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Rye plant parameters in the Westsik crop rotation experiment

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SUMMARY

Our research work was carried out in the Westsik crop rotation field experiment in 2018. The main research purpose was to analyse the effect of the different organic and chemical fertilizers on parameters of rye. Our results revealed some differences between the different fertilization methods. One spike weight, grain weight of one spike, rye plant height, rye plant weight per m^2 and 1000 seed weight in crop rotations VII, XV and VIII were different from the data of all crop rotations. This finding can be explained by the fact that crop rotations VII and XV were non-fertilized, only 23.3 t ha^{-1} straw manure (VII) or green lupine manure was applied as a second crop (XV). In addition, crop rotation VIII consists of four parts where we apply chemical fertilization with green lupine manure as a main and second crop. There is a positive close correlation between rye plant height and other studied characters (rye plant weight per m^2, spike length, weight of one spike, grain weight per spike, spike weight per m^2, grain weight per m^2 and 1000 seed weight).

Keywords: *long-term crop rotation, organic manures, chemical fertilizer, rye parameters*

INTRODUCTION

Winter rye (*Secale cereale* L.), as one of the most important cereal crops of sandy soils, is mainly used for human and livestock consumption all over the world (Bushuk, 2001). Less than 50% of the rye grown is using for grain while the remainder part used as pasture, hay, cover crop or green manure. In addition, the half of the amount harvested for grain is used for livestock feed and the remainder is used for alcoholic beverages, food and seed. Also, to contributing organic matter, rye reduces soil erosion and enhances water penetration and retention. Furthermore, due to its allelopathic effect, some evidence suggests that rye could be exploited for weed control. Rye residue remained on the soil surface can potentially modify the physical and chemical environment during seed germination and plant growth. The total crop land of rye in Hungary was 25,438 ha with total production of 84,546 tons. However, the total cultivated area in the world reached about 4.48 million ha with total production of 13.73 million tons (FAO, 2018).

Long-term experiments across the world have consistently documented soil quality benefits associated with soil carbon increases and causes changes in soil reaction, cation exchange capacity (Reeves, 1997; Hemalatha and Chellamuthu, 2013; Balkcom et al., 2018). Several investigations indicated the positive effect of organic farming practices on soil quality, the activity of microorganisms and growth and yield of cereal crops in comparison with conventional farming due to regular crop rotation and the absence of synthetic fertilizers NPK (Shannon et al., 2002). More researchers founded that long term experiment has been promoted to increase soil carbon sequestration and enhance crop growth and yield productivity of rye plants (Causarano et al., 2006 and Balkcom et al., 2013). Long term experiment systems combined with winter cover crops can improve soil conditions due to its decreased surface soil disturbance and providing additional residue that increases carbon inputs to the soil (Causarano et al., 2006). Moreover, planting cover crops also protects against soil erosion, enhances the processes of water infiltration, protects against short-term drought stress, and provides a surface mulch layer that promotes suppression of many small seeded weeds (Price et al., 2007 and Faircloth et al., 2012). All these factors consequently led to enhancing soil physical, chemical, and biological functions, which promote the increase of soil health and subsequent increase in the productivity of plants in long-term experiments. Also, next to mineral fertilization, the long-term application of manure resulted in changes in the aforementioned parameters, including a considerable increase in nitrogen content in the soil environment (Li et al., 2010).

Chemical fertilization has been maximized worldwide for cereal production due to the availability of low-cost fertilizers (Abril et al., 2007). The continued use of chemical fertilizers causes health and environmental hazards. Possible options to reduce chemical fertilizer use could be adoption of leguminous crops in cereal based cropping systems and recycling of organic wastes (Patil et al., 2001). Rotation of legumes in cereal based cropping system reduces dependence on chemical fertilizer and improves soil conditions (Rochester et al., 2001 and Achu et al., 2013). For this reason, crop rotations have many benefits that can influence the success of crop production enterprises. Crop rotation is an essential practice in sustainable agriculture, because of its many positive effects like increasing soil fertility and reducing crop competitiveness (Rahnavard et al., 2009 and Morrison et al., 2018). In addition, the autumn development of the rye determines the plant density and the hardy ability so it influences the growth characters and yield components of rye (Kruppa and Szabó, 2005).

