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THE EFFICIENCY OF SUNFLOWER CULTIVATION ON DIFFERENT LEVELS OF BIOLOGIZATION

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Abstract

The article presents experimental materials on the assessment of economic, bio-energy and ecological efficiency of the elements of the levels of technology biologization for sunflower cultivation. The study was dedicated to evaluation of the following cultivation technology elements: sunflower hybrid (factor A); the level of biologization of cultivation technology (factor B). All the elements of biologization of the cultivation technology for sunflower hybrids resulted in significant improvement of basic indexes of economic efficiency. The analysis of the indexes makes it possible to state that, by Factor A, the highest economic attractiveness is characteristic of the variants of an extensive (minimum) cultivation technology, in which the level of profitability during the years of the research was 160.1% on average, and organic technology -159.9%, respectively. If the manufacturer is certified and a batch of commercial sunflower has organic status, it is possible to increase this index to 211.9%, taking into account 20% organic bonus. The highest energy efficiency in the experiment was characteristic of the variants without the use of the most energy-intensive components - mineral fertilizers. The variants of biologized I and organic technologies ensured the value of this index at the level of 4.76 and 5.73, respectively. Analysis of the environmental suitability of the crop hybrids that formed the gradation of factor A of the experiment allows drawing a conclusion that the advantage of the hybrid PR64F66 F_1 in the main indexes reflects its ecological tolerance, and primarily in the plasticity bi (1.06 compared to 0.96 for the variant of the hybrid Tunca F_1) and stability Sd_i^2 (0.00091 vs. 0.00077, respectively).

Key words**:** *sunflower, economic efficiency, energy efficiency, ecological efficiency, organic technology*

INTRODUCTION

Modern trends in the agrarian market set more requirements for the available cultivation technologies than ever before. Nowadays the existing technology of crop cultivation should not only ensure the maximum productivity level of crop yields, but at least result in economic efficiency of yields, i.e. compensate production costs per unit of area or unit of production [2, 4, 19, 11, 9, 10, 15, 14].

However, according to the opinions of a wide range of experts, it is not enough for a modern crop cultivation technology just to have economic efficiency, because under the current conditions any individual technological element and operational technology as a whole should also be evaluated in terms of energy efficiency and environmental suitability for agrocenosis [6, 12, 18, 13], that made us perform thorough analysis of the experimental variants according to these criteria.

MATERIALS AND METHODS

Field trials on the sunflower cultivation technology were conducted during 2016-2021 in the non-irrigated lands of the Farm “Vera” in Hola Prystan district of Kherson region. The experimental plots were located at the latitude 46°20'16.11"N, longitude 32°17'31.38"E, and were elevated to 9 m above the sea level.

The soil of the experimental plots was represented by the dark-chestnut middle-loamy middle-saline soil with the humus content of 2.34-2.60%. The content of mobile forms of the elements of mineral nutrition: nitrogen - 1.7-2.0; phosphorus - 4.9-6.5; potassium - 28-36 mg-eq in 100 g of soil, pH - 6.9-7.2. The soil has moderate natural fertility, which mainly depends on nitrogen content.

The field experiments were conducted in four replications by using the split plot design method. The study was dedicated to evaluation of the following cultivation technology elements: - A - sunflower hybrid: A1 - sunflower hybrid PR64F66 F_1 (bred by Pioneer); A2 – sunflower hybrid Tunca F_1 (bred by Limagrain); - B - the level of biologization of a cultivation technology: B1 (Traditional) - a traditional intensive zonal cultivation technology is recommended by the originator for the conditions of the Southern Steppe of Ukraine with using mineral fertilizers and chemical plant protection products (PPP), aimed at maximum realization of the genetic potential of the hybrid; B2 (Biologized I) - an intensive technology, in which the system of plant care replaces mineral fertilizers by biological fertilizers allowed to be used in the practice of organic farming. The multifunctional preparation TM “Eco-Growth” was used as an organic fertilizer; B3 (Biologized II) - an intensive technology in which the system of plant care replaces mineral fertilizers by biological preparations allowed to be used in organic farming, and herbicides are replaced by mechanical weed control operations. The preparations “ENZIM-Agro” Gaubsin-FORTE and Viridin (Trichodermin) were used as a biological fungicide preparation. The insecticide-acaricides TM "ENZIM-Agro" Entocid (Metarizin) and Aktarofit were used as a biological insecticide; B4 (Organic) - organic - a technology in which the crop care system is based solely on the use of biological preparations (both fertilizers and pesticides); B5 (Extensive) - extensive (minimal) - a technology of crop cultivation, in which the system of crop care is represented only by mechanical operations to control weeds without using chemical and biological fertilizers and PPP.

