Scientific Substantiation of the Timing and Rates of Sprinkling Irrigation of Grain Crops in the Conditions of Karakalpakstan

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Abstract. Efficient use of water resources in arid and semi-arid regions is essential for the sustainable development of irrigated agriculture. Low precipitation and high evaporation in the Republic of Karakalpakstan require the development of scientifically sound irrigation regimes for crop cultivation.
The aim of this study is to determine the optimal timing and application rates for sprinkler irrigation of grain crops in Karakalpakstan and to assess their impact on yield and water use efficiency. Field experiments were conducted on meadow-alluvial, medium loamy, and moderately saline soils of the Nukus district. Soil moisture was maintained at 70-75-70% of the field capacity.
During the growing season, four irrigations were applied at rates of 265, 330, 362, and 420 m3/ha. According to the study results, the rate of 4.0 million seeds and N210 per hectare; P140; In the variant with K105 kg/ha mineral fertilizer application, the highest yield was 67.9 centners/ha. With sprinkler irrigation, water consumption per centner of yield was 87-98 m^3, while with conventional irrigation, this figure was 117-123 m^3.
The results demonstrate that sprinkler irrigation technology ensures efficient use of water resources and is essential for increasing sustainable grain yields in Karakalpakstan.

Keywords: sprinkling, irrigation regime, grain crops, water use efficiency, conditions of Karakalpakstan.

1. Introduction

Efficient water use is essential for the sustainable development of agriculture in arid and semi-arid regions. The particularly arid climate, low precipitation, and high evaporation rates in Central Asian countries, including the Republic of Karakalpakstan in northern Uzbekistan, require efficient water use in crop cultivation. Therefore, improving irrigation technologies and scientifically determining irrigation regimes and watering rates for agricultural crops is a key task.
Grain crops are considered one of the main agricultural crops, strategically important for ensuring the country's food security. Correctly determining irrigation timing and rates during cultivation allows for increased crop yields, maintaining optimal soil moisture levels, and efficient use of water resources. Scientific research shows that organizing an irrigation regime based on maintaining soil moisture at an optimal level relative to field capacity creates favorable conditions for crop growth and development.
In recent years, considerable attention has been paid to the widespread use of water-saving technologies in agriculture. One of these is sprinkler irrigation, which evenly distributes water across the crop surface in the form of fine droplets. Sprinkler irrigation technology promotes uniform soil moisture conservation, reduces water consumption, and increases crop yields.
Research aimed at optimizing irrigation regimes and irrigation rates for grain crop cultivation in the Republic of Karakalpakstan is of particular importance. Therefore, this study aims to scientifically substantiate irrigation timing and irrigation rates for sprinkler irrigation of grain crops in Karakalpakstan, as well as identify opportunities for efficient use of water resources.

Currently, in the context of limited water resources and climate change, the efficient use of water in agriculture is a pressing issue. Most of the world's available water is used in agriculture, and approximately 70% of total water consumption is for irrigation [1]. Therefore, developing optimal irrigation regimes and economical water use occupy an important place in scientific research.

In Central Asia, particularly in Uzbekistan, agriculture is primarily based on irrigated farming. In the Republic of Karakalpakstan, irrigation is the primary agricultural practice for growing crops due to the sharply continental climate, low rainfall, high air temperatures, and high evaporation rates. Therefore, scientifically based determination of irrigation timing and rates for agricultural crops is essential for the efficient use of water resources [2].

Grain crops are considered one of the key strategic crops for ensuring national food security. Scientific research notes that the yield of wheat and other grain crops largely depends on soil moisture conditions and proper irrigation management. Scientifically based determination of timing and rates of irrigation helps maintain optimal soil moisture levels, improve plant physiological processes and increase crop yields [3].

Maintaining soil moisture at a certain level relative to field capacity is an important factor in crop water supply. Numerous studies have noted that maintaining soil moisture at 70-80% of field capacity during crop irrigation creates optimal conditions for normal plant growth and development [4].

Research conducted in Uzbekistan also shows that scientifically designed irrigation regimes are essential for achieving high yields. In particular, several studies emphasize that timing irrigation for grain crops based on soil moisture reduces water consumption and increases yields [5].

