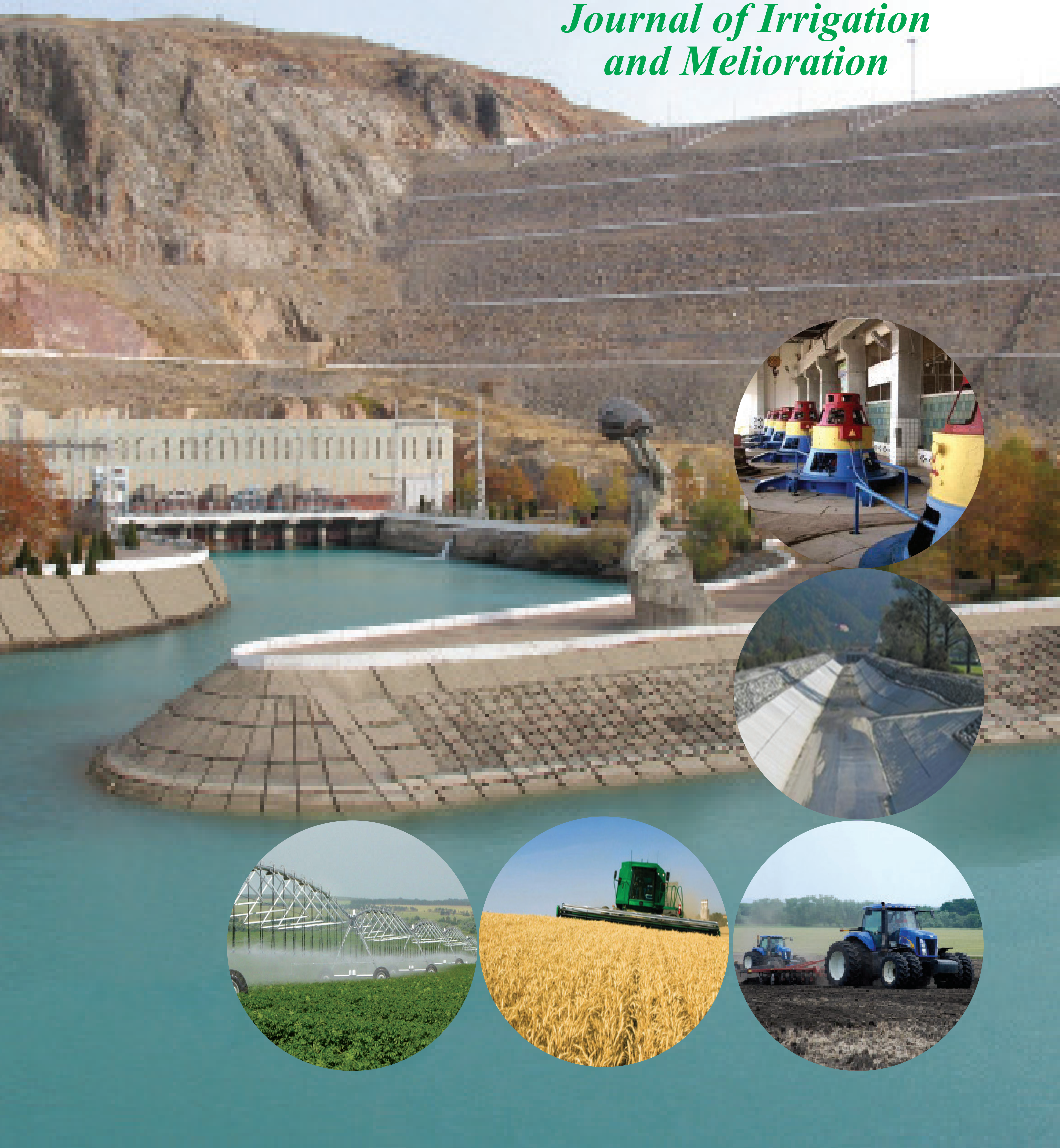

WATER AND POWER PRODUCTIVITY OF GRAPE PRODUCTION IN FERGANA VALLEY

Abdurakhmanov B.U*[1]*., Karimov A.Kh*[1]*., Amirova I.A*[2]*.,

[1]Tashkent Institute of Irrigation and Agricultural Mechanization Engineers (TIIAME), Uzbekistan
[2]Leibniz Institute for Agricultural Development in Countries with Transition Economies

