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Effects of Long-Term Fertilization Methods on Rye Yield Components

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ABSTRACT

To reveal the effect of different fertilization methods on rye yield components, plant samplings were carried out in Westsik's crop rotation long-term experiment of the Research Institute of Nyíregyháza, IAREF, University of Debrecen, Hungary during the 2018 and 2019 seasons. 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 (II) lupine green manure as the main crop, in two crop rotations (III, VIII) lupine for seed, in CR VIII lupine as main crop plus second crop, in one crop rotation (IX) lupine for green forage, in four crop rotations, lupine green manure as a second crop (XII, XIII, XIV, XV) are applied. Eleven crop rotations are treated with NPK fertilizer (II, III, IV, V, VI, VIII, IX, XI, XII, XIII, XIV). Results showed that all studied characters significantly differed due to fertilization methods in both years. Organic manure form plus chemical fertilizers resulted in the higher of analyzed rye plant parameters (plant weight per m2, seed weight per m2, spike number per m2, and 1000 seed weight). Comparing the effects of the three organic fertilization methods without chemical fertilizer, the farmyard manure was the most effective on the winter rye yield components. In addition, there were positive and close correlations between the rye seed weight, the rye plant weight, and 1000 seed weight, in both seasons. It could be concluded applied three organic manure (farmyard manure, straw manure, and lupine green manure) with chemical fertilizers were the most effective on rye yield component production.

INTRODUCTION

Rye (*Secale cereale* L.) is widely grown in Eastern, Central, and Northern Europe as a most important cereal crop for both human and animal feeding, especially in sandy soil (Bushuk, 2001). The total cultivated area of rye plants reached about 4.21 million ha and 25.940 thousand ha in the world and Hungary, respectively. A long-term field experiment is well known worldwide and has a positive effect on soil productivity, this effect is attributed mainly to the release of the constituent nutrients of the organic matter during decomposition and the improvement of the soil's physical condition, increases soil organic material and soil carbon content, which helps to maintain the soil fertility (Hemalatha and Chellamuthu, 2013; Balkcom et al. 2018) and promote to increase soil carbon sequestration, enhance crop growth characters and yield productivity of rye plants (Casarano et al. 2006). By organic manure using, we can increase the organic material content of the soil. The soil's organic material content is a very important factor in soil fertility (Rahman and Parkinson, 2007).

Using chemical fertilizers was increased worldwide for cereal production to face the big difference between production and consumption. With long-term and large-scale use of NPK mineral fertilizers, a lot of environmental issues will appear, such as changing soil pH, disturbances in beneficial microbial ecosystems, increase pests, and even contributing to the release of greenhouse gases, soil acidification, and crust. Possible methods to reduce chemical fertilizer use could be the adoption of leguminous crops in cereal-based cropping systems and the recycling of organic wastes (Patil et al. 2001). Involve legumes in cereal crop production reduced the dependence on chemical fertilizers and improved the soil condition, consequently the yield of rye plants (Rochester et al. 2001; Achu et al. 2013). The soil nutrient content is positively influenced by growing legumes and applying farmyard manure. Several investigations indicated positive effects of farmyard manure especially on soil organic carbon content and soil biological properties in many field experiments (Mäder et al. 2002; Marinari et al. 2006; Heinze et al. 2010) and in conventional farming systems too (Edmeades, 2003; Böhme et al. 2005; Elfstrand et al. 2007). In addition, the farmyard manure had a positive effect on the soil's organic carbon content and winter rye yield opposite the applied green manure fertilizer (Heinze et al. 2011). The interaction between organic and mineral fertilizers was studied by (Fageria et al. 2009; Stępień et al. 2016; Qiuchen, 2018) They found that rye yield and yield attributes significantly increased due to organic and mineral fertilizers compared to no fertilization. In the same way, the nutrient supply greatly influenced the growth characteristics and yield components of winter wheat (Bulman and Hunt, 1984). Rye yield was strongly determined by the genotype, the environment, the nutrient supply, and their interactions (Simmonds, 1981; Sattelmacher et al. 1994). Also, seed weight was considered one of the most important factors of winter rye yield and is genetically determined (Chmielewski and Köhn, 2000).