Furthermore, research conducted in Karakalpakstan has found that soil moisture conditions and irrigation rates have a significant impact on crop growth and yield formation [6]. Therefore, determining the timing and rates of irrigation for grain crops in the Republic of Karakalpakstan, studying soil moisture dynamics, and assessing the potential for efficient water resource use are of significant scientific and practical importance. Therefore, the objective of this study is to determine the timing and rates of irrigation for grain crops in Karakalpakstan, as well as to provide a scientific justification for an effective irrigation regime.

This study is based on the results of research conducted within the framework of applied research project ALM-202306091217, which is being implemented from 2023 to 2026.

Research Objectives. The main objective of this study is to scientifically substantiate irrigation timing and rates using sprinkler irrigation technology for grain crop cultivation in the Republic of Karakalpakstan, as well as to identify opportunities for efficient water resource use.

To achieve this goal, the following objectives were defined:

1. To study the technology for grain crop cultivation in the Republic of Karakalpakstan using sprinkler and traditional irrigation methods;
2. To determine the impact of irrigation timing and rates on soil moisture conditions and plant growth;
3. To assess grain crop yields and water use efficiency using various irrigation methods;
4. Based on the results obtained, to develop practical recommendations for an efficient irrigation regime for grain crop cultivation in Karakalpakstan.

2. Materials and Methods (Study Area Description).

The research is being conducted in 2023-2026 at the experimental site of the Grain and Rice Scientific Production Association located in the Nukus district of the Republic of Karakalpakstan. The experimental site is 2.5 ha, located at coordinates 42.610030° N and 59.456647° E. This region is characterized by arid climatic conditions, low rainfall, and high evaporation rates. The soils of the region are alluvial-algal, with a mechanical composition of medium loamy, chloride-sulfate moderately saline soils. (Fig. 1)

The soils of the study area are meadow-alluvial soils and, in terms of mechanical composition, belong to the medium loamy group. The soil salinity level is moderate, with the salinity type being primarily chloride-sulfate.

The soil bulk density averages 1.22-1.24 g/cm³. The field capacity of the soil (PPV) averages 20-21%, and the irrigation regime was determined based on this indicator.

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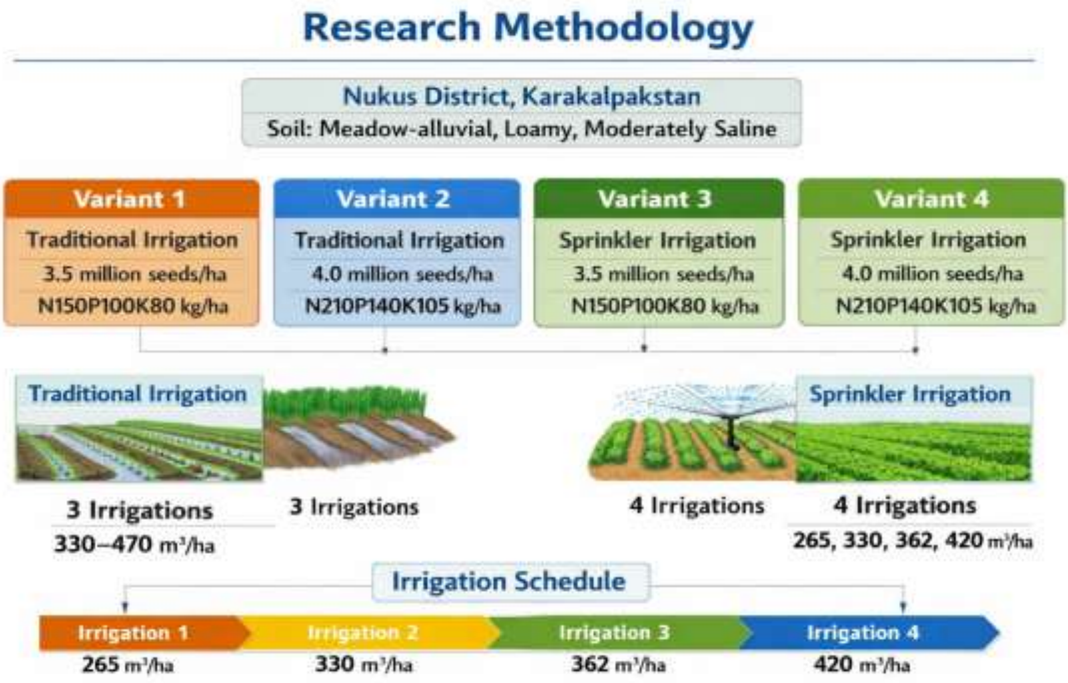
Figure 1. Geographic location of the experimental field in Nukus District, Karakalpakstan, Uzbekistan (42.610030 ° N, 59.456647 ° E).