Abstract

The study was carried out in 2013-2014 at two pilot farms of Fergana Valley cultivating grapevines using canal irrigation and groundwater. The farm data on irrigation applications and power inputs were compared with the experience of farmers in Turkey and Iran. The study indicated that at the farm where the groundwater was used in irrigation the yield of grapes was 2.7 times and water productivity 3 times higher as compared to using canal irrigation. This was found to be the consequence of inadequate applications of organic fertilizers and farming machinery, and poor irrigation scheduling under canal irrigation. The use of groundwater made it possible to carry out frequent irrigation at low rates, which made it possible to maintain optimal soil moisture; as a result, the nutrients were constantly available in a form accessible to plants. With the use of groundwater for irrigation, additional electricity costs of 14349 MJ/ha appeared. Expanding farmers' access to modern pumping equipment reduces these costs by 25%. An even more dramatic solution is the gradual transition to solar energy use in groundwater extraction, which is the object of further research.

Key words: groundwater irrigation, power inputs, grape production, Central Asia.

Introduction. In Central Asian countries over the past twenty years, water resources used for irrigation purposes have decreased significantly; in Uzbekistan the total water resources decreased from 90% to 83%. One of the reasons for this is an increase in their use in other sectors of economy [1,2]. Thus, an increase in the power production in the upper reaches of the Syr Darya river basin led to a reduction in summer water in its middle course by 2 km3/year [1]. Similar risks are typical for the Amu Darya river basin, where climate fluctuation can intensify negative trends in agriculture.

Thus, over the past 30 years, air temperature has increased on average by 0.029°C per year, while precipitation has a more pronounced long-term periodicity [3]. An increase in air temperature in the upper reaches of the Syr Darya and Amu Darya rivers has already led to a one third reduction in the glaciers volume, which, accordingly, affected the summer flow of the rivers. This, in turn, is a factor limiting the production of highly profitable crops, including vineyards. Since there are no unoccupied lands in the canals command zone - they are allocated mainly for cotton and winter wheat, many farmers develop the land outside this zone to grow vineyards using groundwater.

In Uzbekistan, despite the great potential for the use of groundwater, an average of 96% of the water intake for irrigation is provided by river water and only 3.5% by groundwater [4,5]. At the same time, water supply is associated with the additional power consumption for the groundwater extraction. Under these conditions, the costs estimation of water and power resources can contribute to a reasonable choice of irrigation sources.

The studies by Ozkan B., Fert Ce. and Karadeniz CF [6], Gorttapeh AH, Faghenaby F., Mirsoltani H., Zahedmanesh M., Gasmian V. and Haji-Hasani M. [7], Rasouli M., Namdari M. and Hasem Mousavi Avval S. [8], Sattari-Yuzbashkandi S., Khalilian S. and Mortazavi S.A. [9], Mardani A. and Taghavifar H. [10], Baran M.F., Lule F. and Gokdogan O [11], Karimi, M., and Moghaddam, H. [12]] are devoted to the effectiveness assessment of power inputs in grape production.

Ozkan B., Fert Ce. and Karadeniz CF [6] analyzed the power inputs of grapes growing in the fields of Akdeniz University, Turkey, at additional irrigation [6].

The ratio of output power to power inputs (power efficiency) was 5.88, and water and power productivity was 1.54 kg/m^3 and 0.38 kg/kWh, respectively.

Sattari-Yuzbashkandi S., Khalilian S. and Mortazavi S.A. estimated power inputs in 70 farms of East Azerbaijan, Iran, in conditions of intensive irrigation [9]. The power inputs efficiency was 2.38, and the productivity of water resources and energy costs 1.34 kg/m^3 and 0.20 kg/kWh, respectively. Karimi, M. and Moghaddam, H. estimated power flows in 120 grape farms in the Shahriyar region of Iran [12]. The power inputs efficiency, water and power productivity were higher - 5.97; 3.02 kg/m^3 and 0.51 kg/kWh, respectively, when applying high amounts of organic fertilizers.

The aim of these studies is to assess the efficiency of power inputs and the use of this index to select the sources of irrigation water for the vineyard cultivation as one of the most profitable crops not only in Uzbekistan but in neighboring Tajikistan as well. Grapes in the share of export potential of Uzbekistan is the second agricultural product after cotton [13,14]. It has a great importance for the farmers in Tajikistan [15,16]. Vineyard areas in Uzbekistan and Tajikistan are about 128,000 ha and 30,000 ha, respectively [17,18]. Annually on these lands 1.1 and 0.229 million tons of grapes are produced, respectively [19].