The objective of the experiment reported herein was to assess the effect of all fertilization methods of Westsik's crop rotation field experiment on some yield components of rye plants, as the main crop of this long-term experiment.

MATERIALS AND METHODS

Description of the experiment

Our plant samples were collected in the field of Westsik's crop rotation long-term experiment at the Research Institute of Nyíregyháza, IAREF, University of Debrecen, Hungary during the 2018 and 2019seasons. The soil of this experiment is classified as acidic sandy soil (pHKCL 4.47) with low humus content (0.64%) in the 0-20 cm soil layer. The experiment includes 14 three-year-long and 1 four-year-long crop rotations (C.R.) as presented in 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 (II) lupine green manure as the main crop, in two crop rotations (III, VIII) lupine for seed, in CR VIII lupine as main crop plus second crop, in one crop rotation (IX) lupine for green forage, in four crop rotations, lupine green manure as a second crop (XII, XIII, XIV, XV) are applied. Eleven crop rotations are treated with NPK fertilizer (II, III, IV, V, VI, VIII, IX, XI, XII, XIII, XIV).

Sampling and measured parameters

Samples of rye plants were collected randomly from each plot after all plants reached the maturity stage on the 2nd and 11th of July during the 2018 and 2019 seasons, respectively using a square wooden frame 100 × 100 cm (1m2) in three repetitions/parcels, to determine the following characters: plant weight (g m^{-2}), spike number per m-2, seed weight m-2 and 1000-grain weight (g).

Statistical analysis

All collected data were analyzed according to the IBM SPSS Statistical Software Package 21.0 version. 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.

RESULTS

Plant weight

Data presented in Table 2 clearly show that the averages of rye plant weight/m^2 were between 325 and 1652 g m^{-2} and 539 and 1771 g m^{-2} in both the 2018 and 2019 seasons, respectively. The straw manure plus chemical fertilizer in C.Rs IV, V and VI recorded higher values of rye plant weight, which were1219, 1077, 1499 and 1545, 1251, 1202 g m^{-2} respectively as compared with using straw manure alone without chemical fertilizer in C.R. VII in both seasons. The farmyard manure plus chemical fertilizer produced higher rye plant weight in C.R. XI (1238 g m^{-2}) compared with using farmyard manure alone without chemical fertilizer in C.R. X (1166 g m^{-2}) in the 2018 year. The highest values of plant weight resulted in C.R.X (1771 g m^{-2}) and C.R. XI (1637 g m^{-2}) in 2019 and without significant differences between them. In addition, C.R. VIII resulted in higher values of rye plant weight (1652 and 1764g m^{-2}) in both seasons, respectively. Moreover, chemically fertilized lupine green manure in C.Rs VIII, XII, XIII, and XIV resulted in higher plant weight/m^2 compared with lupine green manure alone, without chemical fertilizer in C.R. XV in both years. This can be concluded that those C.Rs, where lupine was grown for seed (III and VIII), for forage (IX) and lupine green manure(II, XII, XIII and XIV) produced higher rye plant weight with chemical fertilizer than those without chemical fertilizer (XV). Applying fallow in C.R. I produced high plant weight/m^2 (1212 and 1356 g m-2) in the 2018 and 2019 seasons.

Table 1. Number of crop rotations, fertilization methods, and fertilization doses of the rye before its sowing in the Westsik's crop rotation experiment.