The method of plot placement in the experiment - split blocks, the total area of the experimental plot was 1.2 ha, the total area of the quartic plot - 672 m^2, the registered plot – 560 m^2. The replication of the experiment was fourfold. In general, the scheme of the field two-factor experiment and the plan of placement of the research plots had the following pattern.

The characteristics of the experimental hybrid: PR64F66 F_1: the originator company - Pioneer® (USA) , simple two-lined highly oleic, the maturity group - medium-early (111-115 days), the actual production yield - 30.8 c/ha, the plant height - below the average (146 cm), convex seeds, the color - black-gray, the inflorescence - flat capitulum, the diameter - 15.4 cm, oil content - 51.1-52.3%, protein content - 16.0-17.2%, the weight of 1,000 seeds – 67 g. Disease and stress resistance: very high resistance to drought, excellent cold resistance, high resistance to lodging, resistance to 7 races of Orobanche cumana (A-G), resistance to various types of cinerea (white, ashy, dry, root), tolerance to phomosis and phomopsis; Tunca F_1: the originator company - Limagrain® (France), simple two-lined, the maturity group - medium-early (110 days), the actual production yield - 29.5 c/ha, the plant height - medium (150 cm), elongated seeds, the color - black-gray, the inflorescence - flat capitulum, the diameter - 15.9 cm, oil content - 50.6-51.7%, protein content - 16.2-17.0%, the weight of 1,000 seeds – 73 g. Disease and stress resistance: high resistance to drought, excellent cold resistance, resistance to lodging, resistance to 7 races of Orobanche cumana (A-G), resistance to various types of cinerea (white, ashy, dry, root), tolerance to phomosis and phomopsis.

During the research we were guided by the generally accepted methods of conducting field experiments and performing laboratory experiments. The experiments were accompanied by appropriate observations, measurements and analysis of soil and plant samples. All the records and observations were performed in two non-contiguous replications.

The economic efficiency of epy crop cultivation was determined with the generally accepted method using zonal production standards [5, 16, 7]. Calculations of bio-energetic efficiency were performed according to the guidelines of bioenergy assessment of crop production technologies [6, 12, 13, 3, 20]. The ecological plasticity of the experimental variants was determined using the Ebergard-Russell method modified by Khotylova and Letun [20, 1, 21, 8, 17].

The agricultural techniques in the experiments, provided that the specified technological operation or its gradation was not a factor studied according to the scheme of the experiment, had the following pattern: winter wheat was a pre-crop, after harvesting it there was disking to a depth of 10-12 cm with BDT-7. In 14 days after the last disking, the stubble was plowed to the depth of 22-24 cm, leveling with KPE-3.8 (8-10 cm), double pre-sowing tillage with the Lemken Compactor S unit. According to a preliminary agreement with the regional representatives of the companies-originators of sunflower hybrids, the crop seeds without pre-sowing incrustation with fungicidal-insecticidal composition were purchased for the experiment. Pre-sowing treatment was carried out independently: in the variant of intensive and biologized I technologies - with a mixture of Cruiser 6 l/t (thiamethoxam 350 g/l) and Maxim 1 l/t (fludioxanil 25 g/l), in the variant of biologized II and organic technologies - with a mixture of biological preparations (Table 1) at the recommended rates with the expense of the working liquid of 10 l/t. Mineral fertilizers (ammonium nitrate and granular superphosphate) were used in the variants of intensive and biologized II technologies at the calculated rate $N_{54}P_{46}$, average for the years of the research (40% nitrogen and 100% phosphorus - for basic tillage, 60% nitrogen - for pre-sowing tillage) And in the variant of an organic technology - with biological fertilizers at the recommended rates (Table 2). Sunflower seeds were sown in the middle of spring at a soil temperature of 6-7^{o}C at a depth of 5 cm using a wide row method with a row spacing of 0.7 m and a seeding rate of 55 thousand units/ha with SUPN-8 seeder with post-sowing soil rolling with KKSH-3 rollers.

