



***Рослинництво, технології комовиробництва та
забезпечення якості кормів***

***Crop production, fodder production technologies, and feed
quality assurance***

DOI 10.32900/2312-8402-2025-134-228-237

UDK 633.522:631.5:631.427

**THE INFLUENCE OF FERTILISERS AND PRE-SOWING SEED
TREATMENT ON THE YIELD OF INDUSTRIAL HEMP
(*CANNABIS SATIVA L.*)**

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After a long-standing prohibition on cultivation, industrial hemp is being reintroduced to agriculture. Its importance is difficult to overestimate in the context of global ecological and economic trends in crop production. Considerable attention is paid to optimising the hemp fertilisation by using compound fertilisers and pre-sowing treatment of seeds with growth stimulants, which promotes early plant development especially under adverse growing conditions. A positive effect was established from the use of the following humic preparations Humifield, 1R Seed Treatment, Ultra Boost, and Zinovii grand for pre-sowing seed treatment and foliar application in combination with plant protection agents such as insecticides and fungicides. These treatments were applied against the background of high application rates of compound mineral fertilisers: Polifoska 8:24:24 9S at 165 kg/ha + UAN-32 at 300 kg/ha, and Ecoplant at 200 kg/ha + UAN-32 at 300 kg/ha. The application of humic preparations for pre-sowing treatment and in combination with foliar pesticides increased the seed yield by 0.14–0.21 t/ha and the straw yield by 0.45–0.53 t/ha. The use of Ultra Boost and Zinovii grand for foliar application enhanced the oil content in seeds by 0.5%. The growing conditions were found to have a significant influence on seed yield formation, under hot and dry conditions, seed yield decreased by 46%, whereas straw yield slightly increased from 4.77 t/ha in 2023 to 5.09 t/ha in 2024. In view of these findings, particular attention was paid to the nature of the correlations between the economically valuable characteristics of hemp, such as the duration of the the growing season, plant height, seed and straw yield, and oil content.

The study found that correlation coefficients can vary significantly depending on the contrast of growing conditions. Thus, correlation behaviour can be used as a tool to select varieties for cultivation and develop adaptive cultivation technologies.



Keywords: industrial hemp, fertilisers, pre-sowing treatment, seed yield, straw yield.

ВПЛИВ ДОБРИВ ТА ПЕРЕДПОСІВНОЇ ОБРОБКИ НАСІННЯ НА ФОРМУВАННЯ УРОЖАЙНОСТІ КОНОПЕЛЬ ПОСІВНИХ (CANNABIS SATIVA L.)

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Після тривалої заборони на вирощування в культуру землеробства повертаються коноплі посівні. Їхнє значення важко переоцінити в контексті еколого-економічних тенденцій розвитку галузі рослинництва в світі. Значна увага приділяється оптимізації удобрення конопель посівних шляхом застосування комплексних добрив, передпосівної обробки насіння стимуляторами росту, що сприяє розвитку рослин на ранніх етапах, особливо в несприятливих умовах вирощування. Встановлена позитивна дія використання гумінових препаратів – Гуміфілду, 1R Seed treatment, Ultra Boost та Zinovii grand для передпосівної обробки насіння та позакореневого застосування у сумішах з засобами захисту рослин – інсектицидами й фунгіцидами на фоні високих норм комплексних мінеральних добрив Поліфоска 8:24:24 9S, 165 кг/га + КАС-32, 300 кг/га та Екоплант, 200 кг/га + КАС-32, 300 кг/га. Застосування гумінових препаратів для передпосівної обробки та сумісного внесення з пестицидами по листю сприяло збільшенню врожайності насіння на 0,14–0,21 т/га і врожайності соломи на 0,45–0,53 т/га. Використання Ultra Boost та Zinovii grand для листової аплікації збільшило вміст олії в насінні на 0,5 %. Встановлено істотний вплив умов вирощування на формування урожайності насіння – в посушливих і спекотних умовах вона зменшилася на 46 %, в той час як урожайність соломи, навіть, децю, зросла – з 4,77 т/га у 2023-му році до 5,09 – у 2024-му. Враховуючи це, було звернено увагу на характер кореляційних зв'язків між господарсько-цінними ознаками конопель – тривалістю вегетаційного періоду, висотою рослин, урожайністю насіння та соломи, вмісту олії. Встановлено, що за контрастності умов вирощування кореляційні зв'язки можуть істотно змінюватися за силою. Таким чином, поведінка кореляцій може бути використаною для підбору сортів для вирощування та створення адаптивних технологій вирощування.

