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INFLUENCE OF BASIC TILLAGE SYSTEMS AND FERTILIZATION ON PRODUCTIVITY AND ECONOMIC EFFICIENCY OF IRRIGATED CROP ROTATION

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Abstract

The article presents the results of experimental studies on the influence of different methods and depth of basic tillage at the background of organic and organo-mineral fertilization systems on agrophysical properties of soil, its water regime and yields of the cultivated crops. The goal of the study was to scientifically substantiate the optimal parameters of the systems of basic tillage and fertilization in the row short crop rotation in the conditions of irrigation, which guarantee the improvement of effective fertility of the dark-chestnut soils and reduce the chemical load on the environment. Field, laboratory, statistical and computational methods were used in the study conduction. Optimal parameters of agrophysical conditions, both at the beginning of vegetation and before harvesting, were formed by differentiated-1 system of basic tillage where during the crop rotation we alternated shallow plowless tillage for the crops of the Steppe ecological type with combined disc-chisel loosening to 38-40 cm for grain sorghum. As a result, the most favorable conditions for growth, development and crop formation are created by differentiated-1 system of basic tillage under fertilization with by-products and mineral fertilizers application in the dose of $N_{120}P_{60}$ kg/ha. Differentiated by ways and depth system of basic tillage with one para-plowing per the crop rotation contributed to the formation of the highest productivity of the crop rotation: under organic fertilization system – 3.71 t/ha of grain units; under organo-mineral, with the application of $N_{82.5}P_{60}$ per the unit of the crop rotation area – 6.92 t/ha; and under organo-mineral, with the application of $N_{120}P_{60}$ – 8.50 t/ha. The mentioned cultivation technology guarantees obtaining the best profitability level of 110.1%.

Key words: *method and depth of basic tillage, agrophysical properties, productivity, crop rotation, irrigation*

INTRODUCTION

Peculiarities of the southern part of the Steppe zone of Ukraine are insufficient natural humidification due to the lack of precipitation under significant potential of heat and solar energy income. Due to such natural features, almost every year there is an acute shortage of moisture, which prevents obtaining the planned level of crops.

Irrigation changes the ratio of moisture and heat in the soil, as well as the intensity of plants' use of radiant solar energy, contributing to the transformation of agriculture into highly productive and sustainable one. At the same time, there is a need to solve the problem of preservation soil fertility on the irrigated lands.

One of the main ways for efficient and sustainable agriculture in the region and reduction of its dependence on the influence of natural and climatic factors is irrigation. Irrigation helps to reduce or even eliminate the water balance deficit, increase crop yields by almost 3-5 times and ensure food security in Ukraine.

Analysis of the yield of major crops on irrigated and non-irrigated lands proves the high efficiency of irrigated agriculture.

In this regard, the relevance of the developed topic is in the need for scientific substantiation of the possibility of using the systems of basic tillage, fertilization, and irrigation.

Given that in the market conditions the final result is a high profit, the constituents of agricultural systems on the irrigated lands should be based on the optimization of material and energy costs and obtaining the highest level of profitability.

Crop yields and the quality of crop products are directly related to the meliorative conditions and soil fertility.

The main measures to achieve this goal are the regulation of biological processes, which take place in soil, as well as its nutrient, water, air and heat regimes. In solving these issues, the systems of basic tillage and fertilization play a leading role [2, 12, 17].

Technogenic resource provision of the agricultural sector should include the development and implementation of the latest intensive farming systems, based on rational low-energy basic tillage, based on the use of tillage tools with different design of working bodies and organic and organo-mineral fertilization systems with the use of crop by-products. An important feature is the effect of such systems of basic tillage and fertilization on the processes, which take place in soil, growth, and development of plants and on the environment in general [1, 10, 11].

This versatility and the degree of the effect of tillage on the dynamics of effective soil fertility, creation of favorable conditions for growth and development of crops, protection of them against harmful effects of weeds, pathogens, pests, erosion have increased over the centuries of agricultural history. Therefore, there is a need to constantly improve existing and develop new most advanced agronomic measures, especially fertilization and tillage systems, considering zonal characteristics and the level of intensification of agricultural production, i.e., a comprehensive approach to the development of fertilization systems and basic tillage to increase the efficiency of irrigated agriculture in general [4, 15, 16].

