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Effects of Seeding Rates and Sowing Times on Grain Yield and Yield Components in Rye (*Scale cereale* L.) Under Dry Condition

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ABSTRACT

Rye is one of the most important cereals for marginal land and cold climates in Turkey. A 2 year experiment was conducted in Kırşehir, Turkey, to determine the impact of seeding rates and sowing times on rye (*Secale cereale* L. 'Aslım 95). Rye seed was sown in different sowing times (1th October, 15th October, 1th November, 15th November and 1th December) at four seeding rates (300, 400, 500 and 600 seeds m^{-2}). A split-plot design was used, with sowing times as main plots and seeding rates randomized as subplots. Grain yield tended to increase with earlier sowing dates and higher seeding rates, based on two-year means. Seeding rates and sowing dates interaction effects on grain yield were significant. Therefore, the highest grain yield with 397.7 kg da^{-1} was obtained from the highest seeding rate (600 seeds m^{-2}) at the second sowing date (15th October). In contrast, the lowest grain yield (92.8 kg da^{-1}) was obtained from the lowest seeding rate with the delayed sowing dates. It is concluded that the present study showed that the reduction in grain yield depended on sowing time and seeding rates, which led to a significant reduction of number of fertile spike per unit area.

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INTRODUCTION

Rye is one of the most important cereals for marginal lands of Turkey. The Kırşehir has a very cold winter climate compared to other provinces in Turkey to the west and south. Kırşehir Province has a very cold winter climate and rainfall is taken, especially in late December as snow.

The world rye cultivation area is 4.4 million hectares and the growth rate is 13 million tons. Rye planting and most of it is trained by Germany, Russia, Poland, Belarus, Spain, Turkey, Canada, China, Ukraine and USA (Anonymous 2018).

There has been a contraction in the cultivation area of rye around the world and in Turkey in recent years. The main reason for the decrease in cultivation area is the inability of the existing rye varieties to compete with the newly developed different species in the necessary breeding studies, the inability to increase the yield per kg of the existing rye species, and the difficulties in reaching the desired level of the breeding studies due to the foreign pollination of rye. In this respect, there is a narrowing of the cultivation area. Although there are narrowings in cultivation areas, rye has a high adaptability, benefits from the nutrients and water in the soil in the best way with its strong root system, is resistant to cold and hot areas, can be grown in areas with a precipitation amount of 150 mm, and has a rugged, stony, and infertile soil content that is poor in organic matter soils (Öztürkci 2009).

Plant genetics, environmental conditions and breeding techniques are the most important factors determining yield and quality in plant production. Since it will be very difficult to make changes in environmental conditions in rye as in all grain plants, it is aimed to increase grain yield and quality per unit area with changes in plant genetics and cultivation techniques. In the studies, it has been reported that factors such as the number of fertile ears per unit area, the number of grains per ear and the grain yield per ear are values that vary according to the plant density and directly affect the yield (Kaydan et al. 2011). One of the important factors affecting the grain yield in cereals is the seeding rate (Kaydan and Yağmur 2008). It has been reported that suitable seeding rates in wheat increase grain yield (Joseph et al. 1985; Lafond 1994) and this effect varies from region to region (Black and Aase 1982). Moreover, Yagmur and Sozen (2021) reported that sowing times significantly influenced the grain yield and yield components in two consecutive years in barley. They also reported that most of the yield components were adversely affected by delayed sowing dates. In another study conducted in wheat, Yagmur et al. (2021) reported that different seeding rates significantly affected all yield characters examined in the study.

This study was aimed in dry conditions to determine the effects of seeding rates and sowing times on grain yield and yield traits in rye.

MATERIALS AND METHODS

Location of the Research Site: The research area is 5 km away from Kırşehir and its altitude is 1107 m, latitude 39° 9′ N, longitude 34° 10′ E. Kırşehir has a severely cold and snowy winter, a relatively cool spring, and a rainy and dry summer. Rainfall is extremely variable, from season to season and within a year. Aslım-95 rye (*Secale cereale* L.) variety was used as plant material.

The monthly rainfall and average temperature data for 2014-15, 2015-16, and long-term (1929-2017) averages are in Table 1. In the experimental years, including 2014-2015 and 2015-2016 winter growing seasons, total rainfall was higher than those of the long-term average for the region. Moreover, total rainfall was higher in 2014-2015 (532.3 mm) growing season than in 2015-2016 (390.2) (Anonymous 2017).