Table 1. The characteristics of biological preparations used in the variants of the experiment

Preparation	Content	Methods and rates of application
Organic fertilizer **"Eco-Growth"**	Strains of the culture Bacillus thermophiles, Bacillus subtilis, phosphorus-mobilizing, nitrifying bacteria and chelate micro-fertilizer (51 g/l N, 12.0 g/l K_2O, 58 g/l MgO, 50 g/l SO_3, 6.5 g/l B, 12.5 g/l Cu, 12.4 g/l Fe, 12.0 g/l Mn, 0.2 g/l Mo, 6.4 g/l Zn, 0.1 g/l Co, 66.4 g/l amino acids, 67.8 g/l organic acids (succinic, malic, tartaric and citric), 3.3 g/l humic acids, 0.58 g/l fulvic acids, 0.0055 g/l phytohormones, 0.049 g/l of polysaccharides, vitamins, cytokinins, gibberellins compounds) pre-sowing seed treatment -2 l/t; vegetative foliar feeding – 2 l/ha	pre-sowing seed treatment – 2 l/t; vegetative foliar feeding – 2 l/ha
Bio-fungicide **Gaubsin-FORTE**	Two strains of Pseudomonas aureofaciens with a cell titer of at least 4×10^9 KUO/ml	plant vegetative spraying – 2 l/ha
Biofungicide **Viridin** (Trichodermin)	Spores and mycelium of fungi of the genus *Trichoderma spp*. with a titer of not less than 1×10^8 KUO/ml and metabolic products - biologically active substances pre-sowing seed treatment – 5 l/t; vegetative spraying of plants – 2 l/ha	pre-sowing seed treatment – 5 l/t; plant vegetative spraying – 2 l/ha
Biofungicide **Entocid** (Metaryzyn)	Spores of entomopathogenic fungi - not less than 2×10^8 KUO /ml	soil spraying for pre-sowing treatment – 5 l/ha
Biofungicide **Actarofit**	complex of natural avermectins produced by the beneficial soil fungus Streptomyces avermitilis (abamectin - 50%, emamectin - 50%). The total content of toxins is not less than 1.8%	plant spraying - 0,2 l/ha

Source: Own description based on materials provided by firm manufacturers.

The care of sunflower plants was represented by the measures protecting the crop against a complex of pests in case of exceeding the rate of the economic threshold. Protection against weeds in the variant of intensive and biologized I technologies was realized by application of the soil herbicide Triflurex at the rate of 3 l/t (triflurex 480 g/l) and the post-emergent herbicide Select 2 l/ha (kletodim 120 g/l), in the variants of biologized II, organic and extensive - by means of mechanical methods of weed control (pre- and post-emergent harrowing with weeders and rotary hoes, inter-row tillage). Protection against diseases in the variants of intensive and biologized I technologies was presented by two vegetative treatments with the fungicide Amistar Extra 1 l/ha (azoxystrobin 200 g/l + cyproconazole 80 g/l), biologized II and organic - treatments with biofungicides (Table 1). Pest protection in the variants of intensive and biologized I technologies was presented by two vegetative treatments with Ampligo 150 ZC insecticide 0.3 l/ha, containing chlorantraniliprol 100 g/l and lambda-cyhalothrin 50 g/l, in the variants of biologized II and organic technologies - treatments with bio-insecticides. Vegetative plant treatment was carried out twice at the phase of sunflower development “3 pairs of true leaves” and “capitulum formation”, the rate of working fluid consumption in all the cases was 250 l/ha, with the simultaneous use of preparations and tank mixture 30 minutes before treatment. The crop was harvested by direct combining at the stage of full maturity of seeds with the self-propelled grain harvester John Deere 9660 STS. The data obtained resulted in basic moisture (7%) and 100% purity.

RESULTS AND DISCUSSIONS

We performed analysis of the economic efficiency of different technologies of growing sunflower hybrids taking into account the current market prices for commodities and inputs. It allows stating that, on the average by Factor A, a traditional intensive technology for the crop cultivation chosen as a control variant in the experiment, ensured the product cost price at the level of 10,947 UAH/t, the total production costs – 20,250 UAH/ha, the cost of commodities – 38,480 UAH/ha, the operating net profit – 18,230 UAH/ha, that led to the final profitability of production at the level of 90.1% (Table 2).