The rye plants prefer soils rich in macro- and micronutrients and have good water management, but it can grow in soils with low nutrient content too,

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because of its well-developed root systems. Rye plants can utilize well the nutrient content, 25–30 kg ha^{-1} nitrogen resulted in its good growth (Bauer, 1966; Szabó, 1992). The influence of conventional and organic farming in agricultural production in Europe and other parts of the world is continuously increases. Not only does the utilization of organic manure make the necessary nutrients available, but it also completely affects overall soil fertility and can be capably used in conventional agriculture as a component of integrated fertilization systems which leads to increasing growth parameters and yields (Mottaghian et al., 2008; Grantina-Ievina and Ievinsh, 2015). Several investigations indicated that mineral (NPK) and organic fertilizers resulted in a significant increase in plant height, weight of plants per m^2, spike number per plant, spike length, grains weight per plant, 1000 grain weight grain and straw yields per hectare as compared with no fertilization of winter rye plants (Fageria et al., 2009; Stępień et al., 2016; Qiuchen, 2018). Also, phosphorus has positive effect in all energetic transfer and metabolic processes such as root formation of rye as mentioned by Búzás (1983). Many researchers found close correlation between the soil nutrient supply and autumn growth and yield of cereals. Kádár (1999) found that suitable NPK fertilizer doses increased by 2–3 times the biomass of winter wheat by the end of tillering phase. Grant et al. (1984) improved the winter hardiness of the winter wheat with balanced NP fertilizers dosage. According to Bulman and Hunt (1984), nutrient supply was greatly influenced the growth characters and yield components of winter wheat. Mineral fertilization combined with organic fertilization and liming increases cation exchange capacity, total exchangeable bases and base saturation in comparison to exclusive organic or mineral fertilization.

Thus, the purpose of this study was to quantify the effect of different manuring methods of Westsik crop rotation field experiment on growth characters and yield components of the rye plants, as the main crop of this long-term experiment.

MATERIALS AND METHODS

Description of the experiment

Our research work was carried out in the Westsik crop rotation long-term experiment in the field of the Research Institute of Nyíregyháza, IAREF, University of Debrecen. Rye was sown on 20 10 2017 and harvested on 03 07 2018. 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 experiment includes 14 three-year-long and 1 four-year-long crop rotations (*Table 1.*) The fertilization methods are based on different variations and combinations of organic manure and NPK fertilizers. One of the 15 crop rotations is maintained without fertilization, here we apply fallow in one phase (I). In four crop rotations straw manure (IV, V, VI, VII), in two crop rotations farmyard manure (X, XI), in one crop rotation green lupine manure as main crop (II), in five crop rotations green manure as second crop (VIII, XII, XIII, XIV, XV) are applied. The lupine is grown not only as a green manure (III, VIII), but for seed (III, VIII) and for green forage (IX) production, too. Eleven crop rotations are treated with NPK fertilizer (II, III, IV, V, VII, VIII, IX, XI, XII, XIII, XIV). .

Table 1

The applied fertilization methods and fertilization doses of the rye before its sawing in the Westsik crop rotation experiment. Numbers indicates 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 main crop	Lupine green manure as a second crop
I						-	-
II		31	28			+	-
III		31	28			+	-
IV	65	47	56		3.48	-	-
V	65	47	56		11.30	-	-
VI	65	47	56		26.10	-	-
VII					26.10	-	-
VIII	43	31	28			+	+
IX	43	31	28			+	-
X				26.1		-	-
XI		31	28	26.1		-	-
XII		31	28			-	+
XIII	43	31	28			-	+
XIV	43	31	28			-	+
XV						-	+

Sampling and measured parameters

Plant high was measured on 02 07 2018 in the field. After that, plant samples were harvested by using a wooden square frame 100 × 100 cm (m^{-2}), three repetitions/parcels, then the following measurements were done:

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Growth parameters

Plant height (cm) and plant weight (g m^{-2}).