Republic of Karakalpakstan, annual precipitation averages 90-120 mm, and evaporation reaches 1000-1200 mm. Therefore, crop cultivation depends primarily on irrigation, and efficient use of water resources is essential.

Field experiments were conducted in accordance with accepted guidelines for conducting scientific research on agricultural crops [1]. Soil moisture and water consumption were regularly monitored during the experiments to determine the timing and rates of irrigation for grain crops.
The irrigation regime was determined based on maintaining soil moisture at 70-75-70% of the field capacity. Soil moisture was determined using agrophysical analysis before each irrigation. Soil moisture content and its dynamics were determined using standard laboratory and field methods used in agricultural soil science [2].
Irrigation rates were calculated using the following formula:
$M=100\times H\times d\times(W_{\text{ппв}}-W_{\text{ф}})M = 100$
Where:
M- is the irrigation rate, m3/ha;
H- is the estimated soil layer thickness, m;
d- is the soil bulk density, g/cm3;
Wppv- is the field water capacity of the soil, %;
Wf -is the soil moisture content before irrigation, %.
This calculation method is widely used to determine irrigation rates for agricultural crops and is recommended in many scientific studies [3].
Two irrigation methods were used in the experiment:
1 - sprinkler irrigation;
2 - traditional irrigation (control).
The experiments examined the effects of sprinkler and traditional irrigation methods, different seed rates, and mineral fertilizer rates on grain crop yield. The experimental design is shown in Figure 2.



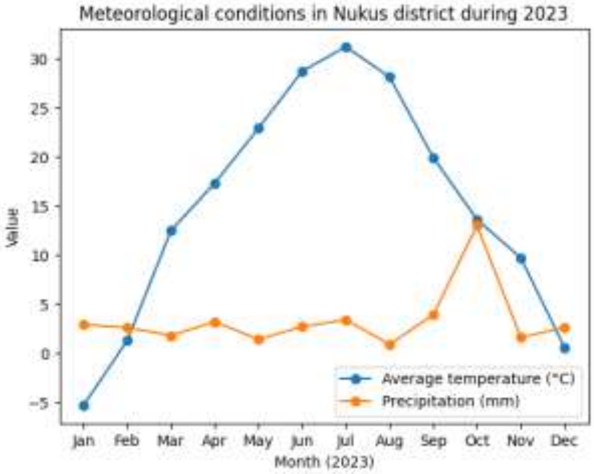
Irrigation was carried out at specified times depending on soil moisture levels during the growing season. Before each irrigation, soil moisture was determined and irrigation rates were calculated on this basis. Also during the experiment, the dynamics of soil moisture, irrigation intervals and water consumption indicators were analyzed. The results of the experiment were evaluated based on generally accepted methods of statistical analysis.

Table-1. Weather conditions of the region (data from the Nukus weather station for 2023)

Months	Minimum temperature (°C)	Maximum temperature (°C)	Average temperature (°C)	Relative humidity (%)	Precipitation (mm)
January	-22.9	12.7	-5.3	59	2.9
February	-11.5	20.4	1.3	65	2.6
March	-1.0	30.0	12.5	45	1.8
April	-0.6	35.4	17.3	37	3.2
May	8.4	37.1	22.9	34	1.4
June	15.2	40.3	28.7	23	2.7
July	17.8	43.0	31.2	28	3.4
August	18.4	37.2	28.1	30	0.9
September	10.1	31.8	19.9	43	3.9
October	1.4	27.0	13.6	56	13.0
November	-4.7	22.6	9.7	57	1.6

December	-22.5	19.0	0.6	63	2.6

Meteorological conditions in the study area were analyzed using data from the Nukus weather station. Air temperature, relative humidity, and precipitation are presented in Table 1.



