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Winter Rye Spike Parameters in the Westsik's Crop Rotation Long-term Field Experiment

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ABSTRACT

Research work was carried out in Westsik's crop rotation long-term field experiment during the 2018 and 2019 seasons. The Westsik's crop rotation long-term field experiment includes fifteen crop rotations (CR), but this study focused on only seven crop rotations (CRs) i.e. (I, VI, VII, X, XI, XIV, and XV). The main purpose of this study was to analyze the effects of long-term crop rotations on rye spike components. Results showed that the effect of the applied straw manure and lupine green manure without chemical fertilizer resulted in the lowest results at every analyzed spike parameter in both years. The fallow was able to result in better spike parameters than the straw manure or lupine green manure without chemical fertilizer. The farmyard manure without chemical fertilizer was more effective than straw manure or lupine green manure without chemical fertilizer at all analyzed spike parameters. The results of correlation analysis indicated a close, positive correlation between the seed weight/spike and spike length, spike weight, and the 1000 seed weight. While the correlation was medium, positive between the seed weight/spike and spike weight in the 2018 season. Moreover, the correlation was close, positive between the seed weight/spike and all other analyzed spike parameters in the 2019 season.

INTRODUCTION

Winter rye (*Secale cereale* L.) is an important cereal crop well adaptive for growing in newly reclaimed sandy soil, its seed is used for both human consumption and animal feeding (Bushuk, 2001). According to (FAO, 2020) the total production area of rye in Hungary reached about 25767 hectares with a total production of 84.116 tonnes.

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The fallow system was not a modern soil cultivation method when our research field experiment was established in 1929 but it has many benefits for the soil. Vilmos Westsik wanted to compare its effect with different organic and chemical fertilization effects. In this connection, applying the land fallow is a natural soil fertility regeneration method (Barrios et al., 2005). The farmers let the land fallow for restoration of soil fertility in the tropical area (Sánchez, 1995). Fallow is used for sustainable soil fertility improvement (Tian et al., 2005). In general, using different manuring methods in a long-term field experiment is well known worldwide having a lot of advantages. Many researchers noticed that long-term organic manure application improves the soil's physical and chemical properties, increases the carbon concentration in the soil, and consequently increases the soil fertility (Kätterer et al., 2011). Applying organic manure significantly increased the organic carbon content of the soil and soil fertility which is realized in yield parameters as compared to chemical fertilizer (Dersch and Bohm, 2001). In addition, using organic manures in combination with inorganic fertilizers increase the nitrogen (N) and phosphorus (P) contents of soil, maintains and renews the organic matter of soil, and improves the physical and chemical properties of soil (Alam et al., 1997). Organic manure has several benefits, like balancing the nutrient supply including the micronutrients, increasing the soil nutrient availability, increasing the soil microbial activity, improving the soil structure, and increasing soil water availability (Han et al., 2016).

Many researchers found that rye seed components *i.e.* spike parameters are strongly influenced by not only the soil fertility but the manuring system, too. Also, spike length, spike weight, seed weight/spike determine the yield of rye and they have a positive connection with rye yield (Kilic and Yağbasanlar, 2010). Moreover, seed weight/spike is considered the most important component of grain yield (Yağbasanlar and Ozkan, 1995; Parado and Joshi, 1970).

Thus, the purpose of this study was to analyze the effect of organic manuring methods of Westsik's crop rotation long-term field experiment on spike parameters of winter rye plants.

MATERIAL AND METHODS

Study site and objectives

Research work was carried out during 2018 and 2019 at the Westsik's crop rotation long-term field experiment, Research Institute of Nyíregyháza, IAREF, University of Debrecen, Hungary. The winter rye was sown on September 2017 and October 2018 in both seasons, respectively. The soil of this experiment is acidic sandy soil (pH_{KCL} 3.80-5.17) with low humus content (0.43-0.86%) in the 0-20 cm soil layer.