Ключові слова: коноплі посівні, добрива, передпосівна обробка, урожайність насіння, урожайність соломи.

Introduction. Fertilisers are regarded as one of the most important factor in crop yield management, accounting for the largest share of input costs (O. A. Prymakov and M. P. Kozorizenko, 2015). According to Deng G. et al. (2019), nitrogen is the most critical factor, followed by potassium and phosphorus fertilisers. Nitrogen fertilisers influence plant height, stem diameter, and the ratio of generative to vegetative parts of the plant (E. Campiglia et al., 2017).

Just as nitrogen is key for the growth and structure of hemp plants, it also contributes to a reduction in water usage by 19–29%, depending on plant density



(Mishchenko S. V. et al., 2022). According to Tang K. et al. (2016), for optimal crop nutrition an application rate of 60 kg of nitrogen per hectare is sufficient, whereas 60–100 kg/ha of nitrogen promotes the development of high-quality fibre. However, high fertiliser rates should be applied taking into account varietal characteristics and the intended use of the raw material (I. M. Laiko and S. V. Mishchenko, 2022, Campiglia E. et al., 2017).

The application rates of nitrogen fertiliser must be determined with consideration of seeding rates, as these can vary significantly, as well as the influence of environmental conditions. Some scientists note that in order to achieve both high yields and high-quality fibre, optimal application rates are 251–273 kg/ha for nitrogen, 85–195 kg/ha for phosphorus, and 212–238 kg/ha for potassium (Deng G. et al., 2019). In continuous cropping systems, it is recommended to apply organic fertilisers at rates of 20–40 t/ha or in the form of N₂₀₀P₁₀₀K₂₄₀ (Kabanets V. M. et al., 2017, 2020; Laiko H., 2024). Several authors highlight waste products from sericulture and similar materials as particularly promising organic fertilisers (Łochyńska M. et al., 2019, 2022; Laleh S. et al., 2021). However, in Ukraine, assessing their fertiliser effectiveness remains practically unfeasible.

Biostar-type fertilizers may also prove effective for hemp crops. These fertilisers have been developed based on the metabolic products of red earthworms, a combination of cattle manure and plant biomass, and can be used for foliar feeding (Dan A. I. et al., 2015; Stramkale V. et al., 2021). The application of nitrogen fertilisers requires strict control, considering environmental and economic aspects; therefore, it is recommended to use nitrogen inhibitors (urease or nitrification inhibitors) in combination with nitrogen fertilisers (Ahmadi F. et al., 2024).

Increasing the application rates of phosphorus fertilisers may lead to the accumulation of heavy metals. Moreover, there is evidence suggesting a weak hemp yield response to this nutrient (Wielgusz K. et al., 2022; Łochyńska M., Frankowski J., 2019), although some data indicate that phosphorus may play a role comparable to that of nitrogen. This inconsistency is likely related to the agrochemical properties of soils and specific climatic conditions.

The use of potassium fertilisers also remains a subject of debate. For instance, according to Varga I. et al. (2024), potassium fertilisation may not significantly affect stem height, diameter, or quality indicators such as cellulose and lignin content in hemp stems [87]. Chinese researchers say that the optimal NPK ratio for hemp cultivation is 3:1:2.

The significant nutrient requirements of industrial hemp increase the need to optimise the fertilisation system. One approach to addressing this issue involves the use of humic substances. The issue requires detailed study, as humic substances can significantly enhance the effect of macronutrients (Šerá B., Novák F. (2022), Bernstein N. et al., 2019). This effect may be particularly relevant under conditions of unstable and insufficient moisture (Da Cunha Leme Filho J. F. et al., 2020). Attention should be paid to the possibility of using humic preparations during pre-sowing seed preparation and throughout a long part of the growing season (Ievinsh G., 2017).