Yield components

Spike number (pc m^{-2}), spike weight and grain weight (g m^{-2}) were determined by counting and measuring all the number of spikes and measuring all the grains per m^2. Spike length (cm), weight of one spike and grain weight of one spike (g/spike) were determined from 10 spikes m^{-2}. To determine the 1000 grain weight (g), 1000 grains from each sample was measured.

Statistical analysis

The obtained data was statistically analysed 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 determine the treatment effect. In addition, Pearson's correlation analysis was done to find relations between the fertilization methods and rye plant growth, yield and yield components.

RESULTS

Growth parameters

Data presented in *Table 2* clearly showed that rye plant height significantly differed due to the fertilization methods. The height of the rye plant in the experiment was between 87 and 153 cm. The lowest rye plant height was measured in the VII and XV crop rotations (87 and 92 cm). While, the height of the rye was between 128 and 138 cm in the X, XIV, XIII, XII, V, IV crop rotations. The measured data were between 142 and 145 cm in the I, II, III, IX, and XI crop rotations, while the tallest rye plants were recorded in the VI and VIII crop rotations (148 and 153 cm).

The weight of rye plant per m^2 was between 325.3 and 1652.0 g (*Table 2*). The minimum values were measured in the VII and XV crop rotations (352.3 and 379.3 g). In addition, the plant weight was between 855.3 and 1218.7 g in the XIV, XIII, XII, V, X and IV crop rotations. The maximum values were estimated in the XI, I, IX, III and II crop rotations between 1238.0 and 1362.0 g. The weight of rye plant was the highest (1499.3 and 1652.0 g) in the VI and VIII crop rotations.

Table 2

Rye plant height and plant weight/m^{2}in different manuring systems of Westsik crop rotation (mean±Standard Error, n=3). Number of crop rotation is defined in the Materials and Methods section

Number of crop rotation	Plant height (cm)	Plant weight (g m^{-2})
I	142^{cdef} ±1.7	1292.7^{cde}±95.3
II	143^{cdef}±1.7	1362.0^{cde}±24.7
III	143^{cdef}±1.3	1341.3^{cde}±102.7
IV	138^{bcde}±2.0	1218.7^{bcd}±124.7
V	138^{bcde}±1.7	1076.7^{bc}±53.5
VI	148^{ef}±1.7	1499.3^{de}±133.6
VII	87^{a}±4.4	325.3^{a}±40.3
VIII	153^{f}±3.3	1652.0^{e}±17.0
IX	143^{cdef}±3.3	1310.7^{cde}±49.3
X	128^{b}±1.7	1166.0^{bcd}±74.0
XI	145^{def}±2.9	1238.0^{cd}±68.1
XII	132^{bcd}±1.7	1025.3^{bc}±30.1
XIII	132^{bcd}±1.7	870.7^{b}±94.0
XIV	130^{bc}±5.0	855.3^{b}±86.3
XV	92^{a}±1.7	379.3^{a}±23.9
Main averages	132.9±2.8	1107.6±56.7

Yield components

The spike number of rye plant was between 372.0 and 744.67 pc m^{-2}. The least spike (under 500 pc m^{-2}) was counted in the VII, V and XIII crop rotations. The spike number was between 500 and 600 pc m^{-2} in the XV, XIV, IV, XII, II, III, XI and IX crop rotations. The most spikes were between 641.33 and 744.67 pc m^{-2} in the VIII, I, and X crop rotations (*Table 3*).

Data presented in *Table 3* clearly showed that the averages of spike weight in the crop rotations were between 135.00 and 730.00 g per m^2 which means a strong, five times difference between the least and the highest mass. The least masses were measured in the VII and XV crop rotations (135.00 and 160.73 g). The weight was higher in the XIV, XIII, XII, V and X crop rotations (from 368.8 to 499.07 g). The weights were between the 533.20 and 673.27 g in the IV, IX, III, II, VI crop rotations. The highest weight was measured in the VIII crop rotation (730.20 g).