Table 2. Indexes of economic efficiency of growing sunflower hybrids under different levels of technology biologization

Hybrid (Factor A)	Cultivation technology (Factor B)	Crop productivity, t/ha	Cost price of 1 t, UAH	Total production costs, UAH/ha	The cost of commodities, UAH/ha	Operating net profit, UAH/ha	Profitability, %
PR64F66 F_1	Traditional	1.87	10,830	20,251	38,896	18,645	92.1
	Biologized I	1.94	10,444	20,261	40,352	20,091	99.2
	Biologized II	2.02	8,014	16,187	42,016	25,829	159.6
	Organic	2.27	7,810	17,729	47,216*	29,487	166.3
	Extensive	0.94	7,995	7,516	19,552	12,036	160.1
Tunca F_1	Traditional	1.83	11,065	20,248	38,064	17,816	88.0
	Biologized I	1.96	10,338	20,263	40,768	20,505	101.2
	Biologized II	1.99	8,133	16,185	41,392	25,207	155.7
	Organic	2.16	8,204	17,720	44,928*	27,208	153.5
	Extensive	0.94	7,995	7,516	19,552	12,036	160.1

Note.* without taking into account the added value of the products with organic status.
Source: original data calculated based on the experimental data obtained.

The refusal to apply mineral fertilizers and the use of organic multifunctional fertilizers (biologized and technology) instead of them in the technology of the crop cultivation ensured significant improvement in all the indexes of economic efficiency, namely: the cost price decreased to 10,391 UAH/t, the total production costs remained unchanged at the level of 20,262 UAH/ha, the cost of commodities increased significantly to 40,560 UAH/ha, the operating net profit amounted to 20,298 UAH/ha, and the profitability of production increased to 100.2%. This is due to a relatively low price of modern organic fertilizers and plant-growth regulators at the market in comparison with the traditional mineral fertilizers, and their significant positive impact on the formation of sunflower seed yields.
The crop cultivation with a biologized AI

technology implying the refusal to apply synthetic PPP and the involvement of only organic pesticides, was also characterized by significant improvement in the economic efficiency when compared to the control variant. Despite a little higher market price of insecticides and fungicides of organic origin, relatively higher rates of their use, and the involvement of inter-row mechanical tillage as an alternative to soil and post-emergent herbicides in the cultivation technology, the production costs decreased significantly to 8,073 UAH/t, the total production costs were 16,186 UAH/ha, the value of commodities increased to 41,704 UAH/ha, the operating net profit increased to 25,518 UAH/ha with the profitability of production at the level of 157.7%.

The combination of individual elements of biologization of sunflower cultivation technology in a general organic technology resulted in significant improvement in all the indexes of economic efficiency, namely: the cost price decreased to 8,007 UAH/t, the total production costs dropped to 17,725 UAH/ha, the cost of commodities increased to 46,072 UAH/ha, the operating net profit was 28,347 UAH/ha, and the profitability increased to 159.9%.

Even under these conditions, an organic technology looks completely competitive in comparison with a traditional intensive technology for sunflower cultivation, but we have involved an additional factor to optimize the economic component of crop production, namely, the so-called "organic ratio" - the additional market value of a unit of crop products provided that the operator (a business entity) received a certificate confirming the compliance of the technology of crop cultivation with the requirements of the European Union for such products.

Analysis of the modern market of organic products allows stating that if the technology of sunflower cultivation meets the requirements of EU regulations №834/2007 and EU №889/2008, confirmed by the relevant certificate issued by an accredited certification organization in Ukraine, the actual market value of organic sunflower increases at least by 20% in comparison with the products of conventional origin [17, 19]. Therefore, the main economic indexes of sunflower cultivation using organic technology in the farm, certified as an organic agricultural producer, will look in the following way (Table 3).

