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Response of Fertile Tiller Characteristics and Seed Yield of *Elymus sibiricus* L. to Row Space Alteration

Jinping Liu[1] and Minghong You[2]
1 School of Life Science, China West Normal University, Nanchong, 637009, China
2 Sichuan Academy of Grassland Sciences, Chengdu, 611743, China
Corresponding author email: Jinping Liu Ph.D., E-mail: jpgg2000@163.com

Keywords: *Elymus sibiricus* L.; row spacing; seed yield; setting percentage.

1 SUMMARY

In order to investigate the influence of different row spacing on fertile tiller characteristics and seed yield of *Elymus sibiricus* L., and discussed the most reasonable spacing for the increase of its seed yield and quality, we conducted the present study. *E. sibiricus* L. cv. chuancao no.2 was allocated to plots in a randomized block design with five row gradients (30, 45, 60, 75 and 90 cm), and the characteristics of the shoots, inflorescence and seed yield were measured and analyzed. The results showed: First, row spacing showed highly significant effects on the numbers of tillers, ratio of fertile tillers, number of fertile tillers per square meter, height and diameter of fertile tillers This resulted in very significant differences among the lengths and diameters of the ear stalks, length of cobs, and number of spikelets and florets per fertile tiller. These results eventually led to differences among the setting percentage, presentation seed yield, and harvested seed yield. However, the total number of florets per square meter (m^2) and potential seed yield remained stable with the different row spacing. Partial correlation analysis further showed the following: Plant height was the main factor affecting the setting percentage. Ear stalk length reflected the number of spikelets and seeds of the fertile tillers and harvested seed yield. Therefore, we may predict the setting percentage and seed yield by the plant height and ear stalk length. The 1000-seed weight and other parameters were relatively stable traits, which only had very low correlations among each other. The comprehensive experimental data showed that sowing with row spacing of 60 cm resulted in the highest potential seed yield, presentation seed yield and harvested seed yield, which is worthy of application in practice.

2 INTRODUCTION

Elymus sibiricus L., which is a perennial, mesoxerophytes plant belonging to the *Elymus* genus of Gramineae, is one of most nutritional forages in the *Elymus* genus (Chen and Jia2002, Yan *et al.* 2010). In this study, *E. sibiricus* L. cv. chuancao no. 2 has been characterized with the traits of fast-growing, strong-tilling, high grass quality, high productivity, and strong resistance to cold and high moisture, which was bred from a group of wild *E. sibiricus* L. on the Northwest Plateau of Sichuan. Currently, the plant has been widely cultivated in the alpine region of China (Pan 1989, You *et al.* 2008). In recent years, the Seed Production Base of 3500 ha was established on the Northwest Plateau of Sichuan (You *et al.* 2010), but the seeds from the Seed Production Base are unable to meet the demands of major projects, such as ecological restoration, degradation grassland control, Three Rivers conservation, and artificial grassland establishment. Therefore, in order to further research seed production technology, which may provide technical support and security for seed production, practical production problems need to be solved. At present, studies concerning *E. sibiricus* L. have mainly focused on the influence of fertilizing and harvest time on seed yield and its components. The impact of single row spacing on seed yield has yet to be reported. This experiment analyzed the impact of different row spacing on seed yield and its components of *E. sibiricus* L., and discussed the most reasonable spacing for the increase of seed yield and quality of *E. sibiricus* L. on the Northwest Plateau of Sichuan. The objective of this study is to determine the methods for providing enough quality seed for developing animal husbandry, adjusting agricultural structure, and managing ecological environment. At the same time, the study results may provide a scientific basis for large-scale seed production.

3 METHODOLOGY

3.1 Study site: The experiment was carried out in Qiongxi Township, Hongyuan County, Aba State (32°46'N, 102°32' E, altitude of 3497 m). The base is a continental plateau temperate monsoon climate. The long-term averages of annual average temperature, precipitation and relative humidity are 1.1°C, 738 mm and 71%, respectively. The soil is meadow soil with 5.91 pH, 276 mg kg^{-1} available N, 10.2 mg kg^{-1} available P and 131 mg kg^{-1} exchangeable K in the 0-20 cm layer.

3.2 Materials and design: *E. sibiricus* L. cv. chuancao no. 2 was used as the test material, and a randomized block design was utilized with five row gradients (30 cm(11 lines), 45 cm (18 lines), 60 cm (8 lines), 75 cm (6 lines), and 90 cm (5 lines)). Each gradient was repeated three times. The plot size was 3 m× 5 m =15 m^2, with 1 m alleys between the neighbouring plots. Each plot was sown for 100-grain seed per 1 m of length. After sowing, same field management was used. In the third year, the data were determined and analyzed.