Table 1. *Climate data for Kırşehir Province in 2014-2015, 2015-2016 and long-term (LTA) averages*

	Temperature (°C)			Rainfall (mm)		
	LTA	2014-2015	2015-2016	LTA	2014-2015	2015-2016
August	22.9	25.8	25.9	4.9	5.5	11.8
September	18.2	19.6	23.8	11.6	29.8	1.0
October	12.3	13.5	14.6	27.8	37.2	30.8
November	6.2	6.7	8.4	36.4	28.4	8.8
December	1.9	6.0	-1.2	47.0	29.2	10.2
January	-0.1	1.3	0.0	46.2	35.2	72.1
February	1.3	3.4	6.2	35.2	35.9	36.4
March	5.3	6.9	7.2	35.2	88.6	39.2
April	10.7	8.8	14.1	43.7	26.8	23.8
May	15.4	16.4	15.1	44.3	39.2	95.8
June	19.6	18.9	21.3	36.8	161.4	16.1
July	23.1	25.7	24.9	6.8	20.6	1.0
Total				375.9	532.3	390.2
Average	11.4	12.7	13.3			

Soil analysis has been described in detail by Kacar (1995). Soil samples were taken from the surface layer of the experimental area (0-30 cm). Analysis showed the soil to have a sandy-clay-loamy texture with low organic matter (1.81 %) and nitrogen (0.15 %) content, high potassium with 63.78 ppm and lime (21.8 %) content, low phosphorus (0.19 %) content and slight alkalinity (pH: 7.59).

Table 2. *Physical and chemical properties of field soil **

Physical and chemical properties	0-30 cm
pH	7.59
Total Salt (%)	0.02
EC (mmhos cm^{-1})	0.52
Organic matter (%)	1.81
Nitrogen (%)	0.15
Phosphorus (%)	0.19
Potassium (ppm)	63.78
Lime (%)	21.8

* Soil analysis was done at Tokat Soil and Water Resources Research Institute.

Experimental procedure

A 2-year field trial was conducted in Kırşehir, Turkey, to determine the impact of seeding rates and sowing times on rye (*Secale cereale* L. 'Aslım 95'). The experiment was conducted in a split plot design with five sowing times and four seeding rates with three replications. The experimental design consisted of 20 split plots with three replications for a total of 60 plots. Each plot contained five rows, each 5 m in length and spaced 0.20 cm apart. Seeds were hand-drilled at depths of 5 cm.

The field was prepared by ploughing to a depth of 20 cm, which was followed by surface cultivation. Each year, rye was sown at five sowing times (1th October, 15th October, 1th November, 15th November and 1th December) at four seeding rates (300, 400, 500 and 600 seeds m^{-2}). A split-plot design was used, with sowing times as the main plots and seeding rates randomized as subplots. Sowing time was arranged as close as possible to 15-day intervals (1th October, 15th October, 1th November, 15th November and 01th December).

Fertilizer was applied by hand and mixed into the top 2-8 cm of soil at sowing time. All plots were fertilized at sowing with 15 kg DAP/da^{-1} (N 18 % - P 46 %), and 20 kg ammonium sulphate da^{-1} (N, 21 %) was applied as a top dressing before ear emergence. Weeds were controlled with hand weeding or by mechanical cultivation as needed. Plots were not irrigated during both growing seasons. No insects, pests, or disease infestations were observed.

At harvest, ten plants were collected randomly from the central row and the following growth and yield component variables were recorded for each plot: (1) fertile spike per square meter, (2) plant height (cm), (3) number of grain per spike, (4) grain weight per spike, (5) 1000 grain weight (g^{-1}) and (6) grain yield (kg da^{-1}). Grain yield was taken at maturity by harvesting the center row of each plot for grain yield determination in July 2015 and 2016. Grain yield was adjusted to a 14.0 % moisture basis.

Analysis of variance (ANOVA) was performed using the MSTATc statistical package. Data were combined over years and presented as 2-year mean values. Duncan tests were used to compare means.

RESULT AND DISCUSSION

The variance analysis results are shown in Table 3, it has been determined that the years (Y), sowing times (ST) and seeding rates (SR) have a statistically significant effect on all the examined characteristics. In addition to these, it was determined that the interaction between the sowing time and the seeding rates in the study affected most of the yield and yield components (Table 3).