Table 3. Estimated economic efficiency of growing sunflower hybrids under conditions of organic product certification

Hybrid	Crop productivity, t/ha	Cost price of 1 t, UAH	Total production costs, UAH/ha	Cost price of commodities, UAH/ha	Operating net profit, UAH/ha	Profitability, %
PR64F66 F_1	2.27	7,810	17,729	56,659	38,930	219.6
Tunca F_1	2.16	8,204	17,720	53,914	36,194	204.3
Average	2.21	12,383	27,411	55,286	27,875	211.9

Source: original data calculated based on the experimental data obtained.

The above data show that certification of organic sunflower production places the economy of its cultivation to a qualitatively new level, allowing it to exceed the traditional intensive technology of cultivation 2.35 times by the final index of economic efficiency - the level of profitability of production. Taking into account 20% surcharge for organic status, the cost prices of commodities and the operating net profit per unit of sown area of organic crops (UAH 55,286 and UAH 27,875, respectively) are the highest among the experimental variants.

Sunflower cultivation using an extensive (minimal) technology, which has recently become very popular in small farms and private farms, looks attractive in terms of economic efficiency, but it is completely hopeless because this level of productivity and, consequently, economic indexes have been formed due to the residual level of soil fertility. For instance, on the average by Factor A, the refusal to apply fertilizers and plant protection products of any origin in the cultivation technology provided the cost price of products at the level of 7,995 UAH/t, the total production costs – 7,516 UAH/ha, the cost of commodities- 19,552 UAH/ha, the operating net profit -12,036 UAH/ha, that led to the final profitability of production at the level of only 160.1% (Table 4).

Table 4. Indexes of energy efficiency of growing sunflower hybrids under different levels of technology biologization

Hybrid (Factor A)	Technology of cultivation (Factor B)	Crop productivity, t/ha	Energy consumption, GJ/t	Energy gain, CJ/ha	Energy expenses, GJ/ha	Energy increment GJ/ha	Energy coefficient
PR64F66 F_1	Traditional	1.87	7.70	36.24	14.41	21.83	2.51
	Biologized I	1.94	4.10	37.60	7.93	29.66	4.74
	Biologized II	2.02	6.90	39.15	14.01	25.14	2.79
	Organic	2.27	3.30	43.99	7.53	36.46	5.84
	Extensive	0.94	5.50	18.22	5.15	13.06	3.53
Tunca F_1	Traditional	1.83	7.90	35.47	14.37	21.10	2.47
	Biologized I	1.96	4.10	37.98	7.95	30.03	4.78
	Biologized II	1.99	7.00	38.57	13.98	24.58	2.76
	Organic	2.16	3.40	41.86	7.45	34.41	5.62
	Extensive	0.94	5.50	18.22	5.15	13.06	3.53

Source: original data calculated based on the experimental data obtained.

In order to perform more thorough analysis of the proposed technologies for growing commercial sunflower seeds not depending on a number of objective and subjective factors, primarily determined by the market conditions, we performed a bio-energetic evaluation of the experimental variants according to the modern requirements (Table 4).

The analysis of the above research results allows drawing a conclusion that the final index of energy efficiency of sunflower cultivation - energy coefficient on average by Factor A - had the highest values under organic technology (using organic fertilizers instead of synthetic mineral fertilizers, and organic insecticides instead of chemical PPP) and made up 5.73, that characterizes the technology as extremely highly efficient in the energy aspect. Under the traditional intensive cultivation technology, this index was 2.49, that also allows characterizing the technology as highly efficient in terms of total energy consumption. Using organic PPP instead of synthetic pesticides (biologized II technology) in the cultivation technology was also characterized by a significant level of energy efficiency - the amount of energy consumed per unit of sown area was 2.77 times less than the amount obtained with the yield harvested in the same area.

The variant of organic I cultivation technology was also characterized by a high level of energy efficiency: on average by Factor A, it was 4.76 (we explain this value to be a result of removing mineral fertilizers from the structure of the production costs, which are the most energy-intensive). Sunflower cultivation with using a minimal extensive technology also led to a significant level of energy efficiency of the process - the average value of the organic coefficient was 3.53, which exceeded all the other variants of the experiment, except of an organic technology for sunflower cultivation.