Materials and methods. The material for the study was the Hlesia variety of industrial hemp, developed by breeders at the Institute of Bast Crops of the National Academy of Agrarian Sciences of Ukraine. The vegetation period is 118 days. The variety is characterized by plant heights of up to 263 cm, with technical stem lengths reaching 173 cm. The potential stem yield may reach 8.0 t/ha, fiber yield 2.5 t/ha, and seed yield 2.1 t/ha.



The following fertilisers were used to fertilise the crops: Polifoska (165 kg/ha), Ecoplant (200 kg/ha), and UAN-32 (300 kg/ha), the latter applied in combination with the first two. Polifoska 8:24:24 9S is a universal granular compound fertiliser recommended for various crops. It primarily promotes seed germination and root system development. Ecoplant is a complex granular fertiliser, the main components of which are potassium (28–34%), phosphorus (4–6%), magnesium (8–12%), calcium (10–17%), and sulphur (8–16%). The fertiliser also contains the following micronutrients: iron (Fe) – 1340 mg/kg, boron (B) – 1000 mg/kg, zinc (Zn) – 900 mg/kg, copper (Cu) – 240 mg/kg, manganese (Mn) – 150 mg/kg, chromium (Cr) – 6.3 mg/kg, molybdenum (Mo) – 1.5 mg/kg, and cobalt (Co) – 0.37 mg/kg.

Plant nutrition was optimised by pre-sowing seed treatment and foliar application of humic preparations Humifield (0.2 kg/t), 1R Seed treatment (1.0 kg/t), and Zinovii grand (1.0 kg/t) following the recommended rates. Humifield (0.2 kg/t) and Ultra Boost (2.0 l/ha) were used for foliar treatment.

Humifield is a growth stimulator that contains fulvic and humic acids in concentrations of 80 and 750 g/kg, respectively, along with 100–120 g/kg of amino acids, a similar amount of potassium, and 9–10.2 g/kg of micronutrients. 1R Seed Treatment contains 10% humic acids, 3% fulvic acids, and 6% micronutrients. Zinovii grand is a complex growth stimulator comprising up to 8.0% organic matter, up to 2.0% nitrogen, 3.5% potassium, and 0.1% phosphorus. The preparation also includes micronutrients such as manganese, zinc, copper, molybdenum, boron, and iron. Ultra Boost is a humic growth stimulator containing 14.9% humic acids and 12% micronutrients.

Field experiments were conducted on chernozem soils with a humus content of up to 2.68%. A detailed agrochemical analysis is given in Table 1.

The experimental design involved the study of two factors: fertiliser application (Factor A) and humic preparations (Factor B). The variants were arranged randomly, with three repetitions. The size of the accounting (harvested) plot was 300 m².

Table 1.

Agrochemical characteristics of soils

Field number 540/33 Soil characteristics	Level of development according to the index NDVI		
	low	moderate	high
pH (1:1) soil	8.0	8.1	8.1
pH buffering	7.2	7.2	7.2
Soluble salts, mmol/cm	0.10	0.19	0.33
Organic matter, %	2.2	3.2	7.9
Nitrate nitrogen, mg/kg	7.4	12.5	24.6
Mobile phosphorus, mg/kg	44	25	28
Potassium, mg/kg	23	31	43
Calcium, mg/kg	2109	3130	4181
Magnesium, mg/kg	85	244	555
Sodium, mg/kg	13	16	39
Sulphur, mg/kg	9	12	12
Zinc, mg/kg	0.43	0.38	0.48
Iron, mg/kg	37.6	26.6	83.7
Manganese, mg/kg	3.6	4.2	5.5
Copper, mg/kg	0.16	0.40	0.79



Research results. According to the obtained data, the application of humic substances within the fertilisation system positively affected plant height, straw yield, and seed yield. However, this effect was observed to depend on the application rate of the respective preparation (Table 2). The use of 200 g/t for pre-sowing seed treatment did not lead to a significant increase in plant height. In contrast, the 1 kg/t application rate of the preparations 1R Seed Treatment and Zinovii grand increased hemp plant height. A positive effect was also observed from the foliar application of Ultra Boost (2 l/ha) and Zinovii grand (2 kg/ha), which were applied in the middle of the growing season in a mixture with the insecticide Belt (0.15 l/ha) and the fungicide Custodia (0.6 L/ha). Under these treatment conditions, plants reached their maximum height.