The Westsik's crop rotation long-term field experiment includes fifteen crop rotations (CR), but this study focused on only seven crop rotations (CRs) *i.e.* (I, VI, VII, X, XI, XIV, XV) as presented in Table 1. In gernal, the fallow was applied before the rye plant (CR I); straw manure is applied directly before the rye plant in CRs VI and VII; farmyard manure is the applied of the rye plant in CRs X and XI and the lupine green manure (as a second crop) was grown as a previous crop before sowing rye plant in CRs XIV and XV.

Sampling and measured parameters

Rye plant samples were collected at the end of ripening, at the 2nd and 11th of July in both seasons, respectively. The plant samples were harvested by using a square wooden frame 100 × 100 cm ($1m^{-2}$), three repetitions/plot. The spike parameters *i.e.,* spike length (cm), spike weight (g), seed weight/spike (g) were determined from 10 spikes per m^{-2}. To determine the 1000 grain weight (g), 1000 grains from each sample were measured. The ratio of seed

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weight/spike to the weight of spike was calculated.

Table 1. The number of crop rotations, the applied fertilization methods and fertilization doses of the rye before its sowing in the Westsik's crop rotation experiment. Numbers indicate the applied fertilizers/manures of the studied rotation phase

Number of crop rotation	N (kg ha^{-1} active ingredient)	P_2O_5 (kg ha^{-1} active ingredient)	K_2O (kg ha^{-1} active ingredient)	Farmyard manure (t ha^{-1})	Straw manure (t ha^{-1})	Lupine green manure as a second crop
I						-
VI	65	47	56		26.1	-
VII					26.1	-
X				26.1		-
XI		31	28	26.1		-
XIV	43	31	28			+
XV						+

Statistical analysis

The obtained data were statistically analyzed using the IBM SPSS Statistical Software Package 21.0 version by one-way ANOVA as described by (Snedecor and Cochran, 1980) then Tukey's test, $P<0.05$ as mentioned by (Tukey, 1977) was used to compare the means. In addition, Pearson's correlation analysis was done to find relations between the fertilization methods and rye yield components.

RESULTS

Spike length

Data presented in Table 2 clearly show that the average rye spike length in the crop rotations was between 4.3 and 8.1 cm in 2018 and between 6.4 and 9.4 cm in 2019. The CR I resulted in a 7.6 cm spike length in 2018, and 6.7 cm in 2019. The straw manured with chemical fertilizer resulted in longer spikes (8.1 and 8.6 cm) than CR VII without chemical fertilizer (4.3 and 6.4 cm) in both years, respectively. Moreover, using the farmyard manure with chemical fertilizers resulted in the highest averages of spike length (7.6 cm) in 2018, while a longer spike (9.4 cm) resulted in CR X of farmyard manure without chemical fertilizer in 2019. Also, at lupine green manured CRs XIV and XV, where lupine was grown as a second crop, CR XIV resulted in longer spikes with chemical fertilizer (6.6 and 9.0 cm) than CR XV without fertilizer (5.9 and 7.1 cm) in both years, respectively. Straw manure and lupine green manure with NPK fertilizer resulted in longer spikes compared to the similar CRs without NPK fertilizer. On the other hand, results of statistical analysis in the 2018 and 2019 seasons, showed that CR VII without chemical fertilizers produced the shortest spikes (4.3 and 6.4 cm), respectively. The straw manure with chemical fertilizer was more effective than farmyard manure or lupine green manure (as a second crop). The farmyard manure was more effective in the 2018 season as compared with the 2019 season.

Table 2. Spike length (cm) as influenced by Westsik's crop rotation experiment (mean ± standard deviation, n=3).

Crop rotations system	2018	2019
I	7.6 ± 0.93 ^{c}	6.7 ± 0.34 ^{a}
VI	8.1 ± 0.61 ^{c}	8.8 ± 0.41 ^{b}
VII	4.3 ± 0.10 ^{a}	6.4 ± 0.85 ^{a}
X	6.8 ± 0.20 ^{bc}	9.4 ± 0.78 ^{b}

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XI	7.6 ± 0.26 [c]	8.9 ± 0.35 [b]
XIV	6.6 ± 0.51 [bc]	9.0 ± 0.40 [b]
XV	5.9 ± 0.96 [b]	7.1 ± 0.58 [a]
Main average	6.7 ± 1.33	8.0 ± 1.29

Different letters indicate significant differences of means according to Tukey's test (p<0.05).

