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Bioenergetic efficiency of drip irrigation modes of grapes

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Abstract. In modern conditions of water scarcity, the research of the energy evaluation of different modes of drip irrigation to reduce the consumption of irrigation water, material and energy resources, their effective use on irrigated grape plantations cultivated on the sandy chernozems of the left bank of the Lower Dnieper, where only irrigation is the guarantee of annual, constant high yield of vineyards. The purpose of the research was to study the energy efficiency of grape drip irrigation regimes, determine the volume and structure of resource costs, and the level of their payback. Field and comparative-calculation methods were used during the research. The establishment and conduct of experiments were carried out according to the methodology of the research case. The paper presents the results of research on the energy efficiency of drip irrigation modes of grape plantations. It is established that maintaining an unhindered moisture supply to plants during the growing season is achieved by an additional cost of 9.29 GJ/ha of anthropogenic energy. A more economical regime of humidity of the active soil layer during the growing season reduces energy costs to 5.2-7.7 GJ/ha. The structure of additional energy costs, regardless of the irrigation regime of plantings, is dominated by the energy of irrigation water – 80% and energy carriers – 18 %. The practical significance of the research is to conduct an energy assessment of different modes of drip irrigation of grapes to reduce the consumption of irrigation water, material and energy resources and their efficient use

Keywords: moisture consumption; differentiated irrigation regime; optimal soil moisture; energy; energy intensity

INTRODUCTION

In the world where drinking water is becoming an increasingly scarce resource, 80% of which is used for irrigation of crops, optimizing water use should be a top priority for agriculture (Bulukazari *et al.*, 2022). This is especially true in viticulture, where the trade-off between crop loss and improved quality can be economically costly for producers and highly dependent on water supply. In arid regions, where limited precipitation is a limiting factor for the grape plant, irrigation plays an important role in compensating for water scarcity (Silvestroni *et al.*, 2020). Global warming leads to changes in precipitation patterns and an increasingly negative water balance during the growing season of plants, which increases the risk of drought (Tabari, 2020; Korkhova & Mykolaichuk, 2022).

Changes in namely an increase in the average annual temperature by more than 2°C (Avalos & Araujo, 2021), observed over the past decades, a reduction in the precipitation rate and a violation of the precipitation regime significantly increase the likelihood of an acute shortage of moisture supply to grapes, very often before

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the beginning of the first phase of bush vegetation. In the subsequent stages of grape development, the lack of moisture consumption only increases, so you can prevent the harmful effects of drought by using artificial irrigation of plantings. Drip irrigation has the greatest prospects, the use of which provides an optimal water regime with lower irrigation water costs, it activates the production processes of plants during the defining periods of growth and development, and guarantees the most complete realization of the biological potential of various grape varieties (Miras-Avalos & Araujo, 2021; Ma , 2020). In turn, the effectiveness of reception directly depends on the humidity regime of the active soil layer.

Numerous studies and extensive practice of using drip irrigation of vineyards show that the greatest efficiency of local irrigation is provided at clearly defined upper and lower thresholds for moistening the local soil volume (Scholasch & Rienth, 2019; Romero *et al.*, 2022). Violation of the irrigation regime increases the consumption of irrigation water, financial and energy resources, it reduces the yield of plantings, worsens the quality and marketability of berries, which directly affects the economic efficiency of the industry (Gomez-Zavaglia *et al.*, 2020). It complicates the determination of the efficiency of viticulture as a branch of agricultural production, additional costs of energy resources and the use of various units of measurement: Hryvnia, kg, T, L, m^3, people/hour, kWh, which increase the probability of error in economic calculations, limit the search for promising areas for reducing technological costs, rational use of Natural Resources (Noha, 2022; Sassu *et al.*, 2021). In addition, in a market economy, the efficiency of viticulture in general, and irrigated, in particular, depends on fluctuations in prices for energy carriers, fertilizers, plant protection products, the level of wages of workers, the demand and cost of viticulture products, and therefore complicates an objective assessment of the balance of costs and revenues from the sale of viticulture products (Strub & Loose, 2020; Sylva *et al.*, 2021). In this sense, the greatest prospect is energy analysis, which is based on the application of constant energy indicators that do not depend on constant changes in the price of viticulture products, fertilizers, fuels and lubricants, pesticides, etc. Comparison of the energy parameters of grape cultivation technology allows objectively determine the difference in the balance of technogenic and biological energy consumption. Energy analysis is particularly relevant today in the context of global and regional climate changes and the urgent need for economical use of resources, development and use of agricultural measures aimed at moisture accumulation and reducing the cost of moisture for the formation of a unit of viticulture production (Leeuwen *et al.*, 2019; Droulia & Charalampopoulos, 2022; Xyrafis *et al.*, 2022). This corresponds to a detailed justification of the bioenergetic efficiency of various modes of drip irrigation of grapes, as it allows you to establish the most effective mode of drip irrigation of plantings, to ensure an optimal balance of man-made energy costs and energy receipts synthesized by plants (Shevchenko *et al.*, 2021).

Purpose of research was to study the energy efficiency of drip irrigation modes of grapes, determine the volume and structure of resource costs, the level of their payback.