The spike length was between 4.30 and 8.53 cm (*Table 3*). The shortest spikes were measured (between 4.30 and 7.13 cm) in the VII, XV, XIV, X, XII and XIII crop rotations. From these crop rotations the VII, X and XV are maintained without chemical fertilizer, only organic fertilizer is applied. The XIV, XII and XIII crop rotations work with organic, and chemical fertilizers, too. The length of 1 spike were between 7.60 and 7.80 cm in the XI, I, V, II and III crop rotations where chemical fertilizer (I) or chemical fertilizer with organic manure are applied. The longest spikes were

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measured in the VI, IV, IX and VIII crop rotations, the values were between 8.10 cm and 8.53 cm. These crop rotations get both chemical fertilizer and organic manure.

Table 3

Spike number per m^{-2}, spike weight per m^{-2} and spike length (cm) in different manuring systems of Westsik crop rotation (mean±Standard Error, n=3). Number of crop rotation is defined in the Materials and Methods section

Number of crop rotation	Spike number (pc m^{-2})	Spike weight (g m^{-2})	Spike length (cm)
I	712.0^{bc}±64.0	569.2^{cdef}±25.4	7.6^{cdef}±7.6
II	542.0^{abc}±60.7	649.5^{def}±26.9	7.8^{cdef}±0.4
III	555.3^{abc}±51.8	619.9^{def}±16.5	7.8^{cdef}±0.4
IV	522.7^{abc}±90.1	586.3^{def}±72.1	8.2^{def}±0.1
V	482.7^{ab}±17.9	492.7^{bcd}±25.9	7.7^{cdef}±0.1
VI	641.3^{bc}±58.3	673.3^{ef}±62.3	8.1^{cdef}±0.3
VII	372.0^{a}±44.3	135.0^{a}±15.2	4.3^{a}±0.1
VIII	678.7^{bc}±18.0	730.2^{f}±14.8	8.5^{f}±0.1
IX	580.7^{abc}±46.7	604.3de^{f}±24.3	8.4^{ef}±0.2
X	744.7^{c}±50.6	499.1^{bcd}±8.1	6.8^{bcd}±0.1
XI	574.0^{abc}±16.0	533.2^{cde}±24.4	7.6^{cdef}±0.2
XII	522.7^{abc}±39.2	417.8^{bc}±12.0	6.9^{bcde}±0.2
XIII	496.7^{abc}±27.8	372.0^{b}±52.7	7.1^{bcdef}±0.4
XIV	509.3^{abc}±31.5	368.8^{b}±29.0	6.6^{bc}±0.3
XV	502.7^{abc}±53.6	160.7^{a}±9.7	5.9^{b}±0.5
Main averages	562.5±17.6	494.1±26.6	7.3±0.2

The grain weight per spike was between 0.33 and 1.33 g (*Table 4.*) The least grain weight per spike was found in the VII, XV and XIV crop rotations. These grains were only between 0.33 and 0.70 g. The medium grain weight per spike was measured in the X, XII, XIII crop rotations (between 0.86 and 0.97 g). Higher grain weights per spike were measured in the II, I, V, XI, IX, IV and VI crop rotations between 1.03 and 1.23 g. The highest grain weight per spike was in the VIII crop rotation (1.33 g).

Regarding the weight of one spike the data in *Table 4* clearly indicated that the weight of one spike was between 0.43 and 1.67 g. The least weight of spike (under 1.00 g) were in the VII, XV and XIV crop rotations. The spike weight was between 1.07 and 1.10 g in the X, XIII and XII crop rotations. Higher weight of spike was measured in the III, I, XI, II, V, IX and IV crop rotations. These was between 1.23 and 1.37 g. The largest weight of spike was in the VI and VIII crop rotations (1.50 and 1.67 g).