3.3 Measuring indicators and methods

3.3.1 Numbers of tillers and fertile tillers: At the milk stage, the numbers of tillers and fertile tillers of 50 cm in length in the center were measured. The numbers of tillers and fertile tillers per unit area were calculated based on the number of 50 cm × 2 × 3 × number of row / 15. This was repeated three times.

3.3.2 Heights and diameters of fertile tillers, lengths of ear stalks and cobs: At the milk stage, 50 fertile tillers were randomly selected, and the vertical heights and lengths of the ear stalks and cobs were measured with a ruler, then the diameters of the fertile tillers of 10 cm in length on the ground were measured with a vernier calliper.

3.3.3 Numbers of spikelets, florets, and seeds per fertile tiller: At the milk stage, 50 fertile tillers were randomly selected, to measure the numbers of spikelets, florets, and seeds.

3.3.4 Harvested seed yield: At the dough stage, 2 m^2 in the center of each plot was randomly selected to harvest seeds by hand to calculate the seed yield, and this process was repeated three times. The plots in the row spaces of 30, 45, 60, 75 and 90 cm produced the lengths of 7.2, 4.4, 3.2, 2.4 and 2 m, respectively.

3.3.5 1000-grain weight: After drying and cleaning, 1000-grain seed was selected to be weighed, and this process was repeated three times.

Potential seed yield

= fertile tillers / m^2 × spikelets / fertile tillers × florets / spikelets × 1000-grain weight / 1000

Presentation seed yield = fertile tillers / m^2 × spikelets / fertile tillers × seeds / spikelets ×1000-grain weight / 1000.

3.4 Data analysis: All data was carried out using the statistical program SAS9.1.

4 RESULTS

4.1 Number of tillers and ratio of fertile tillers: When the length per line space sown was the same as the amount of seeds, there was highly significant difference in the number of tillers per m ($p<0.01$), and significant difference in the number of vegetative and fertile tillers per meter as the row spacing changed (Table 1). Along with the increase of row space, the number of tillers per m continuously increased, but when the row spacing was more than 75 cm, the number of tillers did not increase significantly ($p>0.05$). Row spacing had a significant influence on the number of fertile tillers per line space ($p<0.01$). There was a significant difference among the numbers of vegetative tillers, fertile tillers and tillers per unit area ($p <0.01$). The number of tillers per unit area significantly decreased with the increase of the row spacing. When the row spacing was more than 60 cm, the difference of tillers per unit area was no longer significant. When row spacing was 30 cm, the number of tillers per unit area was up to 2628 per square m, with a change magnitude of ± 280.5 in the different plots. The ratio of fertile tillers with the row spacing of 60 cm was significantly higher than those of the other treatments.

The height and diameter of fertile tillers: It was found that row spacing had a significant influence on the height of fertile tillers of *E. sibiricus* L. ($p<0.01$) (Table 2). Within a certain range, close planting helped to increase the height of the plants. The heights of the fertile tillers with the row spacing of 30 and 45 cm were significantly lower than those of the other treatments. When the row spacing was more than 60 cm, the heights of the fertile tillers no longer increased. Meanwhile, row spacing also had a highly significant impact on the diameter of fertile tillers ($p<0.01$), which became larger with the increasing of the row spacing.

The characteristics of inflorescence: Row spacing had high significant influence on the characteristics of the inflorescence, and the influence on the ear stalk length was larger than that on the ear stalk diameter of and cob length (Table 2). It was found that the ear stalk length had a synergistic effect with the height of fertile tillers, both of which augmented with the increasing row space. The cob diameter also augmented with the increasing length of the ear stalks, which provided more nutrition for the inflorescence. However, the differences of the characteristics of the ear stalks were not significant among the row spacing of 60, 75 and 90 cm. Row spacing also influenced the cobs, but when the row spacing exceeded 45 cm, the length of the cobs no longer elongated. Row spacing significantly affected the numbers of spikelets and seeds per fertile tiller, and significantly influenced the number of florets per fertile tiller ($p <0.05$). When the value of the row spacing was 60 cm, the number of spikelets reached its maximum, but the number of spikelets in the row space of 30 cm was at its minimum. When the row spacing was greater than 45 cm, no significant difference was found among the treatments. The cob was the position of the spikelets, but the number of spikelets per fertile tiller did not significantly increase with the increasing row space, and only a number of florets per spikelet increased with the increasing row space. Therefore, the number of florets per fertile tiller did not increase in size with the increasing row space. In the larger row spaces, the florets significantly affected the number of seeds per fertile tiller, but in the lower row spaces, the significance decreased. The number of tillers per square m^2 in the row space of 90 cm was smaller, and this was coupled with the emergence of seed shattering by wind at the milky stage, thus the number of seeds per fertile tiller was significantly lower than that with row spacing of 60 to 75 cm.