According to the data, the maximum air temperature in 2023 was 43.0°C (July), while the minimum temperature was -22.9°C (January). During the growing season (April-September), the average temperature The air temperature fluctuated between 17.3 and 31.2 °C. Precipitation was relatively small, with the highest amount of precipitation for the year observed in October (13.0 mm). Figure 3. Dynamics of average air temperature and precipitation observed in the Nukus district in 2023. Analysis of meteorological conditions observed in the Nukus district in 2023 showed that the highest air temperature was in July (31.2 °C), and the lowest in January (-5.3 °C). Atmospheric precipitation was relatively small, with the highest amount observed in October (13.0 mm).

3. Results and Discussion

Field experiments were conducted in the Republic of Karakalpakstan to study the impact of irrigation timing and irrigation rates on crop yields in a mixed crop of winter triticale and mung bean. The irrigation regime was determined based on maintaining soil moisture at 70-75-70% of the field capacity.

Based on the experimental results, sprinkler irrigation was applied four times in April and May. The first irrigation was applied on April 5 at a rate of 265 m³/ha, the second on April 25 at a rate of 330 m³/ha, the third on May 17 at a rate of 362 m³/ha, and the fourth on May 25 at a rate of 420 m³/ha. Leaching irrigation at a rate of 4,500 m³/ha was applied before sowing.

The experimental results showed that crop sowing timing, seed rates, and mineral fertilizer rates significantly impacted crop yields. When sowing in the second ten-day period of September, the yield was 64.2-68.9 c/ha, while when sowing in the third ten-day period of September, this figure was 65.5-71.2 c/ha.

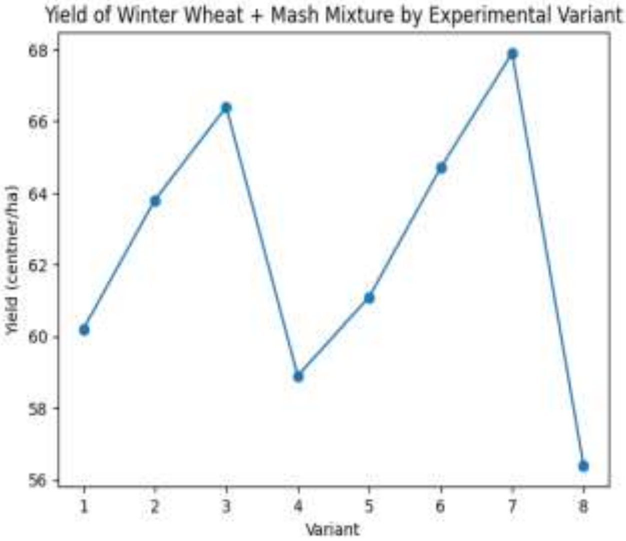
The highest yield was obtained when sowing in the third ten-day period of September at a seed rate of 3.0 million seeds/ha and mineral fertilizers of N-210; P-140; In the variant with K-105 kg/ha, the yield was 71.2 c/ha. This indicates the creation of optimal agronomic conditions for crop growth and development.

It was found that water consumption with sprinkling irrigation is significantly more efficient than with traditional irrigation. While the water consumption per centner of yield with sprinkling irrigation was 83-92 m3, with traditional irrigation, this figure was 105-106 m3. This demonstrates the advantages of sprinkling irrigation in terms of efficient use of water resources. In the control variant, i.e., under traditional irrigation, irrigation was applied twice, with rates of 1,250 and 1,170 m³/ha. However, despite the high total water consumption, yields were lower than in the sprinkler irrigation variants.

These results demonstrate that the correct choice of sprinkler irrigation regime and mineral fertilizer rates when cultivating a mixed crop of winter triticale and mung bean in Karakalpakstan can increase yields and ensure efficient use of water resources. Figure 4. Changes in grain crop yields by treatment under sprinkler irrigation conditions.