Spike weight

Data presented in Table 3 clearly show that the different fertilization methods resulted in different spike weights. The main averages of spike weight were 1.000 and 1.171 g in 2018 and 2019, respectively. The CR I produced 1.267 and 0.907 g of spike weight in 2018 and 2019, resp. In addition, applying straw manure besides using chemical fertilizers in CR VI resulted in the highest values of spike weight (1.500g and 1.263g) as compared with without chemical fertilizer in CR VII (0.433 and 0.673g) in both seasons, respectively. Also, applying farmyard manured in CR X and XI resulted in spike weight 1.067 and 1.267g and 1.570 and 1.446 g in both seasons, respectively. The rye plants received farmyard manure with or without chemical fertilizers resulted in the highest values of spike weight in 2019. Moreover, the lupine green manure with chemical fertilizer in CR XIV resulted in a higher spike weight (0.900 and 1.421g) as compared with without chemical fertilizers in CRXV (0.700 and 0.919g). On the other side, straw manured CR VII resulted in the lowest averages of spike weight (0.433 and 0.673g) in both years, respectively. The farmyard manure besides chemical fertilizers and fallow system resulted in the same effect to the increase of spike weight this year moreover, the results of statistical analysis showed a significant difference between the manuring systems in both years as shown in Table 3.

Seed weight/spike

Data presented in Table 4 clearly show that the crop rotation system significantly affected seed weight/spike in both years. Results show that the highest values of seed weight/spike were resulted from CRs VI, XI, and I and without significant differences between them. The corresponding data were 1.233, 1.067, and 1.033gin the first year, respectively. On the other side, straw manured without chemical fertilizer CR VII recorded the lowest values of seed weight/spike (0.333) in the first year. Lupine green manure with chemical fertilizer CR XIV produced a higher seed weight/spike (0.700g) than without chemical fertilizer CR XV (0.500g).

Table 3. Spike weight (g) as influenced by Westsik's crop rotation experiment (mean± standard deviation, n=3)

Crop rotations system	2018	2019
I	1.267 ± 0.57 [de]	0.907 ± 0.12 [ab]
VI	1.500 ± 0.20 [e]	1.263 ± 0.19 [bc]
VII	0.433 ± 0.57 [a]	0.673 ± 0.16 [a]
X	1.067 ± 0.57 [cd]	1.570 ± 0.07 [c]
XI	1.267 ± 0.57 [de]	1.446 ± 0.09 [c]
XIV	0.900 ± 0.10 [bc]	1.421 ± 0.13 [c]
XV	0.700 ± 0.17 [b]	0.919 ± 0.21 [ab]
Main average	1.000 ± 0.36	1.171 ± 0.31

Different letters indicate significant differences of means according to Tukey's test (p<0.05).

As shown in Table 4 there are no significant differences between the CRs X, XI, XIV and VI on seed weight/spike during the second year 2019, these CR achieved the highest values of these characters (1.317, 1.199, 1.165 and 1.029g, respectively). Moreover, straw

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manure plus chemical fertilizer produced a higher seed weight/spike in CR VI (1.029g) than without chemical fertilizers in CR VII (0.501g). Also, the farmyard manure without chemical fertilizer gave a higher seed weight/spike in CR X (1.317g) than with chemical fertilizer in CR XI (1.199g) but the difference between these data was not significant. Regarding the lupine green manure chemical fertilizer in CR XIV (1.165g) than without chemical fertilizer in CR XV (0.733g).

Table 4. Seed weight/spike (g) as influenced by Westsik's crop rotations experiment (mean± standard deviation, n=3)

Crop rotations system	2018	2019
I	1.033 ± 0.57 ^{de}	0.737 ± 0.12 ^{ab}
VI	1.233 ± 0.15 ^{e}	1.029 ± 0.19 ^{bc}
VII	0.333 ± 0.05 ^{a}	0.501 ± 0.16 ^{a}
X	0.867 ± 0.05 ^{cd}	1.317 ± 0.07 ^{c}
XI	1.067 ± 0.05 ^{de}	1.199 ± 0.09 ^{c}
XIV	0.700 ± 0.10 ^{bc}	1.165 ± 0.13 ^{c}
XV	0.500 ± 0.10 ^{ab}	0.733 ± 0.21 ^{ab}
Main average	0.800 ± 0.31	0.954 ± 0.31

Different letters indicate significant differences of means according to Tukey's test ($p<0.05$).