Recently, there have been discussions in the world between supporters and opponents of tillage minimization. Accumulated over many decades scientific and practical experience convincingly proves the validity of the use, along with moldboard tillage, plowless and surface tillage. In this regard, the data obtained in stationary field experiments are of a great interest.

In a long-term experiment [3] conducted in Hungary, the effect of seven crop sequences and five doses of fertilizers on the stability of corn and wheat yields has been studied. The fertilization system included organic fertilizer (manure or processed crop residues with the addition of NPK) and high levels of NPK fertilizer. The yield of corn and wheat in monocropping in all the cases was inferior to that in the crop rotation. Manure and processing of post-harvest residues (corn stalks, wheat straw) with the addition of NPK were effective fertilizers for corn and wheat. Significantly higher yields were obtained at high levels of NPK fertilizer, especially in the crop rotations, where the proportion of corn or wheat was 50% or higher.

In the early 2000s, 12-year studies in Germany and 4-year-one in Denmark examined different crop rotations, tillage intensity, and pesticide use strategies for yield, humus substitution, and nitrogen balance. The studies have shown that crop yields, energy efficiency in both areas depended significantly on the crop rotation and much less on the intensity of pesticide use or tillage [5].

In the northern regions of the Central Chernozem zone of Russia an effective way of tillage for dark-gray forest soil in the field crop rotation link of "pea-oat mixture-winter wheat-millet" is for the pea-oat mixture – moldboard plowing with PLN 3-35 (control); for winter wheat and millet in terms of agrophysical and biological properties – surface combined tillage with KOS-3.7 [22].

On the sod-podzol sandy soils of Belarus, free enough from weeds, in the fruit-changing crop rotation it is advisable to use instead of traditional moldboard tillage the energy-saving combined tillage system using high-performance chisel and chisel-disk tillage tools, which allow to obtain the same yields, cut the costs, and accelerate the performance of agricultural operations. Plowing should be carried out at least after 2 years, preferably on the bare fallow field, for winter rape, for plowing organic fertilizers during the cultivation of row crops [8].

MATERIALS AND METHODS

In the stationary experiment of the Institute of Irrigated Agriculture of NAAS of Ukraine during 2016-2020 in the 4-field row crop rotation on the dark-chestnut middle loamy soil in the area of the Ingulets irrigation system, five systems of basic tillage (factor A) on the background of organic and two organic and two mineral fertilization systems (factor B) were studied.

Factor A (basic tillage):

(1)The system of multi-depth moldboard plowing with the depth of 14-16 cm for winter wheat and 25-27 cm for soybeans;
(2)The system of multi-depth plowless tillage with the same depth of loosening;
(3)The system of single-depth shallow (12-14 cm) disk tillage for all the crops in the crop rotation;
(4)The system of differentiated tillage with one para-plowing on 38-40 cm per the crop rotation;
(5)The system of differentiated tillage in the crop rotation with one plowing at 18-20 cm per rotation.

Factor B (fertilization system):

(1)Organic fertilization system with the use of by-products.
(2)Organo-mineral system with the application of $N_{82.5}P_{60}$ per 1 ha of the crop rotation area + by-products.
(3)Organo-mineral with the application of $N_{120}P_{60}$ per 1 ha of the crop rotation area + by-products.

The soil of the experimental field is dark-chestnut middle loamy one, and the granulometric composition is coarse-dusty-silty. The humus horizon is 38-40 cm. The content of humus in the soil layer of 0-40 cm is 2.15%, the field capacity of the soil layer of 0-100 cm is 21.5%, wilting point is 9.1%, the content of water-resistant particles is 34.1%, steady-state density is 1.39-1.42 g/cm^3, porosity is 49.2%, water permeability is 1.25 mm/min.

The crops cultivation technology was generally accepted for the irrigated lands of the Southern Steppe of Ukraine, excepting the studied factors.

During the growing season, soil moisture in the layer of 0-50 cm was maintained at the level of not less than 70% FC.

The field experiments were carried out according to the methods of experimental work, special methods of land reclamation, irrigated agriculture, soil science, methodical recommendations, and guidelines [14, 20].

Regional varieties and hybrids of the crops, listed for the Steppe zone in the "State Register of Plant Varieties Suitable for Dissemination in Ukraine", were sown [13].