Table 4

Grain weight m^{-2} and 1000-grain weight (g) in different manuring systems of Westsik crop rotation (mean±Standard Error, n=3) Number of crop rotation is defined in the Materials and Methods section

Number of crop rotation	Grain weight per spike (g)	Weight of one spike	Grain weight per m^{-2} (g)	1000 grain weight (g)
I	1.0^{def}±1.0	1.3^{de}±0.0	447.6^{cd}±36.2	25.0^{b}±0.5
II	1.0^{def}±0.1	1.3^{de}±0.1	537.3^{de}±22.9	26.2^{be}±0.2
III	1.0^{de}±0.0	1.2^{de}±0.0	474.2^{cde}±13.0	26.0^{bc}±1.0
IV	1.1^{ef}±0.0	1.4^{def}±0.1	452.5^{cd}±59.9	26.2^{bc}±0.8
V	1.1^{def}±0.0	1.3^{de}±0.1	402.6^{bcd}±21.5	26.6^{bc}±0.4
VI	1.2^{fe}±0.1	1.5^{ef}±0.1	542.7^{de}±48.3	25.9^{bc}±0.4
VII	0.3^{a}±0.0	0.4^{a}±0.0	86.9^{a}±18.2	21.5^{a}±0.1
VIII	1.3^{e}±0.0	1.7^{f}±0.1	606.6^{e}±15.8	27.6^{c}±0.3
IX	1.1^{def}±0.0	1.3^{de}±0.0	488.7^{de}±13.6	25.9^{bc}±0.4
X	0.9^{cd}±0.0	1.1^{cd}±0.0	405.1^{bcd}±6.9	24.2^{b}±0.2
XI	1.1^{def}±0.0	1.3^{de}±0.0	429.3^{cd}±28.5	27.7±$^{c0.4}$
XII	0.9^{cd}±0.0	1.1^{cd}±0.0	339.6^{bc}±9.9	24.9^{b}±0.4
XIII	0.9^{cde}±0.1	1.1^{cd}±0.1	287.9^{b}±42.5	24.9^{b}±0.3
XIV	0.7^{bc}±0.0	0.9^{bc}±0.1	292.2^{b}±19.5	24.7^{b}±0.5
XV	0.5^{ab}±0.0	0.7^{ab}±0.1	113.9^{a}±15.7	21.7^{e}±0.1
Main averages	0.9±0.0	1.2±0.0	393.8±22.4	25.3±0.3

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The measured grain weight in 1 m^{-2} was between 86.93 and 606.60 g (*Table 4*). The grain weight difference was six-times between the least and the highest grain weight. The least weight was in the VII and XV crop rotations. The grain weight was between 287.86 and 405.07 g m^{-2} in the XIII, XIV, XII, V and X crop rotation. The grain weight was higher in the XI, I, IV and III crop rotations (429.33 and 474.20 g m^{-2}). We measured the highest weight in the IX, II, VI and VIII crop rotations (488.73 and 606.60 g m^{-2}).

Concerning to the 1000 seed weight data presented in Table 4, the average values were between 21.50 and 27.70 g. The smallest and lightest seeds were in the VII and XV crop rotations (21.50 and 21.67 g per1000 seeds). The seed weight was between the 24.23 and 24.97 g per 1000 seeds in the X, XIV, XII, XIII and I crop rotations. The seed weight was higher in the IX, VI, III, II, IV and V crop rotations (between 25.90 and 26.57 g per 1000 seeds). The highest seed weight was measured in the VIII and XI crop rotations (27.57 and 27.70 g per 1000 seeds).

Results of the correlation analysis

Correlation analysis results indicated positive and close correlations between the rye plant height and the other measured rye parameters (*Table 5*). This means that higher plants have higher growth parameters and yield components.

Table 5

Correlation coefficients of the linear relationship (r-values) among rye plant height and other rye parameters (n=3)

Pearson's correlation	Rye plant weight	Spike length	Weight of one spike	Grain weight of a spike	Spike weight	Grain weight (g m^{-2})	1000 seed weight
Rye plant height	0.915**	0.863**	0.894**	0.899**	0.902**	0.900**	0.862**