According to the results of statistical analysis presented in Table 4, the seed weight/spike in CRs VII and XV were significantly different from the CRs I, VI, X., and XI data in the 2018 season. Moreover, seed weight/spike in CRs I, VII, and XV were significantly different from CRs X, XI and XIV data in the 2019 season. Also, the CRs I, VII, and XV produced the lowest values of seed weight/spike. In these CRs only straw manure (VII), lupine green manure as a second crop (XV), and fallow (I) were applied without chemical fertilizers.

1000 seed weight

1000 seed weight (g) was significantly affected by the crop rotations system in both years. Results in Table 5 showed that the main averages of 1000 seed weight were 24.400 and 26.881g in both years. Farmyard manure plus phosphorous and potassium chemical fertilizers in CR XI resulted in the highest values of 1000 seed weight (27.700g) in the first year. The CRs VI, I and XIV recorded the second rank and without significant differences between them. The corresponding data were 25.933, 24.967, and 24.733g in 2018, respectively. On the other hand, CRs VII and XV recorded the lowest averages of 1000 seed weight (21.500 and 21.667g) in 2018.

Table 5. 1000seed weight (g) as influenced by Westsik's crop rotations experiment (mean± standard deviation, n=3)

Crop rotations system	2018	2019
I	24.967 ± 0.86 ^{bc}	27.000 ± 1.80 ^{bc}
VI	25.933 ± 0.73 ^{c}	26.500 ± 0.87 ^{bc}
VII	21.500 ± 0.26 ^{a}	22.500 ± 0.50 ^{a}
X	24.233 ± 0.28 ^{b}	29.667 ± 1.61 ^{c}
XI	27.700 ± 0.70 ^{d}	28.333 ± 2.57 ^{bc}
XIV	24.733 ± 0.80 ^{bc}	29.000 ± 0.87 ^{bc}
XV	21.667 ± 0.23 ^{a}	25.167 ± 1.15 ^{ab}
Main average	24.400 ± 2.16	26.881 ± 2.69

Different letters indicate significant differences of means according to Tukey's test ($p<0.05$).

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Regarding the obtained results in Table 5, 1000 seed weight was higher in CRs X, XIV, I, and VI, and there were no significant differences between them in 2019, the weight of 28.333g in 2019. It could notice that using farmyard manure in a long-term period, plus or without NPK fertilizer led to increasing the soil cation exchange capacity and the organic carbon content of the soil. Lupine green manure without chemical fertilizer in CR XV resulted in 25.167g for 1000 seed weight in the 2019 year.

Data statistical analysis showed that CRs VII and XV were significantly different from all of the other data recorded from other crop rotation systems. As shown in Table 5, these crop rotations recorded the lowest values of 1000 seed weight (21.500 and 21.667g) in 2018seasons. Also, CR VII recorded 22.500g and was significantly different from CRI, VI, X, XI, and XIV in 2019. The CR VII received straw manure only. According to (Prasad 1996) neither inorganic fertilizer nor organic manure can alone maintain plant productivity. In addition, organic fertilizer (straw manure and lupine green manure) with chemical fertilizer, resulted in a higher 1000 seed weight than without chemical fertilizer in both years.

corresponding data were 29.667, 29.000, 27.000, and 26.500g, respectively. Also, applying the farmyard manure with chemical fertilizer in CR XI resulted in a 1000 seed

The ratio of seed weight/spike to spike weight

Data presented in Table 6 clearly showed that the ratio of seed weight/spike to spike weight was significantly affected by the crop rotation system in both years. Data revealed that the main averages of this character were 79.44 and 81.06% in both 2018 and 2019years. The straw manure and green lupine manure crop rotations with chemical fertilizer in CRs VI and XIV resulted in a higher ratio of seed weight/spike to spike weight (82.32%, 81.31%, and 77.59%, 79.48%) than without chemical fertilizer (76.67%, 74.37% and72.50%, 79.48%) in both years. In addition, the analyzed data of farmyard manure CRs X and XI was higher with chemical fertilizer (84.19%), than without chemical fertilizer (81.21%) in 2018. While in 2019 the farmyard manure produced a higher ratio between seed weight/spike and spike weight without chemical fertilizer in CR X (83.90%), than with chemical fertilizer in CR XI (82.88%) and the difference between them was not significant.