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Table 1: Multiple Comparison about Tillers and Ratio of Fertile Tiller in Different Row Spacing

Item	Vegetative shoots /50cm	Reproductive shoots/50cm	Tillers/50cm	Vegetative shoots/㎡	Reproductive shoots/㎡	Tillers/㎡	Ratio of fertile tiller/%
30cm	205±15.5B	160±26D	365±39C	1476±112.5A	1152±185.5A	2628±280.5A	43.66±2.28C
45cm	205±7.5B	194±9C	399±14.5BC	901±33B	854±39.5BC	1754±59.5B	48.66±1.07D
60cm	142±12C	276±7.5B	418±15B	453±39.5D	883±24B	1337±49C	66.12±2A
75cm	266±19A	290±11B	556±35A	638±57.5C	697±21.5C	1334±84C	52.28±1.78C
90cm	250±17A	355±7.5A	605±16A	501±34D	709±15C	1210±32C	58.65±1.75B
F	24.21	78.64	42.19	108.32	11.33	42.95	62.18
p	<.0001	<.0001	<.0001	<.0001	0.001	<.0001	<.0001

Note: Values in a same column with different capital letters indicate significant difference. The same below.

Table 2: Multiple Comparison on Fertile Tillers and Inflorescence Characters in Different Row Spacing

Item	Height of fertile tiller/cm	Diameter of fertile tiller/mm	Length of ear stalk/cm	Diameter of ear stalk/mm	Length of cob/cm	Ears/fertile tiller	Florets/fertile tiller	seeds/fertile tiller
30cm	95.27±1B	35.38±2.34D	30.37±2.05C	13.61±0.86B	15.8±0.08B	36.52±1.03C	95.59±13.16B	39.43±0.11C
45cm	95.6±1.55B	40.26±1.53C	36.19±1.62B	14.84±1.38B	16.98±0.1A	43.98±0.92B	113.27±6.16AB	47.84.17±3.4C
60cm	105.27±2.7A	47.34±1.63B	44.19±1.33A	16.33±0.2A	17.78±0.42A	48.38±0.88A	137±20.09A	74.58±10.01A
75cm	105.1±4.55A	50.42±0.61A	45.24±0.09A	16.5±0.09A	17.88±1A	48.08±0.21 AB	129±132.31A	73.71±1.14A
90cm	105.6±2.4A	52.45±0.8A	45.39±0.2A	16.77±0.24A	17.78±0.4A	45.94±24B	127±12.16A	65.08±2.04B
F	11.68	60.72	74.03	9.90	7.78	13.14	4.14	24.75
p	0.0009	<.0001	<.0001	0.0017	0.0041	0.0005	0.0311	<.0001

Characteristics of seed yield: Row spacing significantly influenced the setting percentage ($p<0.05$) (Table 3). The larger the row spacing was, the higher the setting percentage was. However, the difference of 1000-grain weight was not significant with the different row spacing ($p > 0.05$). Row spacing significantly influenced the presentation seed yield. When the value of the row spacing was 60 cm, the presentation seed yield reached its maximum, with the value of 2107.75 ± 151.79 kg/hm², which was significantly higher than that of the other treatments. Due to inconsistent seed maturity and strong seed shattering, the harvested seed yield was far below the presentation seed yield. When the value of the row spacing was 60 cm, the harvested seed yield reached its maximum, with the value of 1764.85 ± 119.63 kg/hm², which was significantly higher than those of the others. For the potential seed yield, no significant influence was found in the different row spacing ($p >0.05$). That is to say, the potential seed yield perm² remained stable. The restrain of water, fertilization, light, etc. brought about the differences of the presentation seed yield and harvested seed yield. Therefore, improving the ecological condition was shown to be an effective way to increase seed yield in practice.