With the expansion of export opportunities and the reduction of river summer water, the farmers of both countries are expanding vineyards areas using groundwater resources. Therefore, when irrigating vineyards from canals and wells, it is important to assess the effectiveness of water and power use. In the context of rapid growth of population and, accordingly, food demand, improved access to markets in neighboring regions and increased grape production, the assessment of resource use efficiency under various sources of irrigation water can be used for further development of this industry.

Object of research. The studies were conducted in the Fergana Valley in the Republics of Tajikistan and Uzbekistan. In the Fergana Valley, the Syr Darya river is formed at the confluence of the Naryn and Karadarya rivers. These two rivers, as well as numerous small rivers flowing into the valley from south and north, are the main sources of irrigation water. Filtration from riverbeds, water loss from canals and irrigated fields form groundwater. Despite significant groundwater reserves [20], groundwater is used only in individual systems as an additional source of water.

The studies were conducted at two grape growing farms. The first farm is located in the western part of the Fergana Valley in Bobozhon Gafur district of the Sogd region of Tajikistan (hereinafter referred to as farm1); the farm refers to the Research Institute of Horticulture and Vegetable, it has 630 hectares of irrigated land, of which 86 hectares are allocated for vineyards. Mechanical composition of soil is sandy loam, underlain by pebble deposits. Water for irrigation is supplied by gravity from the Khojabakirgan Canal. Vineyards are grown in rows using trellis; watering was carried out along the furrows laid along the rows.

The second plot belongs to the "Anvar Nurli Zamin" farm (hereinafter referred to as farm 2) and is located in the Altyaryk region of the Fergana region of Uzbekistan. In the early 1990s, the land was transferred by the government to the farm for a long-term lease; it has 10 hectares of irrigated land, of which 6 hectares are under vineyards and 4 hectares are under orchards. The soil of the site is sandy loam, underlain by pebble at a depth of 50 cm, vineyard are irrigated from the wells. A survey of farmers showed that in this zone the total area of vineyards under similar conditions is about 500 hectares.

Farm 1 is a relatively large farm, it has the necessary agricultural equipment for agro-technical work and gravity irrigation, thereby representing an example of Tajik farm before its fragmentation. Farm 2 has a relatively small area where manual labor is widely used; irrigation is carried out by groundwater.

In farm 2, the vineyard bushes are placed in such a way that their vines at a height of 2 m cover the entire area, which dramatically increases the use of solar energy. Plant roots are spread in soil to a depth of no more than 0.5 m and occupy the entire inter-row space. This arrangement of bushes and roots allows plants to effectively use solar energy, water and nutrients. The farm uses frequent irrigation by small rates along the short furrows with a width of 60 cm, watering the inter-row spaces, shaded by leaves.

Methods of research. An effectiveness assessment of the use of water and energy resources was carried out below in several stages. At the first stage, the farms kept daily records of agricultural activities, resource costs and the use of agricultural machinery. In farm 1 an account for activities was carried out by employees of the Research Institute of Horticulture and Olericulture, in farm 2 - by farmers. For this purpose, the institute's employees and farmers were given the forms to account for the type and volume of work, resource costs, and the staff training was provided on data acquisition and filling out the forms.

Grapes are one of the most widespread fruit products in the world with an annual production of 75 million tons. Turkey and Iran are among the leading countries -producers of grapes in the world, with 2.1 and 1.1 million tons of table grapes per year, respectively [19]. Therefore, the energy costs in the Fergana Valley farms were compared with the costs in Turkey and Iran:

in agricultural fields of Akdeniz University (AU) [6] (Turkey), located in the province of Antalya, bounded in the south by the Mediterranean Sea, where the average annual rainfall is more than 600 mm;

in a farm located near the city of Shakhriyar [9], Tehran province (Iran), where the average annual rainfall is 310 mm and climatic conditions are close to those of the Fergana Valley.

At the third stage, on the basis of the data obtained, the efficiency indicators of water and energy use are estimated (Table 2).