LITERATURE REVIEW

Agriculture, including industrial viticulture, is based on the process of converting solar energy through plant photosynthesis into the energy of macro-energy bonds of organic matter (Cataldo *et al.*, 2021). The volume of bound solar energy in the form of plant biomass is an integral indicator of the efficiency of cultivation of all crops, including grapes (Simon & Hülsbergen, 2021).

In the absolute majority of examples, the high productivity of modern grape growing technologies involves substantial costs for soil cultivation, fertilization, plantation care, irrigation, which directly affects the efficiency and terms of cultivation and the prospects of viticulture, causes negative changes in the environment, often irreversible. Permanent improvements and introduction of new methods of cultivation technology of grape plantations do not reduce the overall energy intensity, but involve certain additional financial and material costs, often significant, which in the absolute majority of cases are not fully covered by the additional harvest of berries (Mynkin, 2020). That is, the increase in productivity is achieved by the constant growth of direct and indirect costs of anthropogenic energy tenfold, and in the event of their termination or reduction, the production system degrades. One of the high-energy methods for optimizing environmental conditions is the widespread use of irrigation in the practice of growing a high yield of traditional agricultural crops, including grapes (Neupane & Guo, 2019).

Almost until the beginning of the 21st century, most often soil moisture was maintained by applying sprinkling and irrigation on the soil surface, which was achieved by high costs of man-made energy, natural energy resources (water), and their inefficient use (Vytoptova & Bondarenko, 2010). Producers have several options for minimizing the negative impact of drought, including switching to more efficient irrigation technologies, which are understood as technologies that increase the share of water available to the root system of a plant with a smaller amount of it (Novikov *et al.*, 2021; Bayala & Prieto, 2020). Recently, drip irrigation has been introduced into the practice of growing grape crops, which, unlike continuous moistening methods, provides humidity at a given level of 20-25% of the design volume of soil, which varies within 0.75-0.9 m^3/bush and depends on the area of plant nutrition and their age, the depth of maximum root system development, which significantly reduces the cost of man-made and natural energy resources (Pisciotta *et al.*, 2018; Mirás-Avalos & Araujo, 2021). However, the different level of pre-irrigation humidity of the active soil layer, during the growing season of grapes, causes significant fluctuations in the consumption of irrigation water, energy carriers, and affects the productivity of grape plantations in different ways, the specific consumption of water, man-made energy per unit of production, and so on.

Irrigation of vineyards is one of the most expensive technological techniques for growing grapes in conditions of insufficient natural moisture. This problem becomes especially important in connection with the shortage of water all over the world and irrigated agriculture is one of the most inefficient consumers of this resource. Low water use efficiency (WUE) combined with increased competition for water resources with other industries is forcing producers to adopt new irrigation methods that use water more economically. In areas with arid and hot climates, deficit irrigation strategies, such as regulated deficit irrigation or partial root desiccation, have been used to conserve water, allowing crops to withstand moderate water stress with little or no reduction in yield and quality (Miguel Costa *et al.*, 2007). In their opinion, the irrigation deficit helps to save irrigation water in viticulture. Thus, a better understanding of grapevine response to water and heat stress combined with temperature-based yield monitoring will help optimize irrigation and soil management in viticulture.

T. Scholasch & M. Rienth (2019) indicate that when the root mass and root absorption sites are concentrated near the soil surface, the water consumption of the grape plant depends on the moisture content of the soil, which is located below the surface. K. Nader *et al.* (2019) acknowledge that older vines do have deeper and more developed root systems, making them more drought tolerant than younger plants.

Despite some inconsistencies in the obtained research results, all the mentioned authors believe that the greatest efficiency of local irrigation, reduction of energy consumption, and high efficiency of their use are achieved at clearly defined upper and lower thresholds for moistening the local soil volume (Vozhehova *et al.*, 2017; Lemos-Paiao *et al.*, 2022; Scholasch & Rienth, 2019). Reducing soil moisture, or increasing it beyond the established limits, reduces the yield of plantings, the quality of berries, and the efficiency of using energy resources (Weiler *et al.*, 2018).

The vast majority of studies on the effectiveness of various drip irrigation regimes of grapes were conducted on plantings cultivated on heavy loamy or southern chernozems of the country (Zelenyanska & Borun, 2021). Such studies are especially relevant for irrigated grape plantations cultivated on sandy loam chernozems of the left-bank lower Dnieper region, where only irrigation guarantees an annual, stable high yield of vineyards.

Problem statement – conducting an energy assessment of various modes of drip irrigation of grapes to reduce the consumption of irrigation water, material and energy resources, and their efficient use.

MATERIALS AND METHODS

The experiment was conducted during 2019-2021 carried out on 15-year-old plantings of the Rkatsiteli variety cultivated in Agricultural Private Firm (APF) "Tavria" of the Kherson region.

The study scheme included the following options:

1. Control (without irrigation);
2. Humidity of the active soil layer at the level of 100-80% the lowest moisture content during the growing season of plants;
3. 100-80% by the end of the flowering phase, subsequent phases (berry growth, crop maturation) 100-70% the lowest moisture content;
4. 100-70% the lowest moisture content during the entire growing season of plants.

The experiments were performed in a three-dose repetition. In each variant, there are 45 accounting bushes, 15 in repetition. There are 180 registered bushes in total.

The scheme of planting plants is 3.0×1.25 m, the formation of bushes is a high – stamp two – shoulder border with a height of 120 cm. The load of bushes with shoots in all variants of the experiment ranged from 32.4-33.1 PCs/bush.