The depth of tillage was determined from the edge of the uncultivated furrow to its bottom with the help of a furrow-ruler, and at least fifty excavations were made in each section. After determining the average depth at each section of the experiment, the coefficient of flatness of the tillage was determined and evaluated by the five-point scale [6].

The density of the arable layer was determined by the method of cutting rings [7], water permeability – by the method of floodplains in a three-hour exposure with subsequent determination of the depth of soaking [6]. Soil moisture was determined by gravimetric method [20]. Total water use of the crops – by the method of water balance without considering the recharge of groundwater [21].

The total water use for the growing season, as well as for the separate interphase periods of the crops in the crop rotation, was determined by the method of water balance by the formula (1) [19]:

$$\mathbf{E = M + O + (W_h - W_k)}, \qquad (1)$$

where:
E – total water use, m^3/ha;
M – irrigation rate, m^3/ha;
O – precipitation, m^3/ha;
$\mathbf{W_h}$ – moisture content in the active soil layer at the beginning of the growing season, m^3/ha;
$\mathbf{W_k}$ – moisture content in the active soil layer at the end of the growing season, m^3/ha.

The coefficient of water use of the crops in the crop rotation on the irrigated lands was determined by the formula (2) [19]:

$$\mathbf{K_E = E/Y}, \qquad (2)$$

where:
K_E – coefficient of water use, m^3/t;
E – total water use for the growing season, m^3/ha;
Y – yield of the crop, t/ha.

RESULTS AND DISCUSSIONS

The best conditions for growth and development of the plants are formed under the optimal structure of the active soil layer. Numerous studies have proved the necessity for finding out such parameters of loosening or bulk density of the soil, which would be most corresponding to the biological requirements of agricultural plants. It is established that for the soil, which have steady-state density equal to the optimal for a certain crop, there is no need in deep tillage.

Most crops require bulk density of 1.1-1.3 g/cm^3. The share of corn and soybeans in the irrigated crop rotations is 25-50%. These crops require loose, rich in nutrients and water arable and root layer of the soil to grow intensively. The optimal bulk density of the soil for corn, soybeans and sorghum crops is 1.1-1.2 g/cm^3, and 1.1-1.4 g/cm^3 for winter wheat. If this index exceeds the figure of 1.27 g/cm^3 at the time of sprouting in row crops, this has an adverse effect on further growth and development of the plants. The studies of the Institute of Irrigated Agriculture of NAAS established that these conditions are better satisfied on the dark-chestnut soils of the South of Ukraine under moldboard basic tillage when organic fertilizers like by-products (stems and straw of corn, soybeans, and sorghum) and immobile phosphorus fertilizers are incorporated to the depth of 14-16 to 25-27 cm or in the zone of stable humidification and the maximum spreading of the root system. In the variants of plowless basic tillage the bulk density of 0-40 cm soil layer was 1.34-1.36, and in the variants of multi-depth plowing and differentiated systems this figure was 1.33-1.35 g/cm^3. Such a level of bulk density favored to growth and development of winter wheat, while under plowless tillage these figures were lower than biologically optimal for corn, sorghum, and soybeans by 4.6 % (Table 1).

Table 1. Bulk density of 0-40 cm layer of the dark-chestnut soil depending on basic tillage in the crop rotation, beginning of the growing season, g/cm^3

System of basic tillage	Crop				Average by the crop rotation
	Grain corn	Soybeans	Grain sorghum	Winter wheat	
Moldboard multi-depth	1.35	1.32	1.33	1.33	1.33
Plowless multi-depth	1.35	1.34	1.34	1.35	1.34
Shallow single-depth plowless	1.36	1.36	1.35	1.36	1.36
Differentiated-1	1.34	1.33	1.33	1.34	1.33
Differentiated-2	1.34	1.34	1.35	1.35	1.34
LSD_{05}	0.07	0.05	0.08	0.06	

Source: Own study.

Dynamics of the bulk density by the soil layers with deepening from 0-10 to 30-40 cm is important in the initial stages of the plants' growth and development.

The highest loosening of the soil layer 0-20 cm was in the variant of plowing on the depth from 14-16 to 25-27 cm in the system of multi-depth moldboard tillage, and usage of plowless shallow single-depth tillage resulted in compaction of the layers 0-10 and 10-20 cm by 4.0-8.8% in comparison to the control.