Table 2

Efficiency indicators of water and energy use

NN	Expendable resources (measuring units)	Energy equivalents (MJ)
1	Manual labor (hour)	1.96
2	Diesel fuel (l)	56.31
3	Agricultural machinery (hour)	62.7
4	Nitrogen fertilizers kg)	60.6
5	Superphosphate (kg)	11.1
6	Potassium fertilizer (kg)	6.7
7	Sulfur (kg)	1.12
8	Urea (kg)	32.7
9	Manure (kg)	0.3
10	Pesticides (l)	199
11	Herbicides (kg)	238
12	Fungicides (kg)	92
13	Water for irrigation (m^3)	1.02
14	Power (kWh)	3.6
15	Agricultural machinery (kg)	83.8
16	Product, grapes (kg)	11.8

Results and discussion

Energy cost estimate

Power items of expenditure include manual labor and the use of agricultural machinery, fuel, fertilizers, manure, chemicals, irrigation water, and electricity. Table 3 shows the power items expenditure per hectare area measured in 2013 and 2014 at grapes growing in these farms.

In the second farm, a high proportion of manual labor use was noted at all stages of operation. Despite the approximately equal amount of irrigation water supplied, the number of watering carried out varied sharply - 7 with an irrigation rate of 1000-1200 m^3/ha in the first farm and 13 with an irrigation rate of 400-700 m3/ha in the second farm (Fig. 1).

As seen from Fig. 1 inter-irrigation period in the Farm 1 was significant, especially from the second half of June until the end of July, when for 47 days grape bushes did not receive irrigation water. In the Farm 2, irrigation was characterized by small rates with a short

Table 2

Efficiency indicators of water and energy use

NN	Indicators	Measuring units	Defined indicators
1	Water productivity	kg/m³	Yield /(water resources consumption)
2	Energy productivity	kg/MJ	Yield /(total energy consumption)
3	Water and energy productivity	kg/m³/kMJ	Yield / (water resources consumption and total energy consumption)
4	Effectiveness of energy use	MJ/MJ	Output energy/total energy consumption

Table 3

Energy consumption per hectare in grapes growing

NN	Items of expenditure	Meas.units	Farm 1	Farm 2
1	Manual labor	hour	371	1387
2	Irrigation water	m³	8588	7891
3	Power	Mega-joule (MJ)	0	14349
4	Diesel fuel	l	56	60
	Fertilizers and pesticides			
5	Nitrogen (N)	Fertilizers / proportion N (%)/kg	Carbamide (N -46%)/46 kg	Ammonium nitrate
6	Phosphorus (P)	Fertilizers / proportion N (%)/kg	0	0
7	Potassium (K)	Fertilizers / proportion N (%)/kg	0	0
8	Sulfur	kg	1	0
9	Insecticides	kg	1	6
10	Fungicides	kg	1	1
11	Manure	kg	607	0
	Agricultural machinery			
12	Tractor (power / weight / average life / area served)	horsepower/kg/year/ha	80 horsepower /3700 kg/ 10 years (МТЗ-80)/70 ha	30 horsepower /1430 kg/ 10 years (ВУ-304)/15 ha
13	Plow (weight / period of operation / area served)	kg/year/ha	Cultivator: МТЗ-80-ПРВН 2.5: 510 kg/10 years/70 ha	300 kg/10 years/15 ha
14	Chisel (weight / average life / area served)	kg/year/ha		350 kg/10 years/15 ha
15	Other (weight / average life / area served)	kg/year/ha	20 kg/10 years/70 ha	20 kg/10 years/15 ha

inter-irrigation period. Based on the above data, the values of energy costs for the expendable resources and production output per hectare of vineyards were calculated (Table 4).

In farm 1, under gravity irrigation, the sequence of energy costs in decreasing order was as follows: irrigation water / diesel fuel / mineral fertilizers / other types of energy costs. The amount of irrigation water in energy equivalents exceeded all other types of energy costs taken together. Low grape yields and low water productivity indicate the need to increase the use of mineral and organic fertilizers.

In farm 2, where the watering was carried out using groundwater, the sequence of energy costs in decreasing order was as follows: electricity / fertilizers / irrigation water / other types of energy costs. Compared with the first farm, energy costs included the aspect of irrigation water extraction; the costs

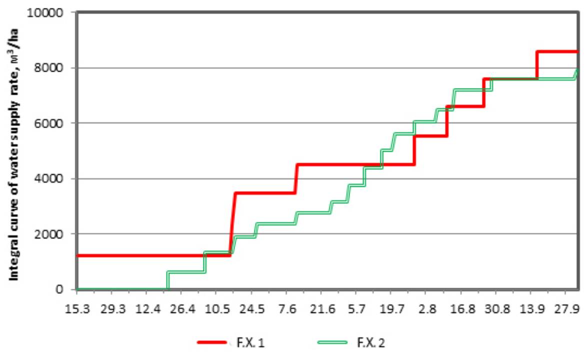

Fig. 1. Integral curve of water supply rate to the fields of farm 1 (F 1) and farm 2 (F 2)

for mineral fertilizers increased. The costs related to irrigation water, its extraction and use, were the main types of energy costs.