The technology of drip irrigation of grapes uses irrigation pipelines with a diameter of 16 mm with integrated water outlets in increments of 0.6 m and a water flow rate of 3.8 dm^3/ha, mounted on the lower wire of the trellis. The timing of regular irrigation, irrigation rates, and the duration of the inter-watering period were determined based on monitoring the dynamics of moisture reserves in the root layer of the soil, the regime and rate of precipitation. Moisture reserves were monitored every decade by the thermostatic-weight method.

Industrial grape plantations of the farm, including the experimental site, are cultivated on unproductive lands of the left-bank lower Dnieper region, which annually receive a large amount of heat and light, are characterized by high evaporation and aridity.

The soil of the experimental site, as well as the entire array of perennial plantings, is sandy loam chernozem with a humus content in a layer of 0-100 cm in the range of 0.4-0.6%. The volume weight of the soil is 1.42 g/cm^3, the duty cycle is 41%, and the lowest moisture capacity is 17.1%. The type of water regime is not washing, the main natural moisture reserves of the soil are formed during the autumn-winter period.

During the research, agrobiological records of the development of eyes and elements of fruitfulness were carried out according to the generally accepted method in viticulture. Records of the berry yield were carried out by weight method, separately for each of the variants of the experiment. Water and electricity consumption was recorded using meters installed directly in the pumping station. The energy intensity of irrigation regimes, the use of natural and man-made energy resources for irrigation of plantings, and the volume of biological energy synthesis were calculated according to methodological recommendations (Tarariko, 2005; Lyannoy *et al.*, 1994).

RESULTS AND DISCUSSION

The dominant factor in the growth, development of grapes and high yield is the humidity of the active soil layer during the growing season of plants, which depends on the norm of precipitation and the mode of their precipitation. In most cases, the main soil moisture reserves in the region are formed during the autumn-winter period and reach 2200-2500 m^3/ha, of which 1500-1600 m³/ha are available for plants and ensure unhindered moisture consumption of grapes until the end of the flowering phase. In subsequent phases, plants vegetate in conditions of acute shortage of moisture consumption, which is not eliminated by summer precipitation, with the exception of individual years.

On average, over three years of research (2019-2021), the total moisture reserves of the active soil layer at the beginning of the first phase of vegetation also ranged from 1850 m³/ha to 2100 m³/ha, which potentially provided optimal conditions for plant moisture consumption until the end of the growth phase shoots. However, the high temperature regime that is established in the Steppe zone in the first decade of April, insignificant amounts of precipitation, or their long-term absence cause a significant loss of moisture and accelerate the formation of an acute deficit of moisture consumption already in the middle of the second phase of vegetation, and humidity at the level of 80% of the lowest moisture content was formed already at the beginning of the shoot growth phase.

Reducing moisture reserves to the lower threshold of optimal moisture content for the second version of the experiment became the basis for regular irrigation of plantings. Soil moisture at the level of 80% the lowest moisture content during the growing season was provided by 14 waterings with an average irrigation rate of 81 m³/ha (Table 1).

Table 1. *Drip irrigation mode of grape plantations depending on the level of pre-irrigation humidity of the local soil volume Agricultural Private Firm "Tavria", Rkatsiteli variety*

RPVG, % the lowest moisture content	Number of waterings	Irrigation rate, m³/ha	Inter-irrigation period, days	Irrigation rate, m³/ha
Control (without irrigation)	-	-	-	-
100-80	14	81	7	1134
100-80-70	9	105	11	945
100-70	5	127	19	635

Source: *authors' own research*

According to the data in Table 1, the irrigated water rate for the growing season of grapes in this version of the experiment was 1134 m³/ha, with fluctuations, depending on the conditions of the year, up to 12%. The differentiated irrigation regime, which was applied with the beginning of the berry growth phase, reduced the number of waterings to 9, while irrigation water standards increased by almost 30% and amounted to 105 m³/ha. The irrigated water rate in this version of the experiment decreased by 17% and amounted to 945 m³/ha. The lowest total irrigation water consumption was achieved by maintaining the lower threshold of optimal soil moisture at the level of 100-70% the lowest moisture content. For three years of research (2019-2021), the optimal soil moisture at the level of 100-70% the lowest moisture content was provided by 5 waterings carried out after 19 days at a rate of 127 m³/ha.

The conditions for providing plants with moisture that have developed under different irrigation modes have had different effects on the structure of energy consumption, the energy intensity of irrigation modes for grape plantations (Table 2).

Table 2. *Structure and energy intensity of drip irrigation regimes for grapes APF "Tavria", Rkatsiteli variety*

Regimes of irrigation, % HB	Energy intensity of resources, MJ				Energy intensity of irrigation modes, MJ/ha
	Irrigation water	Energy carriers	Technical means	Live work	
100-80	7439	1670	125.7	62.5	9297.2
100-80-70	6200	1395	104.5	54.7	7754.2
100-70	4165	957	70.2	35.8	5228.0
%	80.0	18.0	1.35	0.65	100.0

Source: *authors' own research*

According to the data in Table 2, the structure of energy consumption is dominated by the energy of irrigation water, the share of which is 80% and it does not depend on the irrigation regime of plantings. The power consumption used for the operation of pumping and filtering equipment, water supply, creation and maintenance of the required pressure in the irrigated network depends on the operating time of the equipment and ranges from 1670-957 MJ/ha, or 18.0% of the total energy intensity of reception. The energy costs of the technical means involved and live labor are directly related to each other and are aimed at maintenance of pumping and filtering equipment, monitoring the state of the drip irrigation network, and ensuring its reliable operation. The share of these energy costs is insignificant and ranges from 188.2-159.2 MJ/ha, or 0.65-1.35% of the total energy consumption.