Number of crop rotation	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Farmyard manure (t ha^{-1})	Straw manure (t ha^{-1})	Lupine as the main crop	Lupine green manure as a second crop
I						-	-
II		31	28			green manure	-
III		31	28			for seed	-
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			for seed	+
IX	43	31	28			for green forage	-
X				26.1		-	-
XI		31	28	26.1		-	-
XII		31	28			-	+
XIII	43	31	28			-	+
XIV	43	31	28			-	+
XV						-	+

Seed weight per m^{-2}

Data presented in Table 3 clearly showed that seed weight per m-2 was significantly affected by C.R. Straw manure with chemical fertilizer in C.Rs. IV, V and VI resulted in higher seed weight compared with straw manure alone, without chemical fertilizer in C.R. VII, in both years. Farmyard manure plus chemical fertilizer resulted in higher seed weight in C.R. XI (429.3 and 577.7 g m-2) compared with using farmyard manure alone, without chemical fertilizer in C.R. X (405.1 and 573.7 g m-2), in both years. The highest values of seed weight/m2 were recorded in C.R. VIII (606.6 g m-2) in 2018 and in C.R.XI (577.7 g m-2) in 2019. Application of lupine green manure as a second crop plus chemical fertilizer resulted in higher seed weight in C.Rs VIII, XII, XIII and XIV as compared with lupine green manure as a second crop alone, without chemical fertilizer in C.R. XV, in both years. Generally, the data also showed that not only organic fertilizer but chemical fertilizer is very important to increase the rye yield components.

Spike number per m^{-2}

The data presented in Table 4 revealed the significant differences in spike number measured in crop rotations with different fertilization methods in both years. The data of C.R. VII was significantly different from those of the C.Rs VIII and X but was not different from all other C.R. data in 2018. The data of C.R. VI was significantly different from C.Rs II, III and IV data, but was not different from the remained C.Rs data in 2019. The C.Rs II, III and IV data were significantly different from C.Rs VI, VII and VIII data, but were not different from all the remained ones in 2019. Straw manure plus chemical fertilizer in C.Rs IV, V, VI)(523, 483, and 641 spike m^{-2}) resulted in a higher number of spike/m^2 than using straw manure only, without chemical fertilizer as in C.R. VII (372 spike m-2) in 2018. The C.R. X resulted in the highest number of spikes (745 spike m^{-2}) in 2018, while in the 2019 season, the highest number of spikes (640 spikes m-2) resulted in the C.R. XI. In addition, the data in Table 4 clearly showed that among the lupine C.Rs (II, III, VIII, and IX) during 2018, the C.R. VIII produced the highest number of spikes (679 spike m-2). In 2019 CR II produced the highest result (717 pc m-2), but in 2018 this C.R. produced the lowest number of spikes per m-2 (515 pc m-2). Growing lupine green manure as a second crop with or without chemical fertilizer (C.Rs XII, XIII, XIV, and XV) did not produce a high number of spikes. Also, C.R. I (fallow) was nearly the same in both analyzed years (599 and 604 pc m^{-2}).

Table 2. Rye plant weight/m2as affected by fertilization methods and fertilization doses (mean ± Standard deviation, n=3).

Number of crop rotation	Rye plant weight g m^{-2}	
	2018	2019
I	1 212 ^{bcde} ±154.00	1 356 ^{cd} ±102.84
II	1 362 ^{def} ±42.75	1 489 ^{cd} ±134.42
III	1 341 ^{def} ±177.85	1 764 ^{d} ±44.54
IV	1 219 ^{bcde} ±216.07	1 545 ^{cd} ±114.41
V	1 077 ^{bcd} ±92.72	1 251 ^{bc} ±154.79
VI	1 499 ^{ef} ±231.39	1 202 ^{bc} ±196.00
VII	325 ^{a} ±69.89	539 ^{a} ±86.31
VIII	1 652 ^{f} ±29.59	1 345 ^{cd} ±91.09
IX	1 311 ^{def} ±85.44	1 637 ^{cd} ±72.23
X	1 166 ^{bcde} ±128.18	1 771 ^{d} ±294.48
XI	1 238 ^{cde} ±118.05	1 670 ^{cd} ±170.56
XII	1 025 ^{bcd} ±52.16	1 395 ^{cd} ±130.08
XIII	871 ^{bc} ±162.85	1 379 ^{cd} ±201.06
XIV	855 ^{b} ±149.48	1 640 ^{cd} ±348.26
XV	379 ^{a} ±41.48	871 ^{ab} ±108.45
Main averages	**1 102**	**1 390**

