Agronomy Research **22**(3), 1214–1223, 2024
https://doi.org/10.15159/AR.24.092

Partial factor productivity of applied nutrients in tribenuron-methyl resistant sunflower hybrids

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Received: March 29th, 2024; Accepted: May 17th, 2024; Published: October 17th, 2024

Abstract. The experiment was conducted at the experimental field of Agricultural University of Plovdiv, Bulgaria. In a field trial with two levels of fertilization, five sunflower hybrids were studied. Trials were set up using the method of split-plot design after predecessor triticale. Partial factor productivity of applied nutrient at sunflower was calculated in terms of seed and oil yield such as the ratio of seed or oil yield to the input nutrient. For all studied sunflower hybrids no significant genotypic response was found in terms of the partial productivity of nitrogen, phosphorus and potassium for seed or oil yield. Results indicate that the seed and oil yield of sunflowers obtained per kilogram of applied nutrients decrease with increasing fertilization levels. The results indicate a tendency for increased partial productivity of nutrients for seed and oil yield in hybrid LG 59.580 SX. In the increased fertilization, a trend was observed indicating hybrid P64LE25 with efficient use of the three nutrients for the formation of oil yield. The level of fertilization demonstrated a significant effect on the productivity of the sunflower, as well as on the partial productivity of nitrogen, phosphorus and potassium for the yields of seeds and oil. In contrast to the productivity, the partial productivity of nitrogen, phosphorus and potassium individually and their sum decreases with an increase in the level of fertilization or, per unit of applied nutrient, sunflower forms less seeds and oil. The present study indicated the highest values of the partial productivity of potassium at both fertilization rates.

Key words: fertilization, hybrids, partial factor productivity, sunflower.

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is the most important oilseed crop in the temperate climate zone. The largest producers of sunflower in the world are Russia with 7.20 million ha and Ukraine with 5.80 million ha. These two countries provide more than 50% of the total world production of sunflower. Other significant sunflower producers are the European Union with 4.24 million ha and Argentina with 1.82 million ha (Jocić et al., 2015). In Europe, the Balkan countries are some of the largest producers of sunflower, especially Romania (Vrânceanu, 2000), Bulgaria (Georgiev et al., 2019), Turkey (Kaya et al., 2012) and Serbia (Skoric, 2012). Sunflower oil intended for food purposes contains edible oil (38–53%) and protein (20–40%) (Lamyaa et al., 2016). Unsaturated fatty acids are mainly oleic (26–40%) and linoleic (46–65%) (Baydar & Erbas, 2005; Skoufogianni et al., 2019).

One of the main elements of sunflower cultivation technology is soil fertilization. Sunflowers are demanding the availability of nutrients in the soil. As for other crops, N, K, and P are the major macronutrients required by sunflowers. Considerable quantities of these macronutrients are required to support crop growth. The greater proportion is absorbed in the first crop vegetative stage; the crop reproductive stage is characterized mostly by the redistribution of nutrients among different organs of the plant. Each nutrient has an individual pattern of uptake and redistribution and different proportions of each nutrient are removed by harvest of seeds (Alberio et al., 2015).

Nitrogen is involved in the development and growth of leaves and florets. Nitrogen deficiency in early vegetative stages may reduce the leaf expansion (Trápani & Hall, 1996), significantly affecting leaf area index, and therefore yield, by reducing solar radiation. Nitrogen concentration in plants decreases with the increase of plant biomass, so the N nutrition index considers the relationship between the actual tissue N concentration and the N concentration required for maximum crop growth rate (Debaeke et al., 2012). When fertilization takes place at the early stages of crop development, it can stimulate lush biomass development affecting leaf area index after flowering by proliferation of diseases or excessive water consumption that limits their normal provision during grain filling in conditions of limited water input (Alberio et al., 2015). An excess of N availability can cause a reduction in grain oil concentration and oil quality without increasing seed yield (Merrien & Milán, 1992). Recently a specific sunflower N critical dilution curve has been established. It is useful for accurate diagnosis of crop N status and fertilization management. It would also facilitate applications of crop growth simulation models in crop management (Debaeke et al., 2012).

Sunflower is very sensitive to variations in K. Potassium has the major role of maintaining the turgor and cell extension in sunflower organs, particularly stems, leaves, and roots (Connor & Hall, 1997). Consequently, yield increases by increasing potassium (Abbadi et al., 2008).