The level of pre-watering humidity of the active soil layer directly determines the overall energy intensity of irrigation of grape plantations. Unhindered moisture consumption of grapes at the level of 100-80% the lowest moisture content, during the growing season causes the consumption of 9.29 GJ/ha of energy, which is equivalent to 218 kg of diesel fuel. The introduction of a differential irrigation regime for plantings with a threshold of 100-80-70% the lowest moisture content reduces the energy intensity of reception by 16.7%. Maintaining the pre-watering humidity of the active soil layer during the growing season of grape plantations at the level of 100-70% the lowest moisture content, reduces energy consumption to 5.2 GJ/ha or almost 1.7 times.

The conditions for providing plants with moisture that have developed under different irrigation regimes have had different effects on the development of grapes, the volume of biological energy synthesis, the energy intensity of the biological mass of plants and Berry yield, and the level of payback of man-made energy spent (Table 3).

Table 3. *Bioenergetic efficiency of drip irrigation modes of APF "Tavria" grapes, Rkatsiteli variety*

Regimes of irrigation, % HB	Yield of grapes, t/ha		Synthesized energy (Eb) in the crop, MJ		Specific energy consumption, MJ/t of berries	Energy consumption on 1 t additional berry yield, MJ/t	Kee irrigation modes, T*=Tb/Tt
	biological	yield of berries	biological	berries			
Control (without irrigation)	10.1	7.8	45564	24804	5807	-	0.547
100-80	14.3	11.7	66616	37206	4639	2383.9	0.685
100-80-70	14.1	11.3	61884	35934	4695	2215.5	0.677
100-70	13.4	10.7	58766	34026	4586	1802.8	0.673

Note: *E*= Eb, biological /Et, technogenic; Kee-defined for the berry yield*

Source: *authors' own research*

According to the data in Table 3, total energy consumption on the site without irrigation, control – 45.5 GJ/ha. The energy intensity of modern technology for cultivating industrial grape plantations ranges from 45-47 MJ/ha and includes two components: energy costs for creating plantings and caring for them before they enter full fruiting and annual costs for caring for fruit – bearing plants.

The use of irrigation of plantings increases the consumption of man – made energy by an average of 17-20% and depends on the annual volume of soil moisture of natural supply, the efficiency of its use, and the pre-irrigation level of soil moisture maintained by irrigation.

Unhindered moisture supply of grapes at the level of 100-80% the lowest moisture content, during the entire growing season of plants, is achieved by additional man-made energy costs in the range of 9.29 GJ/ha and increases the energy intensity of Berry cultivation technology to 54.27 GJ/ha. A differentiated irrigation regime at the level of 100-80-70% the lowest moisture content reduces the cost of man-made energy by an average of 8%.

As a result of research, it was established that the lowest total cost of man-made energy for growing a grape crop consists in constantly maintaining the humidity of the active soil layer at the level of 100-70% the lowest moisture content, and it does not exceed 49.1 GJ/ha. Under the influence of the moisture supply regime of grapes, the specific energy costs for growing a berry crop also change significantly. With natural moisture supply, the energy consumption for growing 1 ton of berries is, on average, 5.8 GJ of man-made energy. In irrigated areas, regardless of the level of pre-irrigation soil moisture maintained during the growing season, specific energy consumption is reduced to 4.5-4.6 GJ/t of berries, due to the elimination of stress on plants, more efficient use of the natural potential of the environment by plants in irrigation conditions. Optimization of soil moisture has become a key factor in reducing, by more than 50%, the specific cost of man-made energy for growing an additional crop of berries of irrigated variants of the experiment. In addition to the direct impact of the irrigation regime on the energy intensity of the technology, pre-irrigation soil moisture also changes the efficiency of biological energy synthesis, its volume in the biological mass, and the yield of grapes.

The most intensive synthesis of natural energy by plants was observed with an unhindered intake of moisture (100-80% the lowest moisture content) and amounted to 66.6 GJ/ha in the biological yield and 37.2 GJ/ha in grape berries. The differentiated regime of soil moisture at different stages of the growing season, worsening the conditions of plant moisture supply, reduced the total amount of energy synthesized by plants to 61.8 GJ/ha, including in the berry yield to 35.9 GJ/ha. The same trend was observed in the area where soil moisture was constantly maintained at the level of 100-70% the lowest moisture content.

The above analysis shows that the amount of synthesized energy in the berry crop is significantly less than the amount of man-made energy spent on caring for plants during the growing season, regardless of the soil moisture regime that was maintained during the growing season of plants.

Analyzing the level of payback of man-made energy costs by grapes in various conditions of moisture supply, it should be noted that irrigation of plantings contributes to a more efficient synthesis of organic matter in the biological crop and the accumulation of 58.7 GJ/ha of energy in it, which is 19.5-24.0% higher than the cost of anthropogenic resources.