This figure shows the change in grain crop yields by treatment. The analysis revealed yield changes ranging from 56.4 to 67.9 c/ha. The highest yield was observed in treatment 7 (67.9 c/ha). In this treatment, the seed
the rate was 4.0 million pcs/ha and mineral fertilizers N210; P140; K105 kg/ha, optimal conditions for plant growth and development were created. Figure 5. Water consumption per 1 centner of crop yield under different irrigation options. This figure shows the change in the amount of water used per 1 centner of crop yield across the different options. The results demonstrated high water efficiency using the sprinkler irrigation method. Under sprinkler irrigation conditions, water consumption per 1 centner of crop yield was 87–98 m³, while with traditional irrigation, this figure reached 117–123 m³. The highest water efficiency was observed in the 7th variant (87 m³/s). According to the experimental results, seed rates and mineral fertilizer application significantly impacted yield in a mixed winter wheat + mung bean crop. Graphical analysis shows that with a seed rate of 3.0 million seeds/ha, the yield was 60.2 c/ha, while with an increase in the seed rate to 3.5 million seeds/ha, the yield increased to 63.8

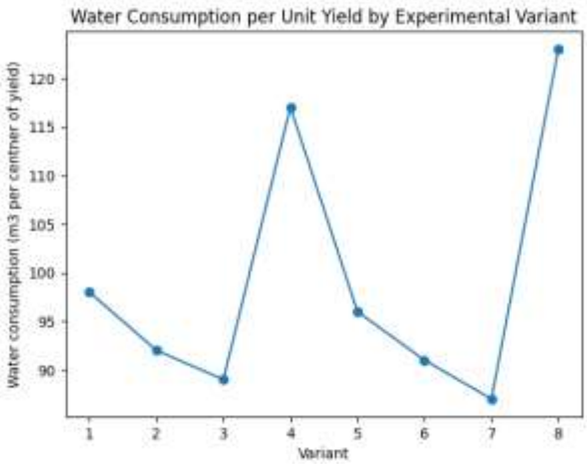
c/ha. The highest yield was observed with a seed rate of 4.0 million seeds/ha and application of N210P140K105 kg/ha mineral fertilizer, reaching 66.4-67.9 c/ha.



A comparison of sowing dates revealed slightly higher yields when sowing in the third ten-day period of September. For example, under these conditions, the yield in the second ten-day period was 67.9 c/ha, higher than in the first ten-day period.

Water consumption analysis also revealed important results. While the water consumption per centner of yield using the sprinkler method was 87–98 m³, with traditional irrigation this figure reached 117–123 m³. This demonstrates the significant advantage of the sprinkler method in terms of water efficiency.

Graphical analysis shows that sprinkler irrigation with a seed rate of 4.0 million seeds/ha and application of mineral fertilizers N210P140K105 kg/ha yielded the highest yield while simultaneously reducing water consumption.



According to experimental results, the highest yield was 67.9 centners/ha in the variant with a seed rate of 4.0 million seeds/ha and application of mineral fertilizers N210;P140;K105 kg/ha.

Water consumption analysis showed that the sprinkler irrigation method increases water efficiency. With sprinkler irrigation, water consumption per centner of yield was 87–98 m³, while with traditional irrigation, this figure reached 117–123 m³.

Based on the research results, it is recommended to use sprinkler irrigation when cultivating grain crops in Karakalpakstan, maintain soil moisture at 70–75–70%, and apply optimal seed and mineral fertilizer rates, which enables high yields and efficient use of water resources.

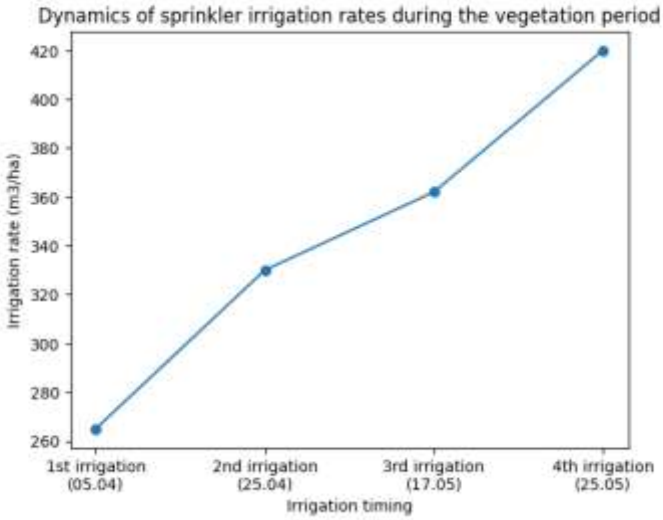
Table 2. Changes in yield by variants under sprinkler irrigation of grain crops in Karakalpakstan (with 4 replicates), c/ha

options	Repetition of the experiment				
	I	II	III	IV	average
1	59.5	60.8	60.1	60.4	60.2
2	63.1	64.2	63.5	64.4	63.8
3	65.8	66.9	66.2	66.7	66.4