Phosphorus is required in smaller amounts than K and N. For well-watered sunflowers, 6.1 kg P ton^{-1} biomass and 3.8 kg P ton^{-1} grain is required (Andrade et al., 2002). A P concentration of 2 g kg^{-1} in the plant appears critical for sunflower growth (Blamey et al., 1997). This nutrient is an essential component in metabolically active cells. However, sunflower plants grown in P-enriched media enhanced biomass (Padmanabhan & Sahi, 2011), increasing yield (Amanullah & Khan, 2010). If P is available in the soil, it could be uptaken by sunflower in later phenological phases (Connor & Hall, 1997).

In most cases, unbalanced application and utilization of nitrogen, phosphorus and potassium fertilizers is a reason for low efficiency of fertilization (Romheld, 2006; Nikolova, 2010). The current nitrogen application strategies for field crop cultivation are extremely inefficient, with nitrogen efficiency ranging from 14% to 59% (Melaj et al., 2003; Loppez-Bellido et al., 2005). Baligar et al. (2001) summarizing results from different publications estimate that the overall efficiency of applied fertilizers has been below 50% for N, less than 10% for P, and about 40% for K. The lower the level of soil fertility, the higher the agronomic efficiency of applied phosphorus and potassium (Fixen, 2009). One modern method for assessing the effectiveness of fertilization is by determining Nutrient Use Efficiency (NUE) indicators (Rao, 2007). These indicators represent the ability of plants to translate the uptaken nutrients into economic yield seeds (Delogu et al., 1998). The efficient use of nutrients aims to increase productivity, minimize nutrient losses and maintain the fertility of the soil (Fixen et al., 2015).

The yield and NUE depend on many factors such as the soil, climate conditions, environment, grown cultivars etc. (Delogu et al., 1998; Noulas et al., 2010; Zhu et al., 2011). NUE can also be expressed through agronomic, physiological and economic indicators (Rao, 2007).

The present research aims to study the effect of fertilization and the partial factor productivity of applied nutrients in tibenuron-methyl-resistant sunflower hybrids.

MATERIALS AND METHODS

The experiment was conducted at the experimental field of Agricultural University of Plovdiv, Bulgaria under rain-fed conditions for three growing seasons (2018, 2019 and 2020). Plovdiv is located in the region of the Upper Thracian lowland in central southern Bulgaria.

In a field trial with two levels of fertilization $N_{60}P_{50}K_{20}$ and $N_{120}P_{100}K_{40}$ kg ha^{-1}, five sunflower hybrids were studied: P64LE25 - Pioneer (standard); LG 59.580 SX - Limagrain; Subaru HTS - Syngenta; ES Arcadia - Euralis; Magma SU - Caussade semens. Trials were set up using the method of split-plot design after predecessor triticale in 4 replications (Box et al., 2005).

Fertilization has been carried out with ammonium nitrate (34% N), triple superphosphate (45% P_2O_5) and potassium chloride (50% K_2O). Phosphorus and potassium were applied before the main tillage, and nitrogen - before sowing. Sowing has been carried out in appropriate agrotechnical conditions (depending on the time of occurrence of a permanent increase in soil temperature of 10 cm to 8–10 °C), with a density of 5,400 to 5,800 plants per daa according to the recommendations for the respective hybrid. Weed control is tailored to DuPont™ ExpressSun® technology. Seed yield and oil yield were determined. The experiment has been carried out on alluvial-meadow soil *Mollic fluvisols* (FAO & IIASA, 2023), slightly solontic, with a thickness of the A horizon of 25–28 cm. The soil is medium sandy-clay with a content of physical clay in the A horizon of 33%. The reaction of the soil from the field on which the experiment was carried out (pHH_2O) is slightly alkaline with an average value of 7.80 in the 0–30 cm layer and 7.70 in the 30–60 cm layer. The content of organic matter is 1.3% (Popova & Sevov, 2012).

Partial factor productivity of applied nutrient (N, P_2O_5, K_2O or total NPK) at sunflower was calculated in terms of seed yield and oil yield such as the ratio of seed yield or oil yield to the input nutrient:

Partial factor productivity (PFP), kg kg^{-1} = Seed or Oil yield in kg ha^{-1} / Fertilizer rate of N, P_2O_5, K_2O, NPK in kg ha^{-1}, Dobermann (2007).