The groundwater takeoff using the wells provided timely irrigation with optimal rates, while in case of gravity irrigation, the regime of vineyards watering was determined largely by the flow regime of Khojabakirgan river. Frequent watering at low rates maintained an optimal water and nutrients content in soil in a form accessible for plants, which in turn increased the efficiency of fertilizer use. Taken together, these factors contributed to a three time increase in water productivity. At the same time, energy productivity and total productivity of water and energy resources were similar in gravity and groundwater irrigation systems, and the energy efficiency increased by 8%.

A comparative analysis of the experience of Iran and Turkey indicates possible ways to increase water productivity and energy costs. In Turkey, under conditions of secured dry-farming with more than 600 mm of rainfall, in summer the farmers use an additional irrigation [6]. Under these conditions, the water productivity is higher than in the Fergana Valley under gravity irrigation from canals and lower when using the groundwater irrigation.

Energy resource productivity is lower than in the Fergana Valley, irrespective of the source of irrigation. In Iran, the productivity of water and energy resources is higher than on farms in the Fergana Valley, irrespective of irrigation sources. This is a consequence of the fact that farmers in the Fergana Valley do not use organic fertilizers in sufficient amounts and the use of agricultural machinery is limited. In addition, the farmers growing grapes under gravity irrigation do not comply with the irrigation regime, which is the reason for the low water productivity and low efficiency of energy costs.

The farmers who use the groundwater irrigation spend a lot of energy on groundwater extraction. Replacing obsolete energy-intensive pumps with modern equipment can reduce these costs by 25% [22]. In this case, the power productivity will be 0.52 kg of grapes per MJ, and the energy cost efficiency - 6.14 MJ/MJ. As the experience of India and other countries indicates, a gradual transition to solar energy use in groundwater extraction is an even more cardinal solution [23, 24 , 25].

Conclusions. Studies conducted in two farms of the Fergana Valley and a comparative analysis with the experience of Iran and Turkey showed that the farmers growing grapes under gravity irrigation do not use enough organic fertilizers and agricultural machinery, and do not comply with the recommended irrigation regimes. The use of groundwater in comparison with irrigation from canals allows timely and frequent watering with small rates. In this case, the grape yield is 2.7 times higher and water productivity is 3 times higher than under gravity irrigation.

At the same time, there are additional power costs amounting to 14349 MJ/ha. Expanding farmers' access to modern pumping equipment will reduce these costs by 25%. The energy use productivity can reach 0.52 kg of grapes per MJ, and the energy cost efficiency - 6.14 MJ/MJ, which will exceed the rates reached in Turkey and Iran. An even more cardinal solution to the problem is the gradual transition to solar energy use in groundwater extraction. The transition to groundwater irrigation, in sites with favorable hydrogeological conditions for this, will create the preconditions for the widespread introduction of drip irrigation and micro-sprinkling systems, which will further increase the productivity of water and energy resources. These issues are the subjects of further research.

Table 3

Energy consumption for growing vineyards with gravity irrigation and with groundwater use

NN	Expendable resources	F 1	F 2	AU fields, Turkey*	Farm in Tehran province, Iran**
		MJ	MJ	MJ	MJ
1	Manual labor	727	2719	1344	1988
2	Agricultural machinery	719	1184	2893	1944
3	Mineral fertilizers	1505	8339	5357	13537
4	Organic fertilizers	182	0	0	5337
5	Pesticides	291	1304	468	573
6	Diesel fuel	3153	3379	7546	1881
7	Electric power	0	14349	2304	2929
8	Irrigation water	8760	8049	661	5808
9	Total power consumption	15337	39323	20573	33997
10	Grape yield	6740	18600	10220	17192
11	Output energy	79534	219480	120596	202871
12	Water productivity (kg/m³)	0.77	2.31	1.54	3.02
13	Energy productivity (kg/MJ)	0.44	0.47	0.38	0.51
14	Water and energy productivity (kg/m³/kMJ)	0.051	0.060	0.058	0.089
15	Energy efficiency (MJ/MJ)	5.19	5.58	4.52	5.97

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