Precipitation of the autumn-winter period and seasonal irrigation significantly compacted the soil. The regularity, which was established in the initial time of growing season, remained – plowless tillage resulted in greater bulk density in comparison to biologically optimal for corn, sorghum, and soybeans by 6.9-7.7% (Table 2).

During this period, the compaction of the lower layers of the soil (20-40 cm) is more significant in comparison with the layer of 0-20 cm, both by the variants of the experiment and under the crops. The maximum values of the bulk density in the soil layer of 30-40 cm, on average by the crop rotation, corresponded to the variant of shallow tillage on 12-14 cm in the system of single depth plowless basic tillage and the figures were 1.40-1.45 g/cm^3. At the same time, because the optimal bulk density for cereals is within 1.1-1.4 g/cm^3, it is advisable to replace deep moldboard and plowless loosening with shallow and surface basic tillage. On the dark-chestnut middle loamy soils, the density of which in the steady-state reaches 1.41-1.42 g/cm^3 for row crops – corn, sorghum, and soybeans, the best results are provided by deep moldboard or plowless tillage.

Table 2. Bulk density of 0-40 cm layer of the dark-chestnut soil depending on basic tillage in the crop rotation, end of the growing season, g/cm^3

System of basic tillage	Crop				Average by the crop rotation
	Grain corn	Soybeans	Grain sorghum	Winter wheat	
Moldboard multi-depth	1.36	1.36	1.38	1.36	1.36
Plowless multi-depth	1.37	1.39	1.39	1.36	1.38
Shallow single-depth plowless	1.39	1.40	1.42	1.38	1.40
Differentiated-1	1.36	1.38	1.39	1.38	1.38
Differentiated-2	1.36	1.39	1.41	1.39	1.39
LSD_{05}	0.06	0.06	0.09	0.07	

Source: Own study.

Thus, determined at the beginning of the growing season of the plants porosity of the soil layer of 0-40 cm, on average by the crop rotation, was in the range of 48.0-48.9%, which corresponded to the variants of plowing to the depth of 14-16 to 25-27 cm in the system of multi-depth moldboard basic tillage in the crop rotation (variant 1) and differentiated system (variant 4), while long-term use of shallow (12-14 cm) tillage in the system of single-depth plowless loosening in the crop rotation (variant 3) reduced the porosity by 1.6 %. Before harvesting, the soil was compacted, and the porosity decreased to 46.0-47.4%, or by 2.9-4.2%.

Increased bulk density, and, accordingly, lower porosity in plowless tillage methods, especially under prolonged use of shallow loosening in the crop rotation (variant 3), led to a decrease in water permeability at the beginning of the growing season by 12.0-21.2%, and to the time of harvesting by 20.7-26.3%.

The maximum values of water absorption and filtration rate corresponded to the system of multi-depth moldboard basic tillage (variant 1) and the variant of differentiated-1 tillage with one para-plowing to the depth of 38-40 cm (variant 4) in the crop rotation.

Based on the results of experimental studies, it is established that under the influence of different methods and depth of basic tillage conducted on the dark-chestnut middle loamy soil in the crop rotation, agrophysical properties are formed, which create favorable conditions for accumulation and retention of moisture in the root layer providing optimal conditions for growth and development of the plants and further yield formation.

Determination of moisture reserves in the soil layer of 0-100 cm at the beginning of the renewal of vegetation of winter wheat and sprouting of spring crops (soybeans, grain corn, and sorghum), indicates that the methods and depth of tillage in the crop rotation had an impact on the accumulation and formation of moisture reserves in the soil profile. Higher reserves of productive and total moisture were formed in the variant with differentiated-1 tillage because para-plowing contributed to better absorption of precipitation in the autumn-winter period, and under single-depth shallow disk tillage (12-14 cm) they were minimal. Analysis of moisture reserves and water use during the growing season testifies about the in-time irrigation, which, together with precipitation, provided optimal water conditions for the crops in the rotation.

The total water use of the crops per 1 ha of the crop rotation area ranged within 5,093-5,294 m^3/ha depending their biological features, the length of the growing season and tillage methods.