At the control site, the volume of synthesized energy in the biological mass of the grape crop was 45.5 GJ/ha, which is equivalent to its cost for caring for plantings during the growing season.

Agroclimatic conditions of the southern regions of Ukraine potentially allow binding about 4-5% of photosynthetically active solar radiation, which is equivalent to the yield of grapes in the range of 10-12 t/ha.

DISCUSSION

According to the results of many years of research performed both in Ukraine and in countries with an arid type of climate (USA, Spain, Latin American countries), increasing the lower threshold for optimal moisture content of the active soil layer from 60% the lowest moisture content to 70% the lowest moisture content, during the growing season, increases the consumption of irrigation water and energy resources by almost 42% (Sun *et al.*, 2022; Mboyerwa *et al.*, 2021; Vozhehova *et al.*, 2017). Reduce the consumption of irrigation water, energy and funds allows a differentiated irrigation regime of plantings, which provides for the humidity of the active soil layer at the level of 100-80% the lowest moisture content in the growth phase of shoots and flowering, and its subsequent reduction to 10-70% the lowest moisture content during the berry growth phase and 100-65% the lowest moisture content during the ripening period of the berry crop (Lemos-Paiao *et al.*, 2022). Current research established that the moisture supply of grapes at the level of 100-80% RH, during the entire growing season of the plants, is achieved by additional costs of man-made energy in the range of 9.29 GJ/ha and increases the energy intensity of the berry crop cultivation technology to 54.27 GJ/ha. Differentiated mode of irrigation at the level of 100-80-70% the lowest moisture content reduces man-made energy consumption by an average of 8%.

Previous studies show (Shevchenko *et al.*, 2012) that all modern grape growing technologies used in Ukraine are characterized by high energy intensity, which is 4.6-7.2 times higher than the recommended international standards (15 GJ/ha year). Significant energy costs have a negative effect on the state of grape bushes, significantly reduce the efficiency of using artificial energy. Thus, the irrigation regime has different effects on the efficiency of the use of irrigation water, the consumption of which for the formation of 1 ton of berry crop with an unimpeded supply of moisture (100-80% RH) during the growing season of grapes is 476 m^3/t. Irrigation water is used most sparingly in the irrigation mode at the level of 100-70% RH, which reduces specific water consumption to 266 m^3/t. On the site of this variant, the yield of berries was 10.5 t/ha, that is, it decreased by 8.6%. At the same time, the specific consumption of water decreased by 38.3% compared to similar indicators of the site with unimpeded moisture inflow (Shevchenko *et al.*, 2021).

One of the promising ways of reducing energy costs in irrigated viticulture is the further improvement of irrigation regimes, the use of more modern diagnostic methods to adjust the timing of successive irrigations. Mynkina (2021) recommends adjusting the timing and rates of irrigation in years with insufficient rainfall, which may not coincide with long-term practice. Thus, in dry years, it is recommended to irrigate grape plantations at the beginning of the shoot growth phase at the rate of 80-100 m^3/ha for local irrigation methods. It is advisable to coordinate the timing of subsequent waterings and irrigation rates with the dynamics of the moisture content of the active soil layer of a specific site, using tensiometers or other methods of diagnosing the next watering periods. On the basis of this information, also determine irrigation rates, which is confirmed by current research. Thus, the results of confirm the need for a differentiated irrigation regime, which was applied at the beginning of the berry growth phase, which helped reduce the number of irrigations to 9, while the irrigation water rates increased by almost 30% and amounted to 105 m^3/ha.

In research, the optimization of soil moisture became a key factor in reducing, by more than 50%, the specific costs of man-made energy for growing an additional crop of berries in the irrigated variants of the experiment. In addition to the direct influence of the plantation irrigation regime on the energy intensity of the technology, the pre-irrigation soil moisture also changes the efficiency of the synthesis of biological energy, its volume in biological mass and the yield of grape berries. Similar results were obtained by a number of scientists (Vozhehov *et al.*, 2021), who established that the use of drip irrigation according to a resource-saving and biologically optimal scheme ensured an increase in yield by 16.8-28.3% – up to 7.9-9.2 t/ha. It was established that drip irrigation regimes had the maximum influence on the yield of grapes, as their share of influence was the highest and amounted to 59.8%.

Some researchers, (Cooley *et al.*, 2017; Linares Torres *et al.*, 2018; Scholasch, 2018) to increase the efficiency of water use in vineyards, recommend the use of increased irrigation rates after a period of moderate drought to reduce the water stress of the grapevine. For this purpose, the maximum amount of water that the root system zone can accommodate is applied, while the maximum possible level of vine transpiration (Kcb, max) is achieved and the next watering is postponed as far as possible. Between waterings, drought periods of varying intensity are established in accordance with production tasks. In their opinion, the changes in water deficit between two large irrigations are smoother compared to those observed between irrigations of a smaller volume. These strategies tend to promote water and energy savings and are currently supported by water agencies and energy conservation agencies (Scholasch & Rienth, 2019). Authors of the current research support these assumptions. Thus, the lowest total consumption of irrigation water was achieved with the support of the lower threshold of optimal soil moisture at the level of 100-70% RH. During the research period, the optimal soil moisture at the level of 100-70% RH was provided by 5 irrigations carried out every 19 days at the rate of 127 m^3/ha.