Table 3: Multiple Comparison on Characters of Seed Yield in Different Row Spacing

Treatments	Setting percent/%	1000-seed weight/g	Potential seed yield/kg/hm²	Presentation seed yield/kg/hm²	Harvested seed yield/kg/hm²
30cm	41.88±6.03B	3.07±0.01B	3401.96±948.45AB	1390.23±220.77B	1176.33±28.15C
45cm	42.42±5.29B	3.21±0.18AB	3104.01±281.57AB	1607.54±96.77B	1426.55±103.8B
60cm	54.44±5.07A	3.22±0.15AB	3873.56±320.95A	2107.75±151.79A	1764.85±119.63A
75cm	49.51±5.04AB	3.23±0.05AB	2919.83±330.32B	1835.01±53.30B	1588.05±134.1AB
90cm	51.51±5.14A	3.32±0.06A	2985.03±182.59AB	1531.08±57.12B	1508.2±117.08B
F	3.75	2.09	1.75	15.23	10.48
p	0.0409	0.0158	0.0215	0.0003	0.0013

Correlation analysis of parameters with the different row spacing: Correlation analysis showed that row spacing mainly affected the relevant traits of the tillers and fertile tillers (Table 4), which presented a very significant negative correlation to the number of tillers per m² ($R =-0.8086$), and a significant positive correlation to the heights and diameters of the fertile tillers, as well as the lengths and diameters of the ear stalks. The correlation coefficient with the diameter of fertile tillers reached its maximum, with the value of 0.9583. Row spacing also influenced the characteristics of the inflorescence, which had a significant positive correlation with the numbers of ears, florets and seeds per fertile tiller. However, the correlation coefficient was generally lower than that of the characteristics of the fertile tillers. It is clear that row spacing had significant effects on the seed yield, because row spacing influenced the characteristics of the fertile tillers, which in turn affected the traits of the inflorescence. Partial correlation analysis (Table 5) showed the following: with the fixed row spacing, the heights of the fertile tillers (x1) had little influence on the characteristics of the branches and inflorescence, but had a significant correlation with number of seeds per fertile tiller and presentation seed yield. Plant height was the main factor affecting the setting percentage, but the diameter of fertile tillers (x2) was the main factor influencing the length of the ear stalks (x3). The ear stalk length influenced the numbers of spikelets (x7) and seeds (x10) per fertile tiller, as well as harvested seed yield (x11). Therefore, seed yield may be predicted by ear stalk length. The diameter of the ear stalks (x4) had a significant correlation with number of seeds per fertile tiller (x10) and presentation seed yield (x12).

Table 4: Correlation Analysis of Parameters in Different Row Spacing

Item		X1	X2	X3	X4	X5	X6	X7
Y	R	0.7985	0.9583	0.9037	0.8374	-0.8113	-0.8088	0.6865
	p	0.0004	<.0001	<.0001	<.0001	0.0002	0.0003	0.0047
Y	R	X8	X9	X10	X11	X12	X13	
	p	0.6194	0.6050	0.7132	0.5410	0.1876	-0.2642	

Notes:X1-Height of fertile tiller, X2-Diameter of fertile tiller, X3-Length of ear stalk, X4-Diameter of ear stalk, X5-Fertile tiller/m^2, X6-Tillers/m^2, X7-Ears per fertile tiller, X8-1000-seed weight, X9-Florets per fertile tiller, X10-Seeds per fertile tiller, X11- Harvested seed yield, X12- Presentation seed yield, X13-Potential seed yield, Y- Row space, R-Correlation coefficient, P-Confidence. The same below.

The number of fertile tillers perm^2(x5) had a significant correlation with the number of tillers perm^2(x6) and potential seed yield (x13). The number of spikelets per fertile tiller (x7) had a significant correlation with the number of florets (x9) and seeds (x10) per fertile tiller, as well as the harvested seed yield (x11). The number of seeds per fertile tiller (x10) correlated with the harvested seed yield (x11) and presentation seed yield (X12). The harvested seed yield (x11) correlated with the presentation seed yield (x12) and potential seed yield (x13).

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Table 5 Partial Correlation Analysis of Parameters in Different Row Spacing