Analyzing the amount of moisture used depending on the systems of the basic tillage, it should be mentioned that for multi-depth plowing and differentiated-1 tillage, 1,040 and 1,075 m^3/ha were used, respectively, per 1 ha of the crop rotation area, and for plowless multi-depth, shallow single-depth, and differentiated-2 systems the volumes ranged within 839-964 m^3/ha, or less compared to the control by 19.3-7.3%. In accordance with the use of soil moisture, the level of total water use was formed at the level of 5,294, 5,218 and 5,329 m^3/ha. Under the system of differentiated-2 tillage with one plowing per the crop rotation, this index decreased to 5,192 m^3/ha, and the use of shallow tillage (variant 3) reduced its value to 5,093 m^3/ha.

Analysis of the components of total water use testifies that the need for water by the tillage variants is provided by 18-22% at the expense of productive moisture reserves in the soil, 23-24% by precipitation and 55-58% at the expense of irrigation water (Table 3).

Our results on the effect of tillage methods and depths on the soil water regime are supported by another study, conducted on the dark-chestnut soil with chickpea [9]. It was determined that the highest chickpea yields were provided by moldboard tillage on 28-30 cm, together with the highest desalination of the soil due to the crop cultivation.

Table 3. Water regime of the soil at different systems of basic tillage in the crop rotation under irrigation

Indices	Tillage system				
	Moldboard	Plowless-1	Plowless-2	Differentiated-1	Differentiated-2
Water use, m^3/ha	5,294	5,218	5,093	5,329	5,192
Water balance elements:					
Soil moisture, m^3/ha; %	1,040 20	964 18	839 16	1,075 20	938 18
Precipitation, m^3/ha; %	1,254 24	1,254 24	1,254 25	1,254 24	1,254 24
Irrigation rate, m^3/ha; %	3,000 56	3,000 57	3,000 59	3,000 56	3,000 58
Coefficient of water use, m^3/t	1,134	1,222	1,664	1,064	1,242
Mean daily evaporation, m^3/ha	46.4	45.8	44.6	46.8	45.5

Source: Own study.

The highest efficiency of water use per ton of the product was in the variant with the systems of moldboard multi-depth (1,134 m^3/t) and differentiated-1 tillage (1,064 m^3/t), while plowless shallow tillage (12-14cm) increased the water use up to 1,644 m^3/t or by 33.2%.

Analyzing the values of mean daily evaporation, it is necessary to point out that it increased by 4.9%, from 44.6 m^3/ha under shallow plowless single-depth tillage to 46.8 m^3/ha under differentiated tillage.

The most favorable conditions for the formation of crop yields were created on the organic background with the differentiated system of basic tillage with one deep loosening to the depth of 38-40 cm once per the crop rotation with a rate of 3.71 t/ha of grain units, which exceeds the control by 2.2%.

The organo-mineral background with the application of $N_{82.5}P_{60}$ + by-products resulted in the crop rotation productivity increase, compared to the organic system in the variant with multi-depth plowing and differentiated-1 tillage, by 86.5%, and under plowless and differentiated -2 by 90-103%.

Increasing the dose of mineral fertilizer to $N_{120}P_{60}$ contributed to an increase in the crop rotation productivity compared to the dose of $N_{82.5}P_{60}$ by 19.3-26.0%.

Replacement of moldboard and plowless multi-depth tillage and differentiated by methods and depth with systematic shallow loosening (variant 3) led to a decrease in the productivity to 5.23 grain units in the fertilization system No. 1 and to 6.48 grain units in the fertilization system No. 2 (Table 4).

Table 4. Productivity of the crop rotation at different fertilization systems and systems of basic tillage, average for 2016-2020