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

DISCUSSION AND CONCLUSION

Growth parameters

In the present study, we found that rye plant height of the VII and XV crop rotation is significantly different from that of all crop rotations. These crop rotations were not chemically fertilized; the VII crop rotation was treated only with 26,3 t ha^{-1} straw manure and in the XV crop rotation green lupine manure as a second crop was applied. The rye plant height of I, II, III, VI, VIII, IX, XI crop rotations is significantly different from the other crop rotations. These crop rotations were chemically fertilized with straw manure addition (VI) or with green lupine manure (II, III, VIII, IX). These results were confirmed by Rahnavard et al., 2009 and Morrison et al., 2018 they are indicated that crop rotation system increase soil fertility and reduce crop competitiveness. Moreover, yield and yield components were affected due to this system of crop rotation as mentioned by Kruppa and Szabo (2005). Carbon and organic contents and soil fertility were increased with planting legume crop and green manure Stępień and Kobialka (2019). Moreover, favourable changes in soil mechanical, chemical composition and quality caused by the increase of soil carbon content were discussed by (Hemalatha and Chellamuthu, 2013; Balkcom et al., 2018) The rye plant weight of VI and VIII crop rotation were significantly different from VII and XV crop rotations and that crop rotations which get organic fertilizer + chemical fertilizer (IV, V, XI crop rotations) or organic fertilizer without any chemical fertilizer (X crop rotation) and that crop rotations which get chemical fertilizer + green lupine manure as a main- and second crop (II, III, IX, XII, XIII, XIV). These results are in good line with those obtained by Causarano et al., 2006; Balkcom et al., 2013; Stępień et al., 2016; Qiuchen, 2018.

Yield components

In the present study, we found that yield components (spike number, spike weight, 1000-seed weight) in the VII crop rotation is significantly different of all other crop rotations. This may be a consequence of that this crop rotation is not get any chemical fertilizer only 26.3 t ha^{-1} straw manure. The Cioromele and Contoman. (2015) and Wojtkowiak et al. (2015) reported about that the grain yield is determined by the nitrogen dose. As to Blecharczyk et al. (2004) research result, the NPK fertilizer (N-90 kg ha$^{–1}$, P-26 kg ha$^{–1}$, K-100 kg ha$^{–1}$) of rye increased in the grain yield by 102.9%, in the number of spike m^{-2} by 38.1%, in the number of grains per spike by 41.9%, in the grain weight per spike by 46.9%, and in the 1000 grain weight by13.9% as compared to the without any fertilization. According to our results nearly all of spike yield components of VI, VIII and I crop rotation is significantly different from all other crop rotations. This can be explained by the complex manuring system of rotation VI with chemical fertilizer + 26.3 t ha^{-1} straw manure, of rotation VIII with chemical fertilizer + green lupine manure as a main crop, and the one-year fallow period in the crop rotation I also had positive effects. These results might be attributed to the positive effect of organic farming practices on mechanical, chemical properties and the activity of microorganisms of soil which improve the growth, yield and yield components of cereal crops in comparison with conventional farming (Shannon et al., 2002; Li et al. 2010; Achu et al., 2013). On the other hand, the increase in the spike weight per m^2 results might be due to the vital role of NPK mineral chemical fertilization in improving the growth, yield and yield components of cereal crop production due to the availability of low-cost fertilizers (Abril et al., 2007). The increases of grain and spike weight in the VIII crop rotation might be ascribed to the four part of this crop rotation and to

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the complex manuring system with green lupine manure as a main- and second crop + chemical fertilizer which system has good effect on soil fertility and increase the growth parameters and yield components of plants (Grantina-Ievina and Ievinsh, 2015; Stępień et al., 2016; Qiuchen, 2018).

Our research results indicated that the different fertilization methods resulted in different effects on growth characters and yield components of rye plant. 90 years application of plant nutrition methods in the long-term experiment revealed that on the acidic sandy soil the organic manure has important role in the soil fertility. However, completing the organic manure with NPK fertilizer improved the yield quantity. We stated that the application of lupine green manure and fermented rye straw without NPK fertilizer had lower effect on the yield of rye than the fallow. We concluded that adding stable organic manure or left the soil without tillage – and, in this way decreasing the mineralization of soil organic matter – are the basic and most important agrotechnical methods of sandy soils. Data also proved that there is a positive close correlation between rye plant height and the other studied plant parameters (rye plant weight per m^2, spike length, weight of one spike, grain weight per spike, spike weight per m^2, grain weight per m^2 and 1000 seed weight).

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