At the very end, it should be noted that studies of the influence of drip irrigation regimes on the grape plant in conditions of limited moisture supply have achieved significant results. The attention of scientists was mainly devoted to the study of the influence of irrigation on the productivity and yield of grapes. But in the modern conditions of agricultural production, in connection with limited water resources in the conditions of climatic changes, the energy assessment of all technological methods of crop cultivation becomes especially relevant. Thus, in the future, research in this direction should become the focus of attention of scientists, where the most important is the study of water-saving methods of viticulture, methods of limited irrigation to save energy resources.

CONCLUSIONS

As a result of research conducted on 15-year-old plantings of grapes of the Rkatsiteli variety cultivated on irrigated sandy chernozems of the left bank of the Lower Dnieper in the Kherson region, an energy assessment of various modes of drip irrigation was carried out in order to reduce the consumption of irrigation water, material and energy resources with their effective use. Relevant conclusions are drawn:

The lowest total costs of man-made energy for growing a crop of grapes consist of constant maintenance of the humidity of the active layer of the soil at the level of 100-70% RH, and do not exceed 49.1 GJ/ha.

In irrigated areas, regardless of the level of pre-irrigation soil moisture that was maintained during the growing season, the specific energy consumption is reduced to 4.5-4.6 GJ/t of berries, due to the elimination of stress on plants, more effective use by plants of the natural potential of the environment under irrigation conditions.

Maintaining an unhindered moisture supply to plants during the growing season is achieved by an additional cost of 9.29 GJ/ha of anthropogenic energy. A more economical regime of humidity of the active soil layer during the growing season reduces energy costs to 5.2-7.7 GJ/ha.

The specific consumption of man-made energy for growing 1 ton of grapes ranges from 5.8 GJ for control without irrigation and 4.51-4.69 GJ for areas of different levels of pre-irrigation soil moisture.

Bioenergetic analysis of modern technology of cultivation of industrial plantings allows us to identify the most energy-intensive techniques, provide directions for their improvement for gradual optimization of anthropogenic energy costs, and its more efficient use.

In order to increase the efficiency of water use, the reaction of the variety, its physiology, the characteristics of the soils on which it is grown and energy costs should be studied in order to optimize the irrigation strategies of grape plantations in accordance with production tasks.

Further research should be focused on the study of optimal irrigation regimes in conditions of limited natural moisture when growing a certain variety in specific soil and climatic conditions to reduce material and energy costs.

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CONFLICT OF INTEREST

The authors declare that the study was conducted in the absence of any commercial or financial relationships that could be interpreted as a potential conflict of interest.

REFERENCES

[1] Baraka Wadha, N. (2022). *Viticulture in cold climate toward more sustainable wine production.* Uppsala: Swedish University of Agricultural Sciences. Retrieved from https://stud.epsilon.slu.se/17985/1/baraka-wadha-n-220630.pdf.

[2] Bayala, J., & Prieto, I. (2020). Water acquisition, sharing and redistribution by roots: Applications to agroforestry systems. *Plant and Soil*, 453, 17-28. doi: 10.1007/s11104-019-04173-z.

[3] Bulukazari, S., Babazadeh, H., Ebrahimipak, N., Mousavi-Jahromi, S.H., & Etedali R.H. (2022). Optimization of water and land allocation in salinity and deficit-irrigation conditions at farm level in Qazvin plain. *PLoS One*, 17(7), 0269663. doi: 10.1371/journal.pone.0269663.

[4] Cataldo, E., Fucile, M., & Mattii, B.G. (2021). A review: Soil management, sustainable strategies and approaches to improve the quality of modern viticulture. *Agronomy*, 11(11), 2359. doi: 10.3390/agronomy11112359.

[5] Cooley, N.M., Klingeleffer, P.R., & Walker, R.R. (2017). Effects of water scarcity and seasons on the development and composition of Cabernet Sauvignon (Vitis vinifera L.) grown in hot climates. *Aust J Grape Wine Res,* 23(2), 260-272. doi: 10.1111/ajgw.12274.

[6] Droulia, F., & Charalampopoulos, I. (2022). A review on the observed climate change in Europe and its impacts on viticulture. *Atmosphere*, 13, 837. doi: 10.3390/atmos13050837.

[7] Food and Agriculture Organization of the United Nations. (2017). *Water for sustainable food and agriculture. A report produced for the G20 Presidency of Germany*. Retrieved from https://www.fao.org/3/i7959e/i7959e.pdf.

[8] Gomez-Zavaglia, A., Mejuto, J.C., & Simal-Gandara, J. (2020). Mitigation of emerging implications of climate change on food production systems. *Food Research International*, 134, 109256. doi: 10.1016/j.foodres.2020.109256.

[9] Korkhova, M., & Mykolaichuk, V. (2022). Influence of weather conditions on the duration of interphysical periods and yield of durum winter weat. *Scientific Horizons,* 25(2), 36-46. doi: 10.48077/scihor.25(2).2022.36-46.

[10] Leeuwen, C.V., Destrac-Irvine, A., Dubernet, M., Duchêne, E., Gowdy, M., Marguerit, E., & Ollat, N. (2019). An update on the impact of climate change in viticulture and potential adaptations. *Agronomy*, 9(9), 514. doi: 10.3390/agronomy9090514.