Table 2.
The influence of fertilisation on the Hlesia variety yield (2023–2024)

Fertiliser (A)	Treatment variant (B)	h, cm	Seed yield, t/ha	Straw yield, t/ha
Polifoska 8:24:24 9S, 165 kg/ha + UAN-32, 300 kg/ha	No treatment	224	0.89	4.54
	Humifield, 0.2 kg/t	226	0.88	4.57
	1R Seed treatment, 1 kg/t	253	0.95	4.67
	Zinovii grand 1, kg/t	248	0.96	4.67
	Humifield, 0.2 kg/t + Humifield, 0.2 kg/ha	229	0.89	4.61
	1R Seed treatment, 1 kg/t + Ultra Boost, 2 l/ha	266	1.03	4.99
	Zinovii grand, 1 kg/t + Zinovii grand, 2 kg/ha	263	1.01	4.94
Ecoplant, 200 kg/ha + UAN-32, 300 kg/ha	No treatment	230	0.84	4.82
	Humifield, 0.2 kg/t	232	0.85	4.95
	1R Seed treatment, 1 kg/t	254	0.96	5.27
	Zinovii grand, 1 kg/t	247	0.95	5.23
	Humifield, 0.2 kg/t + Humifield, 0.2 kg/ha	239	0.87	5.08
	1R Seed treatment, 1 kg/t + Ultra Boost, 2 l/ha	264	1.05	5.35
	Zinovii grand 1 kg/t + Zinovii grand 2 kg/ha	262	1.02	5.33
LSD ₀₅ (A)		3.6	0.06	0.07
LSD ₀₅ (B)		8.4	0.10	0.14
LSD ₀₅ (AB)		15.7	0.12	0.19

Seed and straw yield indicators showed a similar reaction. The lack of a noticeable effect from the application of Humifield is likely due to the low application rate and indicates the need for dosage adjustment. The influence of the preparation was also weak when it was used for crop foliar spraying. In contrast, pre-sowing seed treatment with 1R Seed Treatment and Zinovii grand contributed to a slight increase in seed yield. However, the observed deviation was almost within the least significant difference (LSD).

The application of humic preparations, both as part of pre-sowing seed treatment and in combination with foliar application alongside plant protection products, resulted in a significant increase in seed yield by 0.14–0.21 t/ha and straw yield by 0.45–0.53 t/ha.



Thus, using humic preparations may serve as a valuable resource for enhancing the productivity of hemp raw materials. However, it should be emphasized that further research in this area is necessary, especially considering the relatively high cost of humic products, which is one of the reasons for the frequent scepticism of producers towards this group of substances.

A similar effect was also observed on the oil content in seeds. Pre-sowing treatment tended to increase oil content, but it was within the range of the least significant difference. The use of foliar application of Ultra Boost and Zinovii grand increased the seed oil content by almost 0.5% (Table 3).

Table 3.

The influence of fertilisers and growth stimulators on the oil content in hemp seeds (2023–2024)

Fertilizer	Treatment variant	Oil content, %
Polifoska 8:24:24 9S, 165 kg/ha + UAN-32, 300 kg/ha	No treatment	29.1
	Humifield, 0.2 kg/t	29.0
	1R Seed treatment, 1 kg/t	2.1
	Zinovii grand, 1 kg/t	29.1
	Humifield, 0.2 kg/t + Humifield, 0.2 kg/ha	29.1
	1R Seed treatment, 1 kg/t + Ultra Boost, 2 l/ha	29.6
	Zinovii grand, 1 kg/t + Zinovii grand, 2 kg/ha	29.6
Ecoplant, 200 kg/ha + UAN-32, 300 kg/ha	No treatment	29.2
	Humifield, 0.2 kg/t	29.3
	1R Seed treatment, 1 kg/t	29.5
	Zinovii grand, 1 kg/t	29.5
	Humifield, 0.2 kg/t + Humifield, 0.2 kg/ha	29.3
	1R Seed treatment, 1 kg/t + Ultra Boost, 2 l/ha	29.7
	Zinovii grand, 1 kg/t + Zinovii grand, 2 kg/ha	29.7
LSD ₀₅ (A)		0.07
LSD ₀₅ (B)		0.14
LSD ₀₅ (AB)		0.22

It should also be noted that growing conditions significantly impact the yield formation. Moisture deficiency combined with high temperatures caused the signs of water and temperature stress, which primarily affected the seed yield. In 2023, the average seed yield reached 1.38 t/ha, whereas in 2024 it did not exceed 0.74 t/ha, representing a decrease of nearly 46%. The straw yield under these conditions showed an opposite trend — 4.77 t/ha in 2023 and 5.09 t/ha in 2024.