4	58.2	59.1	58.7	59.6	58.9
5	60.3	61.5	61.2	61.4	61.1
6	64.0	65.1	64.5	65.2	64.7
7	66.8	68.5	67.3	69.0	67.9
8	55.7	56.8	56.2	56.9	56.4

$LSD_{0.05}$ = 3.9 c/ha

The experimental results were subjected to statistical analysis. The average yield was 62.4 c/ha (Table 1). According to the analysis of variance, LSD0.05 = 3.9 c/ha. Large differences from this value were considered statistically significant.



The highest yield, 67.9 c/ha, was observed in the variant with a seed rate of 4.0 million units/ha and application of N210P140K105 kg/ha mineral fertilizer. This result demonstrated a statistically significant difference compared to the variants with lower yields.

Figure 6. Dynamics of changes in irrigation rates for sprinkler irrigation during the growing season

This figure shows changes in irrigation timing and rates during the growing season for sprinkler irrigation of grain crops. According to research results, the first irrigation was applied on April 5 at a rate of 265 m³/ha, the second irrigation on April 25 at a rate of 330 m³/ha, the third irrigation on May 17 at a rate of 362 m³/ha, and the fourth irrigation on May 25 at a rate of 420 m³/ha.

The gradual increase in irrigation rates is explained by the increased water requirements of plants during the growth and development phases. This irrigation regime allowed soil moisture to be maintained at 70-75-70% of the field capacity.

4. Conclusion

Field studies conducted in the Republic of Karakalpakstan have shown that scientifically based determination of irrigation timing and rates for grain crop cultivation is essential for efficient water use and achieving high yields. The study found that an irrigation regime based on maintaining soil moisture at 70-75-70% of the field capacity creates optimal conditions for crop growth and development. Sprinkler irrigation at rates of 265, 330, 362, and 420 m³/ha during the growing season ensured stable soil moisture maintenance.

Among the experimental variants with rates of 4.0 million seeds/ha and N210; P140; and the application of K105 kg/ha mineral fertilizers, the highest yield was 67.9 c/ha. Furthermore, while sprinkler irrigation required 87-98 m³ of water per 100 kg of crop, conventional irrigation achieved 117-123 m³.

The results demonstrate that sprinkler irrigation technology can increase grain yields and efficiently utilize water resources in Karakalpakstan. Therefore, this irrigation system is recommended for grain cultivation in the region.

Acknowledgments. This study was conducted as part of the applied research project ALM-202306091217, which runs from 2023 to 2026. The author thanks the project participants for their scientific and organizational assistance.

1. Scientific Novelty. Under the soil and climatic conditions of the Republic of Karakalpakstan, the impact of irrigation timing and rates on the yield and water efficiency of sprinkler irrigation of grain crops was scientifically substantiated.

The study found that an irrigation regime based on maintaining soil moisture at 70-75-70% of the field capacity creates optimal conditions for crop growth and development.

It was also scientifically substantiated that sprinkler irrigation rates of 265-420 m³/ha for grain crops contribute to the stable maintenance of soil moisture and ensure high yields.

As a result of the research conducted during the cultivation of grain crops in the conditions of Karakalpakstan with the seed rate of 4.0 million pcs/ha and mineral fertilizers N210; P140; It was established that when using K105 kg/ha, the highest yield (67.9 c/ha) and high water use efficiency were obtained.

Practical Recommendations. To ensure efficient use of water resources during grain cultivation in the Republic of Karakalpakstan, the following agrotechnical measures are recommended:
1. For sprinkler irrigation of grain crops, apply an irrigation regime based on maintaining soil moisture at 70-75-70% of the field capacity.
2. Irrigate during the growing season in April-May at rates of 265, 330, 362, and 420 m3/ha.
3. To ensure optimal crop growth and high yields, apply 4.0 million seeds per hectare and N210; P140; and K105 kg/ha of mineral fertilizers.
4. Widespread implementation of sprinkler irrigation technology to reduce water consumption and improve water use efficiency compared to traditional irrigation methods.

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