The data were analyzed statistically using ANOVA, and Duncan's multiple range test (P = 0.05) to compare significant differences among means.

RESULTS AND DISCUSSION

The average seed yield of the studied sunflower hybrids was the highest in the experimental year 2018 (Table 1). This is found at both levels of fertilization. The favorable hydro-thermal conditions in 2018, described in a previous study (Garapova, 2020), led to an increase in the average yield of the hybrids grown at the $N_{60}P_{50}K_{20}$ level by 55.6% compared to the average seed yield in 2019 and by 27.8% compared to the seeds obtained in 2020. At the $N_{120}P_{100}K_{40}$ level, in the first experimental year 2018, higher average seed yields were obtained by 61.8% and by 34.1%, respectively, compared to those in 2019 and 2020. A similar influence of rainfall and temperature during the sunflower growing season was found in terms of average oil yield at the higher fertilization level $N_{120}P_{100}K_{40}$. The average oil yield at this level in 2018 exceeds by 82.9% and 49.2%, respectively, the oil yield from sunflower hybrids in 2019 and 2020. A lower average oil yield of sunflower grown at fertilization level $N_{60}P_{50}K_{20}$ was obtained in the 2019 experimental year and there were no significant differences in oil yield between the 2018 and 2020 crop years.

Table 1. Effect of the fertilization level on the seed yield and oil yield of sunflower, kg ha^{-1}

Yield	Years	2018	2019	2020
Seed yield	Average	3,207^{c} ± 305	2,061^{a} ± 381	2,634^{b} ± 382
$N_{60}P_{50}K_{20}$	Min	2,803	1,740	2,393
	Max	3,514	2,713	3,295
Seed yield	Average	4,278^{c} ± 197	2,643^{a} ± 447	3,545^{b} ± 374
$N_{120}P_{100}K_{40}$	Min	4,114	2,075	3,040
	Max	4,524	3,162	3,943
Oil yield	Average	1,366^{b} ± 217	836^{a} ± 136	1,203^{b} ± 187
$N_{60}P_{50}K_{20}$	Min	1,105	705	1,021
	Max	1,592	1,047	1,499
Oil yield	Average	1,690^{c} ± 105	924^{a} ± 264	1,379^{b} ± 246
$N_{120}P_{100}K_{40}$	Min	1,592	668	1,064
	Max	1,814	1,300	1,626

*Values with the same letters do not differ significantly.

For the five studied sunflower hybrids (P64LE25, LG 59.580 SX, Subaru HTS, ES Arcadia and Magma SU) no significant genotypic response was found in terms of the partial productivity of nitrogen, phosphorus and potassium for seed yield or oil yield on average for the period 2018–2020 (Tables 2, 3).

This was observed at both levels of fertilization. Results by year and average for the period 2018–2020 indicate that the seed yield and oil yield of sunflower hybrids obtained per kilogram of applied nitrogen, phosphorus, potassium or total NPK decrease with increasing fertilization. A similar effect of higher fertilizer rates on the partial productivity of nutrients has been found in other studies (Maity & Mukherjee, 2009; Qi et al., 2022; Hou et al., 2023; Yang et al., 2023).

The results for the three experimental years indicate a tendency for increased partial productivity of nutrients for seed yield in hybrid LG 59.580 SX grown at both levels of fertilization. This hybrid showed a tendency for high values of partial productivity of nutrients for oil yield grown at $N_{60}P_{50}K_{20}$ level. In the increased fertilization $N_{120}P_{100}K_{40}$, a trend was observed indicating hybrid P64LE25 with efficient use of the three nutrients for the formation of oil yield.