Table 6. The ratio of seed weight/spike to spike weight (%) is influenced by Westsik's crop rotation experiment (mean ± standard deviation, n=3)

Crop rotations system	2018	2019
I	81.62 ^{ab}± 4.12	81.06 ^{b}± 1.83
VI	82.32 ^{ab}± 2.31	81.31 ^{b}± 1.90
VII	76.67 ^{ab}± 2.89	74.37 ^{a}± 2.17
X	81.21 ^{ab}± 1.05	83.90 ^{b}± 0.34
XI	84.19 ^{b}± 0.74	82.88 ^{b}± 1.36
XIV	77.59 ^{ab}± 2.51	81.85 ^{b}± 2.10
XV	72.50 ^{a}± 9.01	79.48 ^{b}± 2.42
Main average	79.44 ± 5.17	80.69 ± 3.34

Different letters indicate significant differences of means according to Tukey's test ($p<0.05$).

Correlation analysis

Correlation coefficients indicated a positive significant correlation between the seed weight/spike and other measured rye yield parameters (Table 7) in both analysed years.

Data indicated that there was a pronounced positive and close correlation between the seed weight/spike and spike length (0.913**), spike weight (0.992**) and 1000 seed weight (0.832**). This means, in that

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crop rotations, which resulted in higher spike long, spike weight, and 1000 seed weight the seed weight was higher. Moreover, there was a positive and medium correlation between the seed weight and the ratio between seed weight/spike to spike weight in the 2018 season. Several investigations indicated that the grain yield is closely correlated with the number of grains per spike and the number of spikelets (Perryand D'Antuono, 1989; Sayre et al., 1997).

The correlation analysis resulted in a close and positive correlation between all of the analyzed data in 2019 *i.e.* between the seed weight/spike and spike length (0.938**), spike weight (0.998**), 1000 seed weight (0.778**) and the ratio of seed weight/spike to spike weight (0.852**). Moreover, the analyzed data detected between the seed yield and spike weight, seed weight/spike, number of spikes per area were in positive correlation, as was found by (Nouraein 2019).

Table7. The correlation coefficient of the linear relationship (r-values) among the seed weight/spike and other rye spike parameters (n=3)

Person's correlation	Spike length (cm)	Spike weight (g)	1000 seed weight (g)	The ratio between seed weight/spike to spike weight (%)
Spike weight (g)in 2018 season	0.913**	0.992**	0.832**	0.632**
Spike weight (g) in 2019 season	0.938**	0.998**	0.778**	0.852**

Pearson's correlation ** Correlation is significant at the 0.01 level.
*Correlation is significant at the 0.05 level.

DISCUSSION

According to our results, all spike parameters (spike length, spike weight, seed weight/spike, 1000 grain weight, and the ratio of seed weight/spike to the weight of spike significantly different from all other crop rotations. Straw manure and lupine green manure with NPK fertilizer resulted in a longer spike compared to the similar CRs without NPK fertilizer. Applying farmyard manure or green manure improved the organic carbon content of the soil which contributes to reaching the higher yield components (Nambiar, 1994; Swarup, 1999; Kundu et al., 2002; Zhichen et al., 2008), increasing the soil cation exchange capacity and the organic carbon content of soil and increases the soil microbial activity (Tejada et al., 2008). In addition, applying farmyard manure increased the available nutrient and micronutrient content of soil compared to chemical fertilizers (Hemalatha and Chellamuthu, 2013), increase the available nitrogen content and microorganism activity in the soil, which has a good effect on the next plant production (Bhardwaj et al., 1998). In addition, applying organic manure with or without fertilizer to the soil have good benefits for improving the physical and chemical properties of the soil, increasing the spike weight of rye plants (Rabindra et al*.,* 1990; Liu et al*.,* 2010). Using farmyard manure in a long-term period, plus or without NPK fertilizer led to an increase in the soil cation exchange capacity and the organic carbon content of the soil. In addition, applying farmyard manure increased the available nutrient and micronutrient content of soil compared to chemical fertilizers (Hemalatha and Chellamuthu, 2013). Applying N fertilizer alone over years, decreased the number of