Studying the relationships between yield structure elements under different conditions becomes relevant in this regard. The correlation network also reveals specific changes depending on the growing conditions. Thus, plant height at the stage of biological maturity had a strong direct correlation with the duration of the growing season ($r = 0.79$), seed yield ($r = 0.71$), and oil content ($r = 0.73$) in 2023. A moderate direct correlation with straw yield ($r = 0.47$) was also identified. The pattern of the relationships changed slightly: the correlation between the plant height and the duration of the growing season decreased ($r = 0.31$) while the correlation with straw yield increased ($r = 0.74$) in 2024.



Seed yield correlated with the duration of the growing season ($r = 0.68$) in 2023, while in the following year, this relationship was not statistically significant. A consistent correlation was observed between seed yield and oil content, regardless of the year, with coefficients ranging from $r = 0.64$ to 0.68 . As for hemp straw yield, under more favourable conditions, it had a moderate correlation with plant height ($r = 0.34...0.47$). Under the conditions of moisture deficit and elevated temperatures, a moderate correlation emerged between straw yield and seed yield ($r = 0.49$), along with a strong correlation with plant height ($r = 0.74$) and oil content in seeds ($r = 0.83$). The authors think that creating a system of relationships could help to develop adaptive growing techniques. The nature of these relationships is shown in the graph of straw yield regression depending on plant height in Fig. 1.

Analysis of variance revealed that the studied factors had varying effects on the formation of economically valuable traits. Plant height during biological maturity was more influenced by factor B, i.e. pre-sowing seed treatment. No significant interaction between the factors was observed.

In 2023, the duration of growing season was influenced only by factor B. However, under the more extreme conditions of 2024, fertilisation had a significantly greater impact on forming this indicator, and interaction between factors was also observed. A change in influences was also observed for seed yield characteristics and oil content. Under favorable conditions, an interaction between the factors was evident, while it was insignificant under stress conditions. These results suggest that the use of humic preparations is quite effective for enhancing economically valuable traits of industrial hemp, but further research is required.