In our opinion, the evaluation of the variants under study in the light of their compliance with environmental conditions is not less important, especially under the current conditions of significant climatic transformations experienced by all agro-climatic zones of the country. Ecological plasticity is considered to be the average reaction of a variety or hybrid to changes in environmental conditions, and ecological stability is the deviation of empirical data in each environment from the average reaction. According to the data obtained by V.Z. Pakudin and L. M. Lopatina, the regression coefficient (b_i) characterizes the average reaction of a crop under a particular cultivation technology to changes in

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environmental conditions, shows the plasticity of this sample and allows predicting changes in the trait under study in specific conditions. The variance of trait stability (Si^2) shows how reliably this variant corresponds to this plasticity estimated by the regression coefficient. Comparison of the plasticity of the hybrids under study shows that the samples with the coefficient b>1 belong to highly plastic ones (in relation to the group average), with the coefficient 1>b=0 - to relatively low plastic ones. If the plasticity index does not differ significantly from unity, then the variant t does not differ from the group average by the reaction to changes in environmental conditions [22]. The evaluation of ecological plasticity and stability of crop varieties and hybrids makes it possible to characterize them in various ways in terms of the formation of potential productivity of a particular crop, its technological quality and resistance to a set of stressors [18]. These values are complementary indexes in their essence, and highly stable hybrids respond to a change in external conditions with a more predictable reaction [22]. It allows stating that adaptability refers to the reaction to the predicted effects of the environment, and stability - vice versa. The most widely used method for studying the interaction of genotype×environment (G×E) in different crops is a comparative method. The aim of our research was to determine the indexes of ecological plasticity and stability of sunflower hybrids of the medium-maturing ecological group by quantitative characteristics of productivity and to establish high- and medium-plastic samples with its stable manifestation by the analyzed characteristics (Table 5).

Table 5. Indexes of ecological tolerance of sunflower hybrids depending on a cultivation technology

Hybrid	Crop productivity, t/ha	DSI - drought susceptibility index	DTL - Drought tolerance index	YSI - yield stability index	YI - yield index	STI - stress tolerance index	b_i - plasticity index	Sd_i^2 - stability index
PR64F66 F_1	1. 81	0.91	0.87	0.59	109	0.51	1.06	0.00091
Tunca F_1	1.78	0.93	0.82	0.53	104	0.47	0.96	0.00077
Average	1.79	0.92	0.85	0.56	107	0.49	1.01	0.00084

Source: original data calculated based on the experimental data obtained.

In the experiment, we detected the advantage of the hybrid PP64F66 F_1 by the main indexes reflecting environmental tolerance, and mainly by the plasticity index b_i (1.06 in comparison with 0.96 for the hybrid Tunca F_1) and the stability of Sd_i^2 (0.00091 suitability of this hybrid to the environmental conditions of the growing area, primarily, by the indexes of drought resistance.

CONCLUSIONS

All the elements of biologization of the cultivation technology for sunflower hybrids resulted in significant improvement of basic indexes of economic efficiency, firstly, the cost price of a unit of production, total production costs, revenues, operating net profit and the final index - the level of profitability of production. The analysis of the latter index makes it possible to state that, by Factor A, the highest economic attractiveness is characteristic of the variants of an extensive (minimum) cultivation technology, in which the level of profitability during the years of the research was 160.1% on average, and organic technology - 159.9%, respectively. If the manufacturer is certified and a batch of commercial sunflower has organic status, it is possible to increase this index to 211.9%, taking into account 20% organic bonus, that is an essential reserve for improving the economic condition of the farm.

The highest energy efficiency in the experiment was characteristic of the variants without the use of the most energy-intensive components - mineral fertilizers. The variants of biologized I and organic technologies ensured the value of this index at the level of 4.76 and 5.73, respectively. The rest of the variants are also characterized by energy efficiency, as they ensure manifold (2.5 times) return of energy consumed per one hectare with the yield.

Analysis of the environmental suitability of the crop hybrids that formed the gradation of factor A of the experiment allows drawing a conclusion that the advantage of the hybrid PR64F66 F_1 in the main indexes reflects its ecological tolerance, and primarily in the plasticity b_i (1.06 compared to 0.96 for the variant of the hybrid Tunca F_1) and stability Sd_i^2 (0.00091 vs. 0.00077, respectively), that indicates significantly higher suitability of this hybrid for the environmental conditions of the growing region, primarily - in terms of drought resistance, which has recently been considered as the most principal one in terms of modern climatic transformations.

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