Table 3. *Summary of variance analysis results (F value)*

	Fertile spike (m^{-2})	Plant height (cm)	Number of grain per spike	Grain weight per spike	1000 grain weight (g)	Grain yield (kg da^{-1})
Year	28.4 *	216.32**	58.02 *	140.88	68.65*	512.4**
Sowing times	203.3**	181.58**	539.74**	314.67**	140.83**	522.7**
Year x sowing times interaction	7.67**	2.36	10.19**	5.42**	5.37**	7.73**
Seeding rates	301.9**	1.66	13.64**	75.21**	21.12**	225.5**
Year x seeding rates interaction	3.80*	3.59*	0.716	0.002	2.03	1.07
Sowing times x seeding rates interaction	9.14**	3.01**	2.92**	2.92**	1.86	21.97**
Year x sowing times x seeding rates interaction	1.16	2.21*	4.00**	2.49*	2.63**	3.20**
Coefficient of Variations (%)	10.6	3.25	5.93	4.27	4.20	7.47

* P≤0.05, P ** p≤0.01

Number of fertile rye spikes is an important character that was mostly influenced by sowing time and seeding rates in two seasons (Table 4). In the study, among the sowing times examined, the 15th October and 01th November sowing times produced the greatest number of fertile spikes (m^{-2}). The lowest fertile spike was determined in the sowing times at 15th November. The earliest and the delayed sowing times mostly reduced number of fertile spikes per unit area (Table 4). In the study, the seeding rates significantly affected the number of spikes. The number of spikes increased with increasing seeding rates. Moreover the interactive effect of seeding rates and sowing times affected the number of fertile spike. The highest number of fertile spike (m^{-2}) in 15th October sowing time and 600 seeds m^{-2} seeding rates were obtained in comparison to the 15th November sowing date with the 300 seeds m^{-2} seeding rate (Table 4). Moreover, Al-Muhja and Al-Refai (2016) reported that the number of spikes per square meter was found to be significantly affected by the planting date in barley. Furthermore, changes in spikes per square meter were the major contributors to the grain-yield differences observed among sowing times and seeding rates in wheat (Ozturk et al. 2006).

The average plant height values of the years, sowing times, and seeding rates used in the research are given in Table 4. There was a statistically significant difference between years in terms of plant height and this can be explained as follows: The fact that the total rainfall in 2015-2016, when the experiment was conducted, was lower than the total rainfall in 2014-2015, caused the plant height averages determined in 2015-2016 to be shorter than the plant height averages measured in 2014-2015. Early sowing increased plant height, which was attributed to a longer vegetative growth duration. In contrast, the delayed sowing dates significantly reduced plant height compared to early sowing times (Table 4). Yagmur and Sozen (2021) reported that early sowing increased plant height. Ozturk et al. (2006) also reported that the growth and yield of wheat are affected by environmental conditions and can be regulated by sowing time and seeding rate. The highest plant height was obtained at earlier sowing times and at intensive seeding rates. The interaction of seeding rates and sowing times also had a significant effect on plant height. Therefore, the longest plant height (109.0 cm) was obtained from the sowing rates of 600 seed per unit area and 1th October sowing date based on two year means (Table 4). Earlier seeding dates in rye has a substantially longer vegetative period than delayed-sown rye which results in more leaves, more tillers, and greater height (Ozturk et al. 2006).

Table 4. *The average values of some plant characteristics examined in the study and the Duncan test results of the averages of these characteristics*