1000 seed weight

The results of statistical analysis show significant differences between the 1000 seed weights in both years (Table 5). The data of C.R. VII and XV were significantly different from all the other data. These crop rotations produced the least 1000 seed weight in 2018. The data of C.R. VIII and XI were significantly different from C.Rs. I, VII, X, XII, XIII, XIV and XV data but was not significantly different from C.Rs. II, III, IV, V, VI and IX data. The C.Rs. VIII and XI produced the highest values of 1000 seed weight. Also, the data of C.R. VII was not significantly different from C.Rs. II, IV and XV but were significantly different from all other crop rotations data in 2019. As presented in Table 5 C.Rs. IV, V and VI resulted in a higher 1000 seed weight than in C.R. VII in both years. The farmyard manure treatment in C.R. XI produced the highest 1000 seed weight (27.700 g) in 2018 while in CR X (29.667g) during the 2019 season. Also, the results showed that among the lupine-grown C.Rs II, III, VIII and IX, the highest values of 1000 seed weight resulted from C.R. VIII in 2018 (27.567) and CR III in 2019 (27.833). The lowest 1000 seed weight was measured in CR IX (25.900 g) in 2018, while in CR II (25.167 g) in 2019.

Table 3. Seed weight g m^{-2} as affected by fertilization methods and fertilization doses (mean ± Standard deviation, n = 3).

Number of crop rotation	Seed weight g m^{-2}	
	2018	2019
I	411.1 ^{bcde} ±62.93	387.9 ^{bcde} ±69.39
II	537.3 ^{ef} ±39.82	429.5 ^{cde} ±80.47
III	474.2 ^{def} ±22.54	543.9 ^{de} ±21.69
IV	452.5 ^{de} ±103.84	496.5 ^{cde} ±65.93
V	402.6 ^{bcde} ±37.25	362.1 ^{bcd} ±58.50
VI	542.7 ^{ef} ±83.77	362.1 ^{bcd} ±69.60
VII	86.9 ^{a} ±31.64	126.3 ^{a} ±22.62
VIII	606.6 ^{f} ±27.32	432.9 ^{cde} ±47.40
IX	488.7 ^{ef} ±23.67	528.7 ^{cde} ±22.90
X	405.1 ^{bcde} ±11.93	573.7 ^{e} ±106.65
XI	429.3 ^{cde} ±49.42	577.7 ^{e} ±54.64
XII	339.6 ^{bcd} ±17.22	412.7 ^{cde} ±37.02
XIII	287.9 ^{b} ±73.58	459.5 ^{cde} ±78.01
XIV	292.2 ^{bc} ±33.89	534.7 ^{cde} ±107.04
XV	113.9 ^{a} ±27.17	237.2 ^{ab} ±47.72
Main averages	**391.3**	**430.5**

Correlation

Correlation analysis results indicated a significant positive correlation between the seed weight per m-2 and other measured rye yield components as presented in Table 6 in both analyzed years. The correlation was significantly positive and very strong between the seed weight/m2 and plant weight (0.977), and between the seed weight and 1000 seed weight (0.776). In terms of yield, the seed weight, the plant weight and 1000 seed weight were the most important component in the 2018 year. There were a significant medium and positive correlation between the seed weight and spike number (0.592). It can be explained that the yield of rye was not determined mainly by the spike number. Furthermore, during 2019 the correlation was significantly positive and very strong between the seed weight and rye plant weight (0.975) and between the seed weight and 1000 seed weight (0.704). In terms of yield, the seed weight, the plant weight and 1000 seed weight were the most important component in the 2019 year. There was a significantly positive and medium correlation between the rye seed weight and spike number (0.550). These results agree with those obtained by (Leilah and Al-Khateeb 2005; Gulmezoglu et al. 2010; Bhushan et al. 2013; Nouraein 2019.