Table 2. Effect of the fertilization level on the partial factor productivity of nitrogen, phosphorus and potassium for seed yield of sunflower hybrids, kg kg^{-1}

Hybrids	$N_{60}P_{50}K_{20}$				$N_{120}P_{100}K_{40}$			
	2018	2019	2020	Average	2018	2019	2020	Average
PFP-Nseed								
P64LE25	56.3	32.5	43.8	44.2[b]	37.7	25.3	32.9	31.9[c]
LG 59.580 SX	58.6	45.2	54.9	52.9[c]	37.1	26.4	32.4	32.0[c]
Subaru HTS	56.3	34.0	39.9	43.4[b]	34.3	20.7	29.0	28.0[b]
ES Arcadia	46.7	31.1	40.8	39.5[a]	34.8	17.3	25.3	25.8[a]
Magma SU	49.5	29.0	40.1	39.5[a]	34.3	20.6	28.2	27.7[b]
PFP-Pseed								
P64LE25	67.5	39.0	52.5	53.0[b]	45.2	30.3	39.4	38.3[c]
LG 59.580 SX	70.3	54.3	65.9	63.5[c]	44.6	31.6	38.9	38.3[c]
Subaru HTS	67.5	40.8	47.9	52.0[b]	41.2	24.8	34.8	33.6[b]
ES Arcadia	56.1	37.3	49.0	47.5[a]	41.8	20.8	30.4	31.0[a]
Magma SU	59.4	34.8	48.1	47.4[a]	41.1	24.7	33.8	33.2[b]
PFP-Kseed								
P64LE25	168.8	97.5	131.4	132.5[b]	113.1	75.8	98.6	95.8[c]
LG 59.580 SX	175.7	135.7	164.8	158.7[c]	111.4	79.1	97.1	95.9[c]
Subaru HTS	168.8	101.9	119.7	130.1[b]	103.0	62.0	86.9	84.0[b]
ES Arcadia	140.2	93.3	122.5	118.6[a]	104.4	51.9	76.0	77.4[a]
Magma SU	148.5	87.0	120.2	118.5[a]	102.9	61.8	84.5	83.1[b]
PFP-NPKseed								
P64LE25	26.0	15.0	20.2	20.4[b]	17.4	11.7	15.2	14.7[c]
LG 59.580 SX	27.0	20.9	25.3	24.4[c]	17.1	12.2	14.9	14.7[c]
Subaru HTS	26.0	15.7	18.4	20.0[b]	15.9	9.5	13.4	12.9[b]
ES Arcadia	21.6	14.3	18.8	18.3[a]	16.1	8.0	11.7	11.9[a]
Magma SU	22.8	13.4	18.5	18.2[a]	15.8	9.5	13.0	12.8[b]

*Values with the same letters do not differ significantly.

Table 3. Effect of the fertilization level on the partial factor productivity of nitrogen, phosphorus and potassium for oil yield of sunflower hybrids, kg kg^{-1}

Hybrids	$N_{60}P_{50}K_{20}$				$N_{120}P_{100}K_{40}$			
	2018	2019	2020	Average	2018	2019	2020	Average
PFP-Noil								
P64LE25	25.4	14.9	21.0	20.4[b]	15.1	10.8	13.0	13.0[c]
LG 59.580 SX	26.5	17.5	25.0	23.0[c]	14.9	9.1	12.3	12.1[b]
Subaru HTS	24.0	12.9	19.2	18.7[b]	13.8	6.4	13.6	11.3[b]
ES Arcadia	18.4	11.8	18.1	16.1[a]	13.3	5.6	8.9	9.2[a]
Magma SU	19.5	12.7	17.0	16.4[a]	13.3	6.6	9.8	9.9[a]
PFP-Poil								
P64LE25	30.5	17.9	25.2	24.5[b]	18.1	13.0	15.5	15.6[c]
LG 59.580 SX	31.8	20.9	30.0	27.6[c]	17.9	10.9	14.8	14.5[b]
Subaru HTS	28.8	15.4	23.0	22.4[b]	16.6	7.7	16.3	13.5[b]
ES Arcadia	22.1	14.1	21.8	19.3[a]	16.0	6.7	10.6	11.1[a]
Magma SU	23.4	15.2	20.4	19.7[a]	15.9	7.9	11.7	11.8[a]