Years		Fertile spike (m^{-2})	Plant height (cm)	Number of grain per spike	Grain weight per spike (g^{-1})	1000 grain w. (g^{-1})	Grain yield (kg da^{-1})
2014-2015		300.8 a*	90.0 a	25.9 b	0.98	27.8 a	229.7 a
2015-2016		265.4 b	86.6 b	31.3 a	1.02	25.9 b	206.8 b
Sowing times (ST)							
ST1 (1th October)		265.6 c	105.3 a	37.5 a	1.14 a	31.7 a	248.1 b
ST2 (15th October)		389.9 a	97.2 b	33.9 b	1.08 a	29.5 ab	316.1 a
ST3 (1th November)		337.5 b	89.5 c	30.1 c	1.04 a	25.9 bc	235.0 c
ST4 (15th November)		167.2 d	75.5 d	17.1 e	0.82 b	25.1 bc	114.7 e
ST5 (1th December)		255.4 c	73.9 d	24.5 d	0.91 b	22.2 c	177.6 d
Seeding rates (SR)							
SR1 (300 seeds m^{-2})		161.0 d	89.1	29.8 a	1.07 a	28.1 a	167.4 d
SR2 (400 seeds m^{-2})		255.8 c	88.5	29.1 ab	1.03 b	27.2 b	201.5 c
SR3 (500 seeds m^{-2})		338.8 b	88.3	28.4 b	0.97 c	26.5 c	231.5 b
SR4 (600 seeds m^{-2})		377.0 a	87.4	27.1 c	0.92 d	25.8 d	272.7 a
Intereaction of year, sowing times (ST) and seeding rates (SR)							
ST1	SR1	124 kl	104.7 ab	39.6 a	1.26 a	32.6	183 j
	SR2	245.3 gh	102.5 bc	38.1 ab	1.17 b	31.8	215.3 gh
	SR3	321.3 ef	105.3 ab	37.3 b	1.08 de	31.1	262.7 f
	SR4	371.8 cd	109.0a	34.8 cd	1.03 efg	31.3	331.3 c
ST2	SR1	233 ghı	97.7 cd	35.3 c	1.13 bc	30.8	218.2 gh
	SR2	349.5 de	98.1 cd	32.8 de	1.09 cd	29.3	283.7 e
	SR3	456.2 b	96.6 d	33.8 cd	1.08 de	28.6	365.3 b
	SR4	521.0 a	97.1 cd	33.6 cd	1.01 fgh	29.1	397.7 a
ST3	SR1	197.5 hıj	91.1 e	31.0 ef	1.08 de	27.8	194.3 ıj
	SR2	281.5 fg	90.6 e	31.1 ef	1.06 def	26.5	211.7 ghı
	SR3	405.2 c	89.8 e	29.5 fg	1.03 efg	25.6	230.0 g
	SR4	465.8 b	86.7 e	28.6 g	0.99 gh	23.8	304.8 d
ST4	SR1	112.0 l	77.5 f	19.6 j	0.91 ı	26.0	92.8 m
	SR2	167.0 jk	77.1 f	17.3 k	0.85 j	25.6	117.8 l
	SR3	194.2 ıj	75.3 f	16.6 k	0.78 kl	25.5	124.7 l
	SR4	195.8 hıj	72.3 f	14.6 l	0.75 l	23.3	123.7 l
ST5	SR1	138.5 kl	75.0 f	23.5 ı	0.98 ghı	23.0	148.8 k
	SR2	235.7 ghı	74.1 f	26.0 h	0.97 h	22.6	178.8 j
	SR3	317.2 ef	74.3 f	25.0 hı	0.85 j	21.8	175.0 j
	SR4	330.5 def	72.1 f	23.8 ı	0.83 jk	21.5	205.8 hı

*The mean values with the same letter within variable are not significantly different

It was observed in the study that number of seeds per spike significantly decreased with increasing seeding rates. Moreover, delayed sowing dates positively decreased number of seeds per spike (Table 4). High increases in the number of grain per spike were recorded in plots that were earlier sown and at low seeding rates. The interaction between sowing times and dates on s number of grain per spike was significant based on two year means. Therefore, number of grains per spike with 39.6 was obtained from the seeding rates of 300 seed per unit area at the earliest sowing time (Table 4). In contrast, the mean number of grains per spike (14.6) was obtained from the highest seeding rates with delayed sowing date (15th November). The delayed sowing dates reduced number of grains per spike. The lowest number of grains per spike were obtained with the delayed sowing times in this study. Ozturk et al. (2006) reported that delayed sowing dates reduced grain number per spike in wheat. McKenzie et al. (2011) reported that seeding rate generally had a smaller effect on crop yield or quality than seeding date, but triticale and wheat required high seeding rates to achieve maximum yields. Early seeding date and a sufficient seeding rate were required for high crop productivity in irrigated cereals.

In the current study, grain weight per spike changed according to seeding rates and sowing dates based on two-year means (Table 4). The delayed sowing times reduced grain weight per spike. The measured data showed that plots supplied with earlier sowing date had the maximum grain weight per spike with 1.14 g. Although, the lowest grain weight per spike was obtained at the delayed sowing times, whereas, higher grain weight per spike was obtained at the first sowing date in both years. There was a significant reduction in grain weight per spike at higher seeding rates in comparison to lower seeding rates (Table 4). Seeding rates and sowing dates interaction effects on grain yield per spike were significant. Therefore, the highest grain yield per spike with 1.26 g was obtained from the lowest seeding rate (300 seeds per unit area) at the first sowing date (Table 4). In contrast, the lowest grain weight per spike (0.75 g) was obtained from the highest seeding rates with the delayed sowing date.