[11] Lemos-Paiao, A.P., Lopes, S.O., & Pinho, M. (2022). Analytical study for different extremal state solutions of an irrigation optimal control problem with field capacity modes. *International Journal of Applied and Computational Mathematics,* 8(67). doi: 10.1007/s40819-022-01266-9.

[12] Linares Torres, R., De La Fuente Lloreda, M., Junquera González, P., Lissarrag Garcia-Gutiérrez, J.R., & Baeza Trujillo, P. (2018). Effect of soil management strategies on the characteristics of the grapevine root system in irrigated vineyards under semi-arid conditions. *Australian Journal of Grape and Wine Research,* 24(4), 439-449. doi: 10.1111/ajgw.12359.

[13] Lyannoy, A.D. (1994). *Methodological guidelines for the energy assessment of agrotechnical techniques and technologies in viticulture.* Odesa: Institute of Viticulture and Winemaking named after V.E. Tairov.

[14] Ma, X., Jacoby, P.W., & Sanguinet, K.A. (2020). Improving net photosynthetic rate and rooting depth of grapevines through a novel irrigation strategy in a semi-arid climate. *Sec. Crop and Product Physiology*, 11. doi: 10.3389/fpls.2020.575303.

[15] Mboyerwa, P.A., Kibret, K., Mtakwa, P.W., & Aschalew, A. (2021). Evaluation of growth, yield and water productivity of paddy rice with water-saving irrigation and optimization of nitrogen fertilization. *Agronomy*, 11(8), 1629. doi: 10.3390/agronomy11081629.

[16] Miguel Costa, J., Ortuño, M.F., & Chaves, M.M. (2007). Deficit irrigation as a strategy to save water: Physiology and potential application to horticulture. *Journal of Integrative Plant Biology,* 49(10), 1409-1534. doi: 10.1111/j.1672-9072.2007.00556.x.

[17] Minkina, G.O. (2021). Improvement of elements of the technology of cultivation of industrial grape plantations depending on the conditions of moisture supply. *Taurian Scientific Bulletin*, 119, 67-73. doi: 10.32851/2226-0099.2021.119.10.

[18] Mirás-Avalos, G.M., & Araujo, E.S. (2021). Optimization of vineyard water management: Challenges, strategies, and perspectives. *Water,* 13(6), 746. doi: 10.3390/w13060746.

[19] Mynkin, M.V. (2020). *Modern technologies of grape cultivation and promising directions for its improvement.* Kyiv: UkrINTEI.

[20] Nader, K.B., Pfahl, L.M., & Stoll, M. (2019). Evaluation of grapevine trunk size by use of a handheld camera and three-dimensional modelling. *OENO One,* 53(4), 611-618. doi: 10.20870/oeno-one.2019.53.4.2310.

[21] Neupane, J., & Guo, W. (2019). Agronomic basis and strategies for precision water management: A review. *Agronomy*, 9(2), 87. doi:10.3390/agronomy9020087.

[22] Novikov, O., Potryvaieva, N., Karpenko, M., & Sadovy, O. (2021). The role of irrigation in the formation of the innovation and investment environment of the region. *Ukrainian Black Sea Region Agrarian Science,* 3, 4-11. doi: 10.31521/2313-092X/2021-3(111).

[23] Pisciotta, A., Lorenzo, R.D., Santalucia, G., & Barbagallo, M.G. (2018). Response of grapevine (Cabernet Sauvignon cv) to above ground and subsurface drip irrigation under arid conditions. *Agricultural Water Management*, 197, 122-131. doi: 10.1016/j.agwat.2017.11.013.

[24] Romero, P., Navarro, J.M., & Ordaz, P.B. (2022). Towards a sustainable viticulture: The combination of deficit irrigation strategies and agroecological practices in Mediterranean vineyards. A review and update. *Agricultural Water Management*, 259, 107216. doi: 10.1016/j.agwat.2021.107216.

[25] Sassu, A., Gambella, F., Ghiani, L., Mercenaro, L., Caria, M., & Pazzona, A.L. (2021). Advances in unmanned aerial system remote sensing for precision viticulture. *Sensors,* 21(3), 956. doi: 10.3390/s21030956.

[26] Scholasch, T., & Rienth, M. (2019). Review of water deficit mediated changes in vine and berry physiology; Consequences for the optimization of irrigation strategies. *OENO One*, 53, 423-444. doi: 10.20870/oeno-one.2019.53.3.2407.

[27] Scholasch, T., (2018). Improving viticulture through irrigation through sap flow – a 10-year review. *Akta Hortik*, 1222, 155-168. doi: 10.17660/ActaHortic.2018.1222.21.

[28] Shevchenko, I., Mynkin, M., & Mynkina, G. (2021). Modes of drip irrigation of grapes and their efficiency. *Agrobiology*, 2, 183-192. doi: 10.33245/2310-9270-2021-167-2-183-192.

[29] Shevchenko, I.V., Mynkin, M.V., & Mynkina, G.O. (2012). The efficiency of the drip irrigation regime of grape plantations. *Taurian Scientific Bulletin*, 81, 214-219. Retrieved from http://www.tnv-agro.ksauniv.ks.ua/archives/81_2012/39.pdf.