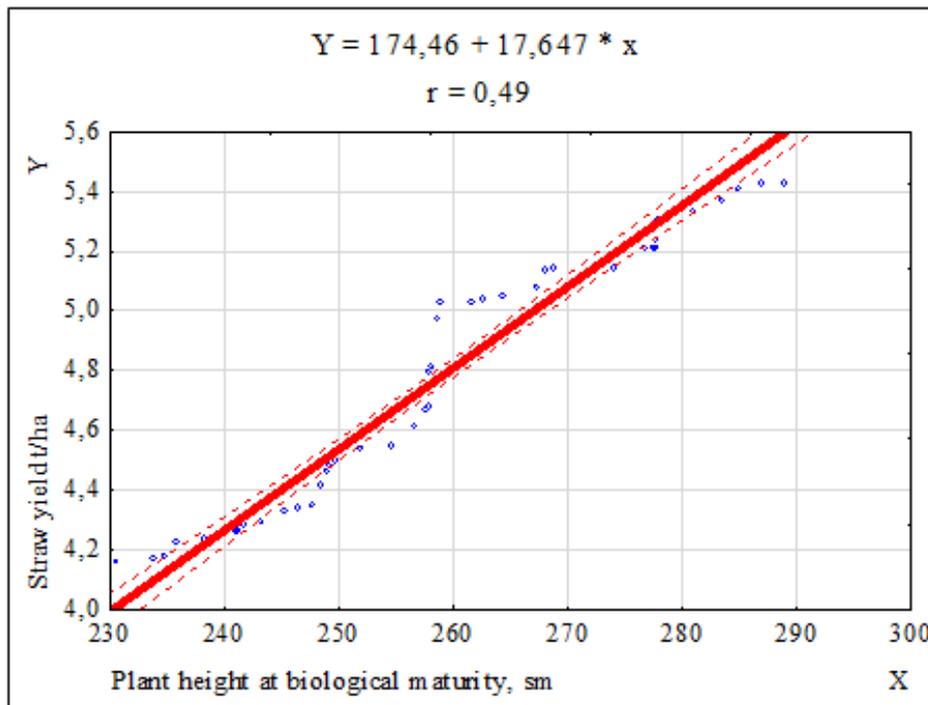


Figure 1. Graph of straw yield regression depending on plant height

Discussion. Industrial hemp is considered a crop that does not require highly specialized cultivation techniques. Indeed, due to its sustained growth habit, this plant can produce yields even under continuous cropping conditions. However, it is precisely this feature that highlights the importance of developing effective fertilisation systems for growing hemp. The results obtained in this study fully support earlier findings



emphasizing the importance of high mineral fertiliser application rates, as reported by O. A. Prymakov and M. P. Kozorizenko (2015) and G. Deng et al. (2019). The high nitrogen fertiliser application rates used in both the experiment and the production fields of the host farm were based on the convincing evidence presented by Mishchenko S. V. et al. (2022), K. Tang et al. (2016), and I. M. Laiko and S. V. Mishchenko (2022), and Campiglia E. et al. (2017).

Under practical farming conditions, it was impossible to establish the effectiveness of organic fertilisers as recommended by A. I. Dan et al. (2015) and V. Stramkale et al. (2021). However, the experiment has confirmed the effectiveness of humic acid-based preparations.

The obtained results largely correlate with the findings of B. Šerá and F. Novák (2022) and N. Bernstein et al. (2019). Given the substantial differences in temperature and moisture conditions between the two study years, it was possible to verify J. F. Da Cunha Leme Filho et al. (2020) conclusions regarding the effectiveness of humic substances under unstable and insufficient moisture conditions. In addition, the results confirm the conclusions of G. Ievinsh (2017), which emphasise the relevance of the comprehensive use of humic preparations — both for pre-treatment of seeds and for foliar application.

Ukraine faces a similar problem of a lack of theoretical knowledge and empirical data, as do most countries worldwide, including developed ones. This is primarily due to the long-standing prohibition on growing this crop, which many scientific publications discuss. Scientists are debating the challenges of selecting appropriate varieties depending on cannabinoid content, growing conditions, intended use, and other factors. At the same time, the hemp sector in Ukraine and globally is experiencing rapid revitalization and development. Therefore, creating and implementing research programmes related to hemp production are highly relevant and necessary.

Conclusions.

1. The analysis of theoretical materials and original research outcomes has allowed for the formulation of conceptual conclusions that define the strategic directions for future research programs. Due to the long-standing prohibition on hemp cultivation in many countries, there is a significant deficit of both theoretical and practical knowledge. Nevertheless, key principles for managing hemp agroecosystem productivity have been outlined, including the selection of varieties based on the intended product use, their adaptive potential, and other relevant criteria.

2. An effective method for increasing yield is the use of humic preparations for pre-sowing seed treatment and foliar application. This was demonstrated in the treatments involving the application of 1R Seed Treatment at 1 kg/t + Ultra Boost at 2 L/ha, as well as Zinovii grand at 1 kg/t + Zinovii grand at 2 kg/ha. Foliar application is optimally carried out in combination with plant protection products throughout the growing season. The use of these substances also increases the seed oil content.

3. The growing season conditions significantly influence the seed yield. Temperature and water stress can cause a nearly 50% reduction in yield, while their impact on straw yield is almost negligible .

4. To develop adaptive cultivation technologies, it is advisable to study the relationships between the economically valuable characteristics of industrial hemp. Particular attention should be given to correlations that vary depending on the growing conditions. In particular, a correlation between seed yield and the duration of the growing season ($r = 0.68$) was observed in 2023, whereas in 2024, this relationship was not statistically substantial. Under more favourable conditions, straw yield had a moderate correlation with plant height ($r = 0.34... 0.47$), whereas under moisture-deficient and high-



temperature conditions, it demonstrated a moderate correlation with seed yield ($r = 0.49$) and a strong correlation with plant height and oil content in seeds – 0.74 and 0.83, respectively.

5. Humic preparations can be an effective method for achieving stable hemp yields, provided that scientifically justified rates are applied – at least 1 kg/t of seeds for pre-sowing treatment and 2 l/ha for foliar application.

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