PFP-Koil								
P64LE25	76.3	44.7	62.9	61.3[b]	45.4	32.5	38.9	38.9[c]
LG 59.580 SX	79.6	52.4	75.0	69.0[c]	44.7	27.4	36.9	36.3[b]
Subaru HTS	71.9	38.6	57.5	56.0[b]	41.5	19.3	40.7	33.8[b]
ES Arcadia	55.3	35.3	54.4	48.3[a]	39.9	16.7	26.6	27.7[a]
Magma SU	58.5	38.1	51.1	49.2[a]	39.8	19.7	29.3	29.6[a]
PFP-NPKoil								
P64LE25	11.7	6.9	9.7	9.4[b]	7.0	5.0	6.0	6.0[c]
LG 59.580 SX	12.2	8.1	11.5	10.6[c]	6.9	4.2	5.7	5.6[b]
Subaru HTS	11.1	5.9	8.8	8.6[b]	6.4	3.0	6.3	5.2[b]
ES Arcadia	8.5	5.4	8.4	7.4[a]	6.1	2.6	4.1	4.3[a]
Magma SU	9.0	5.9	7.9	7.6[a]	6.1	3.0	4.5	4.6[a]

*Values with the same letters do not differ significantly.

The average values of the partial productivity of the imported nutrients for the production of sunflower seeds in the three experimental years correspond to the level of productivity for the corresponding year (Table 4). The efficiency of fertilizer nitrogen, phosphorus and potassium separately or their sum for the production of a unit of seeds was significantly the highest in 2018 and the lowest in the 2019 crop year. Over the three-year study period, PFP-N seed varied from 29.0 to 58.6 kg kg^{-1} at the N60P50K20 level and from 17.3 to 37.7 kg kg^{-1} at the N120P100K40 level. The lowest partial productivity per unit of input nutrients NPK for seed yield in sunflower hybrids of 8 kg kg^{-1} was found in 2019 at the level of N120P100K40 and the highest of 27.0 kg kg^{-1} in the climatically favourable vegetation of 2018.

The average annual values of the partial productivity of nitrogen, phosphorus and potassium separately and their sum for the formation of sunflower oil yield were the lowest in 2019 (Table 5). This was found at both levels of fertilization. The productivity of

Table 4. Partial factor productivity of nutrients for seed yield of sunflower, kg kg^{-1}

Fertilization	Years		
$N_{60}P_{50}K_{20}$	2018	2019	2020
PFP-Nseed	53.5[c] ± 5.1	34.4[a] ± 6.3	43.9[b] ± 6.3
PFP-Pseed	64.2[c] ± 6.0	41.2[a] ± 7.6	52.7[b] ± 7.5
PFP-Kseed	160.4[c] ± 15.2	103.1[a] ± 19.0	131.7[b] ± 19.1
PFP-NPKseed	24.7[c] ± 2.3	15.9[a] ± 2.9	20.2[b] ± 2.8
$N_{120}P_{100}K_{40}$	2018	2019	2020
PFP-Nseed	35.6[c] ± 1.63	22.1[a] ± 3.7	29.6[b] ± 3.1
PFP-Pseed	42.8[c] ± 1.9	26.4[a] ± 4.4	35.5[b] ± 3.7
PFP-Kseed	107.0[c] ± 4.9	66.1[a] ± 11.2	88.6[b] ± 9.3
PFP-NPKseed	16.5[c] ± 0.7	10.2[a] ± 1.7	13.6[b] ± 1.4

*Values with the same letters do not differ significantly.

Table 5. Partial factor productivity of nutrients for oil yield of sunflower, kg kg^{-1}

Fertilization	Years		
$N_{60}P_{50}K_{20}$	2018	2019	2020
PFP-Noil	22.8[b] ± 3.6	14.0[a] ± 2.2	20.1[b] ± 3.1
PFP-Poil	27.3[b] ± 4.3	16.7[a] ± 2.7	24.1[b] ± 3.7
PFP-Koil	68.3[b] ± 10.8	41.8[a] ± 6.8	60.2[b] ± 9.3
PFP-NPKoil	10.5[b] ± 1.6	6.4[a] ± 1.0	9.3[b] ± 1.4
$N_{120}P_{100}K_{40}$	2018	2019	2020
PFP-Noil	14.1[c] ± 0.9	7.7[a] ± 2.2	11.5[b] ± 2.0
PFP-Poil	16.9[c] ± 1.0	9.2[a] ± 2.6	13.8[b] ± 2.3
PFP-Koil	42.3[c] ± 2.6	23.1[a] ± 6.5	34.5[b] ± 6.1
PFP-NPKoil	6.5[c] ± 0.4	3.6[a] ± 1.0	5.3[b] ± 1.0

*Values with the same letters do not differ significantly.

each kilogram of nitrogen, phosphorus and potassium input per unit of oil yield from sunflowers grown at the $N_{120}P_{100}K_{40}$ level was the highest in 2018. At the $N_{60}P_{50}K_{20}$ level, there are no significant differences in the partial productivity of the nutritional elements obtained in 2018 and 2020. Within the framework of the conducted study, the partial productivity of imported NPK for sunflower oil production varies from 2.6 kg kg^{-1} ($N_{120}P_{100}K_{40}$ in 2019) to 12.2 kg kg^{-1} ($N_{60}P_{50}K_{20}$ in 2018).