Item	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
X1 R	1.000	0.3413	0.4573	0.4029	0.2242	0.2266	0.2892	-0.2237	0.3871	0.7301	0.4069	0.7144	0.4413
p		0.2325	0.1002	0.1532	0.4410	0.4359	0.3160	0.4420	0.1715	0.0030	0.1488	0.0041	0.1142
X2 R		1.000	0.5808	0.3629	0.0016	0.0041	0.4245	0.2951	0.2841	0.4468	0.5183	0.4738	0.2947
p			0.0295	0.2021	0.9956	0.9888	0.1303	0.3057	0.3249	0.1092	0.0576	0.0870	0.3064
X3 R			1.000	0.4795	-0.2974	-0.2937	0.8609	0.1195	0.5153	0.6814	0.6567	0.5416	0.2884
p				0.0827	0.3018	0.3082	<.0001	0.6742	0.0593	0.0073	0.0107	0.0455	0.3173
X4 R				1.000	0.1991	0.2058	0.3755	-0.4367	0.3046	0.5843	0.4811	0.5787	0.3411
p					0.4949	0.4803	0.1859	0.1185	0.2897	0.0282	0.0816	0.0302	0.2327
X5 R					1.000	0.9999	-0.3101	-0.1966	-0.0208	-0.0018	-0.0827	0.4213	0.6161
p						<.0001	0.2806	0.5008	0.9438	0.9955	0.7788	0.1335	0.0190
X6 R						1.000	-0.3071	-0.1992	-0.0186	0.0024	-0.0792	0.4247	0.6176
p							0.2856	0.4947	0.9496	0.9936	0.7878	0.1301	0.0186
X7 R							1.000	0.1635	0.6772	0.5584	0.6363	0.4160	0.4148
p								0.5766	0.0078	0.0379	0.0144	0.1390	0.1403
X8 R								1.000	-0.2542	-0.2763	-0.0448	-0.1437	-0.1109
p									0.3804	0.3389	0.8790	0.6240	0.7057
X9 R									1.000	0.7324	0.7431	0.6051	0.7374
p										0.0029	0.0023	0.0219	0.0026
X10R										1.000	0.7668	0.8784	0.5655
P											0.0014	<.0001	0.0351
X11R											1.0000	0.6822	0.5552
p												0.0072	0.0393
X12R												1.0000	0.7838
p													0.0009

DISCUSSION

Planting forage for the purpose of seed production typically involved planting using an unprotected drilling method. Choosing an appropriate row space was the best way to control the density. The optimum plant density cannot only increase seed yield and improve seed quality, it can also control the growth of weeds(Askarian *et al*, 1995, Zhang *et al,* 2008)). The choice of row spacing should be based on the type of grass growth, climate features, soil fertility, irrigation and management strength, and other factors. In particular, reasonable row space should be determined according to the specifications of agricultural machinery to specialization, scale and industrial production(Askarian et al, 1995). The test results of this study showed that the row spacing of 60 cm might produce the highest seed yield. Field production also confirmed the row spacing of 60 cm facilitated field management and mechanization operation, which is worthy of application in practice. Row spacing regulated not only the density of the plants, but also ecological factors (water, fertilizer, gas, heat, light,.), which in turn affected the environment of the plants' vegetative growth. The differences in the environment led to differences of branch traits (density of plants, height of plants, diameter of fertile tillers, ratio of fertile tillers), which significantly affected the traits of the inflorescence. Therefore, row spacing affected the traits of the seeds and seed yield. Currently, more attention has been placed on studying the components and limiting factors of seed yield, yet it is ignored that the distribution and use of ecological factors are the basic influences on seed yield. The test results show that the number of florets and potential seed yield per m^2 in the different row spacing remained stable, but there were significant differences among the presentation seed yield and harvested seed yield. These observations indicated that ecological conditions were the key to determining the formation, development and yield of the seeds. Therefore, the most effective method for the seed production potential of *E. sibiricus* L. was to strengthen the analysis of environmental factors and restrictive factors, thereby optimizing and improving the ecological factors for forage growth. Row spacing significantly affected the height and diameter of the fertile tillers, as well as the lengths and diameters of the ear stalks. In a fixed row space, plant height was the main factor affecting the setting percentage, and ear stalk length affected the number of spikelets, number of seeds and harvested seed yield. However, 1000-grain weight reacting seed fullness showed relatively stable parameters, which had and only lower relativity with other parameters. In practice, seed yield may be predicted by means of plant height and ear stalk length. The test results showed that row spacing significantly affected the seed yield. With the row spacing of 60 cm, the harvested seed yield reached its maximum, but it only had a presentation seed yield of 83.73% and potential yield of 45.56%. In field production, seed loss was very severe due to mechanical collecting and seed cleaning. In this case, the harvested seed yield only had a presentation seed yield of only 25 to 50%, and potential seed yield of 5 to 20%. The presentation seed yield was mainly decided by flowering rate, pollination rate, fertilization rate and abortion rate. However, the harvested seed yield was determined by the rate of seed shattering, consistency of maturity, level of maturity, time and method of seed harvesting, methods of processing and cleaning seed,. Therefore, in order to increase the conversion rate from potential seed yield to harvested seed yield, the entire production process must be systematically studied. Only when the technology of every link of seed production has been improved can the industrialization production of *E. sibiricus* L. and sustainable development of livestock be guaranteed.

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