Table 4. Spike number (pc m^{-2}) as affected by fertilization methods and fertilization doses (mean ± Standard deviation, n=3).

Number of crop rotation	Spike number pc m^{-2}	
	2018	**2019**
I	599 ^{ab} ±170.47	604 ^{abc} ±52.11
II	542 ^{ab} ±105.14	717 ^{c} ±40.01
III	555 ^{ab} ±89.71	701 ^{c} ±52.54
IV	523 ^{ab} ±156.08	709 ^{c} ±14.74
V	483 ^{ab} ±31.06	605 ^{abc} ±44.73
VI	641 ^{ab} ±101.04	515 ^{a} ±79.10
VII	372 ^{a} ±76.86	539 ^{ab} ±50.01
VIII	679 ^{b} ±31.26	534 ^{ab} ±21.63
IX	581 ^{ab} ±80.90	573 ^{abc} ±61.97
X	745 ^{b} ±87.75	599 ^{abc} ±66.58
XI	574 ^{ab} ±27.78	640 ^{abc} ±33.28
XII	523 ^{ab} ±68.03	595 ^{abc} ±46.23
XIII	497 ^{ab} ±48.22	610 ^{abc} ±44.67
XIV	509 ^{ab} ±54.60	678 ^{bc} ±102.52
XV	503 ^{ab} ±92.91	567 ^{abc} ±40.61
Main averages	**554**	**612**

DISCUSSION

Rye yield components

Applying straw manure plus chemical fertilizer in C.Rs IV, V and VI recorded higher values of rye plant weight, seed weight m-2, number of spike m-2 and 1000-seed weight as compared with using straw manure alone without chemical fertilizer in C.R. VII in both seasons. Straw manure treatments could be able to improve the soil's physical and chemical properties, consequently, increase the rye yields parameters (Broumand et al., 2010). Also, organic fertilization promoted the rye plant development significantly as mentioned by (Gill and Meelu, 1982; Jate, 2012; Grantina-Ievina and Ievinsh, 2015). C.R. VIII resulted in higher values of rye plant weight in both seasons, respectively. This can be explained that the C.R. VIII consists of four parts, and this is a complex manuring system with green lupine manure as a main and second crop besides chemical fertilizer, which has a good effect on soil fertility and increases growth characters as well as the yield components of rye plants (Hardarson, 1993; Grantina-Ievina and Ievinsh, 2015; Stępień et al. 2016; Pietrzykowski 2017; Qiuchen 2018). Moreover, green manure has a beneficial effect on plant production, its application reduces the nitrogen losses from the soil, which applies higher nitrogen supply for the next plant, consequently, results in higher yield (Thorup-Kristensen and Bertelsen, 1996). Also, C.R. I (fallow) was nearly the same. These results are in harmony with those obtained by (Sadras and Slafer, 2012; Würschum, 2018; Dreccer et al., 2019). Also, the good effect of organic and chemical fertilization application together on rye weight m-2 was noticed by (Saleque et al. 2004; Bokhtiar and Sakurai, 2005; Mottaghian et al. 2008). Moreover, C.Rs VIII, XII, XIII and XIV resulted in higher plant weight/m2 compared with lupine green manure alone in C.R. XV in both years.

Table 5. 1000 seed weight (g) as affected by the Number of crop rotations, fertilization methods, and fertilization doses (mean ± Standard deviation, n=3).