[30] Silvestroni, O., Palliotti, A., Lena, B., Nuzzo, V., Sabbatini, P., Lattanzi, T., & Lanari, V. (2020). Effects of limited irrigation water volumes on near-isohydric 'Montepulciano' vines trained to overhead trellis system. *Acta Physiologiae Plantarum*, 42, 147. doi: 10.1007/s11738-020-03132-x.

[31] Simon, R.O., & Hülsbergen, K.-J. (2021). Energy balance and energy use efficiency of annual bioenergy crops in field experiments in southern Germany. *Agronomy*, 11(9), 1835. doi: 10.3390/agronomy11091835.

[32] Strub, L., & Loose, S.M. (2020). The cost disadvantage of steep slope viticulture and strategies for its preservation. *OENO One,* 55(1). doi: 10.20870/oeno-one.2021.55.1.4494.

[33] Strub, L., Kurth, A., & Loose, S.M. (2021). The effects of viticultural mechanization on working time requirements and production costs. *American Journal of Enology and Viticulture*, 72(1), 46-55. doi: 10.5344/ajev.2020.20027.

[34] Sun, K., Niu, J., Wang, C., Fu, Q., Yang, G., Liang, F., & Wang, Y. (2022). Effects of different irrigation modes on the growth, physiology, farmland microclimate characteristics, and yield of cotton in an oasis. *Water,* 14(10), 1579. doi: 10.3390/w14101579.

[35] Tabari, H. (2020). Climate change impact on flood and extreme precipitation increases with water availability. *Scientific Reports*, 10, 13768. doi: 10.1038/s41598-020-70816-2.

[36] Tarariko, Y.A. (2005). *Bioenergetic assessment of agricultural production*. Kyiv: Agrarian Science.

[37] Vozhegov, C.G., Oshchypok, O.S., Kokovikhin, S.V., Drobytko, A.V., Girlya, L.M., Kerimov, A.N., & Kazanok, O.O. (2021). The influence of drip irrigation regimes on the productivity of grapes when grown in the conditions of Southern Ukraine. *Agrarian Innovations*, 5, 168-172. doi: 10.32848/agrar.innov.2021.5.26.

[38] Vozhehova, R.A., Maliarchuk, M.P., Markovska, O.Y., & Biliayeva, I.M. (2017). Environmental, economic and energy efficiency of soil tillage systems in crop rotation under irrigation. *Irrigated Agriculture*, 67, 12-18. Retrieved from http://www.irbis-nbuv.gov.ua/.

[39] Vytoptova, V.A., & Bondarenko, N.A. (2010). Ecological and economic features of drip irrigation. *Scientific Works of the Kirovohrad National Technical University. Economic Sciences*, 18(1), 214-219. Retrieved from http://dspace.kntu.kr.ua/jspui/bitstream/123456789/200/1/36.pdf.

[40] Weiler, C.S., Merkt, N., & Graeff-Hönninger, S. (2018). Impact of water deficit during fruit development on quality and yield of young table grape cultivars. *Horticulturae*, 4(4), 45. doi: 10.3390/horticulturae4040045.

[41] Xyrafis, E.G., Christos, H.F., Nakas, T., Koundouras, S. (2022). A study on the effects of climate change on viticulture on Santorini Island. *OENO One*, 56(1), 259-273. doi: 10.20870/oeno-one.2022.56.1.4843.

[42] Zelenyanska, N.M., & Borun, V.V. (2021). Regimes of drip irrigation of grape nursery in the conditions of the south of Ukraine. *Agrarian Innovations*, 35-40. doi: 10.32848/agrar.innov.2021.8.5.

Біоенергетична ефективність режимів краплинного зрошення винограду

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Анотація. В сучасних умовах дефіциту водних ресурсів актуальними є дослідження енергетичної оцінки різних режимів краплинного зрошення. Воно важливе для скорочення витрат поливної води, матеріальних та енергетичних ресурсів, їх ефективного використання на зрошуваних насадженнях винограду, що культивуються на супіщаних чорноземах лівобережного Нижньодніпров'я, де тільки зрошення являється гарантом щорічної, сталої високої врожайності виноградників. Метою досліджень було вивчення енергоефективності режимів краплинного зрошення винограду, визначення обсягів та структури ресурсних витрат, рівня їх окупності. Під час дослідження використано польовий та порівняльно-розрахунковий методи. Закладання та проведення дослідів проводили згідно методики дослідної справи. В роботі отримані результати досліджень із вивчення енергетичної ефективності режимів краплинного зрошення насаджень винограду. Встановлено, що підтримання безперешкодного вологопостачання рослин протягом вегетації досягається додатковими витратами 9,29 ГДж/га антропогенної енергії. Більш ощадливий режим вологості активного шару ґрунту протягом вегетації рослин скорочує енергетичні витрати до 5,2-7,7 ГДж/га. В структурі додаткових енергетичних витрат, незалежно від режиму зрошення насаджень, домінує енергія поливної води – 80 % та енергоносіїв – 18 %. Практичне значення досліджень полягає в проведенні енергетичної оцінки різних режимів краплинного зрошення винограду для скорочення витрат поливної води, матеріальних та енергетичних ресурсів та їх ефективного використання

Ключові слова: вологоспоживання; диференційований режим зрошення; оптимальне зволоження ґрунту; енергія; енергоємність