The level of fertilization demonstrated a significant effect on the productivity of the studied sunflower hybrids, as well as on the partial productivity of nitrogen, phosphorus and potassium for the yields of seeds and oil on average for the period 2018–2020 (Table 6). The result of twice the higher level of N120P100K40 fertilization is the production of 855 kg ha^{-1} more seeds and 196 kg ha^{-1} more sunflower oil. Expressed as a percentage, the increase compared to the $N_{60}P_{50}K_{20}$ level is 32.4% for seed yield and 17.3% for oil yield.

Table 6. Effect of the fertilization level on the productivity and partial factor productivity of sunflower average of the period 2018–2020

Fertilization Parameters	$N_{60}P_{50}K_{20}$	$N_{120}P_{100}K_{40}$	Difference
Seed yield	2,634	3,489***	855
Oil yield	1,135	1,331***	196
PFPseed-N	43.9	29.1***	-15
PFPseed-P	52.7	34.9**	-18
PFPseed-K	131.7	87.2***	-44
PFPseed-NPK	20.3	13.4***	-7
PFPoil-N	18.9	11.1**	-8
PFPoil-P	22.7	13.3***	-9
PFPoil-K	56.8	33.3***	-23
PFPoil-NPK	8.7	5.1**	-4

, * – Significance at P = 5 and 1%.

In contrast to the productivity, the partial productivity of nitrogen, phosphorus and potassium individually and their sum averaged over the period decreases with an increase in the level of fertilization or, per unit of applied nutrient, sunflower forms less seeds and oil. The present study indicated the highest values of the partial productivity of potassium at both fertilization rates. Each kilogram of potassium input at the $N_{60}P_{50}K_{20}$ level forms 131.7 kg of seeds and 56.8 kg of oil. As the level of $N_{120}P_{100}K_{40}$ increases, the partial productivity of potassium decreases with 44 kg of seeds and 23 kg of oil. The partial productivity of imported NPK fertilizer elements for seed yield and oil yield of sunflower at $N_{60}P_{50}K_{20}$ level was 20.3 kg kg^{-1} and 8.7 kg kg^{-1}, respectively. At the $N_{120}P_{100}K_{40}$ level, the values of these indicators decrease to 13.4 kg kg^{-1} and 5.1 kg kg^{-1}, respectively. These results indicated that one kilogram of applied NPK at the double fertilization level formed 7 kg less seeds and 4 kg less sunflower oil yield.

CONCLUSIONS

For all studied sunflower hybrids no significant genotypic response was found in terms of the partial productivity of nitrogen, phosphorus and potassium for seed or oil yield. Results indicate that the seed and oil yield of sunflowers obtained per kilogram of applied nutrients decrease with increasing fertilization levels. The results indicate a tendency for increased partial productivity of nutrients for seed and oil yield in hybrid LG 59.580 SX. In the increased fertilization, a trend was observed indicating hybrid P64LE25 with efficient use of the three nutrients for the formation of oil yield. The level of fertilization demonstrated a significant effect on the productivity of the sunflower, as well as on the partial productivity of nitrogen, phosphorus and potassium for the yields of seeds and oil. In contrast to the productivity, the partial productivity of nitrogen, phosphorus and potassium individually and their sum decreases with an increase in the level of fertilization or, per unit of applied nutrient, sunflower forms less seeds and oil. The present study indicated the highest values of the partial productivity of potassium at both fertilization rates.

ACKNOWLEDGEMENTS. This research work was carried out with the support of Agricultural University of Plovdiv, Bulgaria also was financed from Project 17–12 'Support of the publication activity of the teachers from Agricultural University of Plovdiv'.

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