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microbial organisms, enzyme activity, and soil

pH, which had a negative effect on the plant yield attributes (Prasad, 1996; Bandyopadhyay et al., 2010; Liu et al., 2010). In general, using in combined organic manure and inorganic fertilizer together increase available NPK content and organic matter content of soil (Gill and Meelu, 1982) and increases the fertilizer use efficiency and the yield components (Kumar and Mishra, 1992). These results are similar to those obtained by (Bokhtiar and Sakurai 2006). Also, at lupine green manured CRs XIV and XV, where lupine was grown as a second crop, CR XIV resulted in longer spikes with chemical fertilizer than CR XV without fertilizer in both years. In this connection, (Bokhtiar et al., 2003; Goto and Nagata, 2000) showed that applied green manure plays an important role in increasing the total carbon content and bulk density of the soil, which resulted in the higher yield components. Straw manure and lupine green manure with NPK fertilizer resulted in longer spikes compared to the similar CRs without NPK fertilizer. Applying organic and inorganic fertilizer together is very effective in plant productivity (Naik and Ballal, 1968; Yadav and Sharma, 1981; Bangar et al., 1994). We also found that the fallow method helps to restore the soil organic matter content into the upper layers of the soil, which increase the biological activity in the surface of the soil and to rehabilitate the activity of soil microorganisms, which is reduced during the cultivation phase (Styger et al., 2006). In addition, applying straw manure besides using chemical fertilizers in CR VI resulted in the highest values of spike weight. Results also showed that using straw manure and lupine green manure recorded higher seed weight/spike besides chemical fertilizers, than without chemical fertilizer in both of analyzed years, many researchers indicated that seed weight per spike is influenced by nutrients applications. In this connection, (Castagna et al., 1996; Thorup-Kristensen and Bertelsen, 1996; Granstedt and Kjellenberg, 1997; Takunov and Yagovenko, 2000; Bradley et al., 2008; Gong et al., 2009; Marino et al., 2009; Boumand et al., 2010) noticed that nitrogen doses significantly influence the number of grains per spike, consequently increased the seed weight/spike. Several investigations indicated the positive effect of organic manure and chemical fertilizer using together, through increasing the soil organic carbon and NPK content therefore the crop productivity of soil and decreasing the damage that can be induced by chemical fertilizer using alone (Kaur et al., 2005; Chand et al., 2006; Murmu et al., 2013). In addition, organic matter affects not only the yield by supplying the nutrients but indirectly affects soil physical and chemical properties, too (Darvish *et al.,* 1995).

CONCLUSION

It can be concluded that spike parameters were influenced by the crop rotations system. Application of organic fertilization methods with NPK fertilizer has a good effect on the length of the spike. Application of organic manure with chemical fertilizer had a significantly better effect on the seed weight/spike than without chemical fertilizer in both analyzed years. Application of straw manure and green lupine manure with chemical fertilizer resulted in a higher 1000 seed weight than without chemical fertilizer. However, the farmyard manure could be able to produce the same result without chemical fertilizer, too. In addition, using organic fertilizer with chemical fertilizer was increased the ratio between seed weight/spike to spike weight. On the other hand, using straw manure without chemical fertilizer resulted in the lowest values of spike parameters in both analyzed years. Moreover, applying a fallow system resulted

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in better rye spike parameters than using straw manure and lupine green manure weight/spike and spike length, spike weight, 1000 seed weight, and the ratio between seed weight/spike to spike weight. Finally, seed weight/spike is strongly influenced by the other spike parameters i.e. spike length, spike weight, and 1000 seed weight.

Compliance with ethical standards

without chemical fertilizer. Also, there was a close positive correlation between the seed
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