Number of crop rotation	1000 seed weight (g)	
	2018	**2019**
I	24.967 ^{b}±0.86	27.000 ^{bc}±1.80
II	26.167 ^{bc}±0.40	25.167 ^{ab}±1.04
III	26.000 ^{bc}±1.83	27.833 ^{bc}±0.57
IV	26.233 ^{bc}±1.38	26.000 ^{abc}±0.50
V	26.567 ^{bc}±0.63	25.167 ^{ab}±2.36
VI	25.933 ^{bc}±0.73	26.500 ^{bc}±0.86
VII	21.500 ^{a}±0.26	22.500 ^{a}±0.50
VIII	27.567 ^{c}±0.46	26.167 ^{bc}±0.28
IX	25.900 ^{bc}±0.75	27.167 ^{bc}±1.60
X	24.233 ^{b}±0.28	29.667 ^{c}±1.60
XI	27.700 ^{c}±0.70	28.333 ^{bc}±2.56
XII	24.933 ^{b}±0.73	27.167 ^{bc}±0.28
XIII	24.933 ^{b}±0.45	29.833 ^{c}±0.76
XIV	24.733 ^{b}±0.80	29.000 ^{bc}±0.86
XV	21.667 ^{a}±0.23	25.167 ^{ab}±1.15
Main averages	**25.269**	**26.844**

This can be concluded that those C.Rs, where lupine was grown for seed (III and VIII), for forage (IX) and lupine green manure (II, XII, XIII and XIV) produced higher rye plant weight with chemical fertilizer than without chemical fertilizer (XV). These results are in agreement with those obtained by (Nedzinskiene, 2006; Cioremele and Contoman, 2015; Wojtkowiak et al. 2015; Stępień et al. 2016). 1000 seed weight is an important factor in terms of rye yield and is significantly affected by fertilization methods and the doses used (Sadras and Slafer, 2012; Dreccer et al. 2019).

Table 6. The correlation coefficients of the linear relationship (R-values) among rye seed weight and other rye yield parameters (n=3).

Person's correlation	Plant weight (g m^{-2})	Spike number (pc m^{-2})	1000 seed weight (g)
Seed weight (g m^{-2})in 2018	0.977**	0.592**	0.776**
Seed weight (g m^{-2})in 2019	0.975**	0.550**	0.704**

Person's correlation P<0.05** Correlation is significant at the 0.01 level. *Correlation is significant at the 0.05 level.

As presented in Table 5 C.Rs. IV, V and VI resulted in a higher 1000 seed weight than in C.R. VII in both years. Applying lupine green manure as a second crop with chemical fertilizer in C.Rs XII, XIII and XIV resulted in a higher 1000 seed weight than applying lupine green manure as a second crop alone, without chemical fertilizer in C.R. XV in both years. Using all of the lupine forms (grown lupine for seed or green manure) has high importance due to its nitrogen-fixing capability and role in sustainable crop production systems (Bhardwaj et al. 1998). The green manure application promotes not only crop growth but soil microbial activity, too (Tejada et al., 2008). Our results proved that farmyard manure with chemical fertilizer was more effective than the other applied organic manure form with chemical fertilizer on the 1000 seed weight. Applied fertilization (organic manure with or without chemical fertilizer) has a very important role in terms of the development of grain yield. According to (Erhart et al. 2005) composting with and without chemical fertilizer resulted in higher grain yield (10% on average) than the unfertilized control treatment. Higher rye yield parameters at organic manure plus chemical fertilization application can be explained by the manuring system effect. On the soil N content increase, the soil pH decreased, and P and K deficit will arise in the soil. Applying together organic and chemical fertilizers results in higher microbial and enzyme activity in the soil. Consequently, the long-term application of organic manure with chemical fertilizer has a positive effect on grain yield and soil quality (Liu et al. 2010).

CONCLUSION

Our research indicated that all studied characters were significantly affected by fertilization methods and doses in both years. Different fertilization methods resulted in a different effect on the yield component of the rye plant in both years. Straw manure without chemical fertilizer produced the lowest rye yield components, in both years. Also, growing lupine green manure as a second crop without chemical fertilizer produced the second-lowest data of rye plant weight and seed weight in both analysed years. It could be noticed that farmyard manure from the applied three organic manure (farmyard manure, straw manure, and lupine green manure) with chemical fertilizer was the most effective for the rye yield component production. Moreover, the results of the statistical analysis proved a positive, medium, and strong correlation between the rye yield components in both years.

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