It is known that thousand grain weight is an important yield component, which is mostly determined by genetic potential. Nevertheless, it was observed in the study that increasing seeding rates significantly decreased thousand grain weight (Table 4). Similarly, the delayed sowing time decreased thousand grain weights. Combined effect of seeding rates and sowing times tended to decrease thousand grain weights compared to earlier sowing times and lower seeding rates without any statistical significance.

Grain yield tended to increase with earlier sowing times and higher seeding rates, based on two-year means. The highest grain yield was obtained from the highest seeding rates in comparison to other seeding rates. The increase in seeding rates increased grain yield in a dose-dependent manner. The highest grain yield (272.7 kg da^{-1}) was obtained at the highest seeding rate. It can be suggested that a 600 seeds m^{-2} seeding rate would be sufficient for a higher grain yield. On the other hand, the lowest seeding rates produced the lowest grain yield in average 167.4 kg da^{-1}. Researchers such as Geçit and Şahin (1999) reported that grain yield increased depending on the increase in seeding rates. Higher seeding rates increase the number of spike (Kaydan et al. 2011) and provide more grain yield (Yağmur and Kaydan 2008). According to the results of the research conducted by Teich and Smid (1993); Lloveras et al. (2004), the amount of seed per unit area increases the grain yield. Erbaş Köse and Mut (2022) determined that as the grain density increased in the plots, the yield increased up to a certain point and then decreased. They obtained the highest grain yield from the application of 575 seed m^{-2} sowing density.

The sowing time application had a statistically significant effect on the grain yield. While the earliest sowing time among the sowing times used in the study caused many features to be significantly higher, it was not effective in the first place on grain yield. This situation can be explained as follows, it was caused by the low number of fertile spike due to the irregular rainfall at the earliest sowing time used in the study. The highest grain yield was obtained from the second sowing time in comparison to other sowing dates. The delayed sowing times led to reduced seedling vigor, giving longer and thinner shoots than those on earlier sowing dates. Number of spikes was lower than number of seedling among delayed sowing times because plants with thinner shoots were affected by cold stress. In general, delayed sowing time (15th November) has been shown to result in fewer spikes per area cultivated due to reduced seedling establishment. The very slow seed germination at the sowing time, which is later than this sowing time, caused the emergence to be in early spring. For this reason, seedling deaths were less common on this last sowing date. It can be suggested that 15th October sowing time in rye would be sufficient for a higher grain yield. Inadequate seedling formation due to irregular precipitation at very early sowing times and also seedling deaths due to cold stress at late sowing times reduce grain yield. The present study showed that the reduction in grain yield depended on sowing dates and was attributed to a significant reduction in fertile spike per unit area. Yagmur and Sozen (2021) reported that difference in grain yield at various sowing times was attributed to a significant reduction in fertile spike per m^{-2}, number of grains per spike, grain weight per spike. Yagmur and Sozen (2021) reported that early October and late November sowing dates had a markedly negativeinfluence on grain yield in barley. They noted that essentially no seedling emergence was observed from the early October sowing date untill optimum rainfall.

A significant year × sowing time interaction in grain yield was found. Therefore, the highest grain yield with 397.7 kg da^{-1} was obtained from the highest seeding rate (600 seeds per unit area) at the second sowing date (15th October). In contrast, the lowest grain yield (92.8 kg da^{-1}) was obtained from the lowest seeding rate with the delayed sowing date (15th November). Aksoy and Yağmur, (2022) reported that they were determined rye yield increased as the seeding rate increased.

CONCLUSION

In dry field conditions, sowing dates and seeding rates are the two most important factors for getting a high grain yield in rye. The current results showed that early October and delayed sowing time, such as late November or December sowing dates, had a markedly negative influence on grain yield in rye. Inadequate seedling formation due to irregular precipitation at very early sowing times and seedling deaths due to cold stress at late sowing times reduced grain yield. Moreover, essentially no seedling emergence was observed from the earliest sowing date in October untill optimum rainfall in late October dates. Therefore, the end of October with rainy days is the most suitable sowing time. In addition the present study showed that the reduction in grain yield depended on sowing dates and was attributed to a significant reduction in fertile spike per unit area.

CONFLICT OF INTEREST

The authors of the article declare that there is no conflict of interest between them.

AUTHOR CONTRIBUTION

The first author contributed 100 %.

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