System of basic tillage	Fertilization system	Productivity (t/ha)				
		Corn	Sorghum	Soybeans	Winter wheat	Grain Units (t/ha)
Moldboard multi-depth	organic	4.38	2.83	2.69	3.14	3.63
	$N_{82.5}P_{60}$ +by-products	11.60	6.79	3.55	5.84	6.77
	$N_{120}P_{60}$ +by-products	14.77	6.97	4.22	6.82	8.44
Plowless multi-depth	organic	3.92	2.47	2.41	3.03	3.23
	$N_{82,5}P_{60}$ +by-products	10.94	6.52	3.26	5.67	6.39
	$N_{120}P_{60}$ +by-products	14.04	6.73	3.90	6.46	8.05
Plowless shallow single-depth	organic	3.07	2.04	1.84	2.76	2.75
	$N_{82.5}P_{60}$ +by-products	8.27	4.59	2.47	5.34	5.23
	$N_{120}P_{60}$ +by-products	10.09	4.76	2.91	6.21	6.48
Differentiated-1	organic	4.61	3.12	2.68	3.22	3.71
	$N_{82.5}P_{60}$ +by-products	11.94	7.72	3.62	6.04	6.92
	$N_{120}P_{60}$ +by-products	15.11	7.94	4.12	6.93	8.50
Differentiated-2	organic	4.01	2.44	2.30	2.86	3.20
	$N_{82.5}P_{60}$ +by-products	10.89	6.18	3.22	5.52	6.51
	$N_{120}P_{60}$ +by-products	13.67	6.33	3.71	6.39	7.77

Source: Own study.

The highest level of gross output was obtained with a differentiated system of basic tillage with one para-plowing to the depth of 38-40 cm once per the crop rotation on the background of application of $N_{120}P_{60}$, where its cost was 38.9 thousand UAH (Table 5).

Similar results were obtained in the control with a rate of 38.6 thousand UAH, and cultivation technologies based on the plowless multi-depth tillage led to a decrease in gross output by 4.4%, while single-depth shallow tillage declined the production by 21.8 % and differentiated-2 system of tillage cut the gross output by 10.9%.

A similar pattern was observed on the non-fertilized background and on the generally accepted dose of mineral fertilizers.

Previously, it was also proved that the economic efficiency of crop production is greatly dependent on the fertilization system [18].

The expenditures for the crops cultivation by to the variants of the experiment differed mainly in the operation costs for basic tillage, transportation and processing of the yield.

The highest net profit of 20.4 thousand UAH with a profitability level of 110.1% was obtained under the application of mineral fertilizers in the dose of $N_{120}P_{60}$ and the use of differentiated -1 system of basic tillage with para-plowing to the depth of 38-40 cm once per the crop rotation, while under the systems of multi-depth moldboard basic tillage the profit was lower by 4.1%.

Table 5. Productivity and economic efficiency of the crop rotation under different systems of basic tillage and fertilization

System of basic tillage	Fertilization system	Grain Units, t/ha	Gross Product Cost, UAH	Expenditures, UAH	Profit, UAH/ha	Profitability, %	Fertilizers Output kg/kg of GU
Moldboard multi-depth	No	3.63	16.9	12.1	4.8	38.9	-
	$N_{82.5}P_{60}$	6.77	30.8	17.4	13.4	76.8	23.3
	$N_{120}P_{60}$	8.44	38.6	19.0	19.6	102.6	26.7
Plowless multi-depth	No	3.23	15.1	11.6	3.26	30.1	-
	$N_{82.5}P_{60}$	6.39	29.1	17.0	12.1	71.2	23.4
	$N_{120}P_{60}$	8.05	36.8	18.6	18.2	97.6	26.8
Plowless shallow single-depth	No	2.75	12.9	11.4	1.5	12.8	-
	$N_{82.5}P_{60}$	5.23	24.1	16.7	7.4	44.7	18.4
	$N_{120}P_{60}$	6.48	30.2	18.3	11.9	64.9	20.7
Differentiated-1	No	3.71	17.2	11.6	5.6	48.4	-
	$N_{82.5}P_{60}$	6.92	31.5	16.9	14.6	86.2	23.8
	$N_{120}P_{60}$	8.50	38.9	18.5	20.4	110.1	26.6
Differentiated-2	No	3.20	14.8	11.5	3.3	28.7	-
	$N_{82.5}P_{60}$	6.51	29.5	16.8	12.7	75.4	24.5
	$N_{120}P_{60}$	7.77	34.4	18.4	16.0	86.9	25.4

Source: Own study.

CONCLUSIONS

The most favorable agrophysical properties and water regime of the dark-chestnut soil in the South of Ukraine for the cultivation of row crops is created under differentiated-1 system of basic tillage with application of $N_{120}P_{60}$ + by-products per the hectare of the crop rotation area. The mentioned cultivation technology guarantees obtaining the best profitability level of 110.1% in comparison to 38.9% on the control.

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