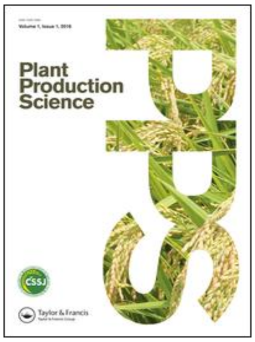

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Smooth bromegrass seed yield and yield component responses to seeding rates and row spacings in two climates

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ABSTRACT

Successful grass seed production depends on identifying a suitable environment for the species and proper agronomic practices. Previous research on many species has addressed identifying appropriate agronomic practices for grass seed production, but these studies have not evaluated the effects of environment. By conducting the same experiments in Jiuquan, China (a desert climate) and Tongliao, China (a semiarid continental monsoon climate), the effects of environment, seeding rate, row spacing and their interactions were determined for smooth bromegrass (*Bromus inermis* Leyss) seed production. Three seeding rates (.3, .5, and .7 g m^{-1} pure live seed) and four row spacings (30, 50, 70, and 90 cm) were evaluated over three years. Jiuquan had comparable seed yield (SY) and greater thousand-seed weight (TSW) than Tongliao. Three-year average SY decreased with increased row spacings at both sites. Results suggest that in both climates, successful smooth bromegrass seed production was possible, but greater TSW is predicted for desert climates with good irrigation conditions than in semiarid continental monsoon climates due to greater sunshine duration (574 h compared with 527 h) and low relative humidity during seed development (48% vs. 66%). A seeding rate of .3 g m^{-1} and a row spacing of no wider than 30 cm appears to be adequate for smooth bromegrass seed production in these research locations and in similar ecological regions around the world.

Abbreviations: Average SY: average seed yield; FS: florets per spikelet; FTD: fertile tillers density; RH: relative humidity; SFT: spikelets per fertile tiller; SS: seeds per spikelet; SY: seed yield; TSW: thousand seed weight

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Bromus inermis Leyss; row spacing; seed production; seeding rate; the Hexi Corridor

Optimal seed production of cool-season, perennial grasses require a combination of suitable environmental conditions and appropriate agronomic practices. Most perennial grasses require cool temperatures (3–21 °C, depending on the grass species) and eight or more weeks of short photoperiod (<12 h) (Bean, 1970; Cooper, 1960; Heide, 1994). During the growing season, adequate light intensity is required as decreased light intensity has negative effects on fertile tiller and floret development (Ryle, 1961). Ample precipitation in autumn and early winter is necessary for increasing fertile tillers density (FTD), closely correlated with seed yield (SY) (Wang et al., 2010). Although the importance of climatic factors have been suggested as a key factor for seed production, few studies have determined the influence on smooth bromegrass seed production.

Smooth bromegrass is an important cool-season grass widely used for pasture and hay in semiarid regions due to its drought tolerance, persistence, and productivity (Gökkuş et al., 1999; Malhi et al., 1986) and to control soil erosion due to its deep rooting and rhizomatous spreading characteristic (Vogel et al., 1996). At present, it is used mainly on roadsides, riversides, and other similar areas for erosion control in China.

Seeding rate and row spacing are known to be important factors affecting grass SY (Deleuran et al., 2010; Han et al., 2013; Simic et al., 2009; Szczepanek, 2015). These two factors may affect spatial arrangement of plants, and as a result of which SY will be influenced. It is widely recognized that plant density should be lower for seed than for forage production. Vuckovic et al. (2003) reviewed numerous investigations and concluded that the highest

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SYs of orchardgrass (*Dactylis glomerata* L.), timothy (*Phleum pretense* L.), meadow fescue (*Festuca pratensis* Huds.) and tall fescue (*Lolium arundinaceum* Schreb.) were obtained from fields sown at seeding rates of 4–8 kg ha^{-1} (.2–.4 g m^{-1} of row length). For Italian ryegrass (*Lolium multiflorum* Lam.) and perennial ryegrass (*Lolium perenne* L.), SYs were highest with sowing rates of 20 kg ha^{-1} (.4 g m^{-1} of row length). The effect of row spacing on tall fescue seed production has been investigated in the US and Canada (Fairey & Lefkovitch, 1999a, 1999b; Young et al., 1998a, 1998b). Row spacing studies also have been conducted in separate climates on red fescue (*Festuca rubra* L. var. rubra) (Fairey and Lefkovitch, 1996a, 1996b), Italian ryegrass (Simic et al., 2009), perennial ryegrass (Deleuran et al., 2009). Optimum row spacing for maximum SY varied greatly, depending on species and cultivars.

Previous research studies have examined the effect of seeding rate and row spacing on SY of smooth bromegrass (Canode, 1968; Torskenaes and Jonassen, 1995) in specific climates. However, studies have not compared SY responses those factors under different climate conditions. The objective of this field trial was to compare two seed producing regions having different climates with respect to their potential for smooth bromegrass seed production, and to examine changes in SY and its components due to changes in seeding rates and row spacings. Results now allow the development of more generalized recommendations for suitable climates and optimal agronomic practices.

Materials and methods

Site description

Field trials were conducted from August 2009 to July 2012 at the China Agricultural University Grassland Research Station in Jiuquan, Gansu Province (39°37′ N latitude, 98°30′ E longitude; asl 1480 m) and at the Research Farm of Inner Mongolia University for the Nationalities in Tongliao, Inner Mongolia (42°36′ N latitude, 122°22′ E longitude; asl 178 m). Soil types for the two areas are: Mot-Cal-Orthic Aridisols at Jiuquan and Fluventic Haplumbrept at Tongliao. Initial soil conditions for both sites are provided in Table 1. Tongliao had higher initial soil nutrient levels than Jiuquan.

There are different climate conditions between Jiuquan and Tongliao. Jiuquan in the Hexi Corridor and is characterized as a temperate, desert climate whereas Tongliao is a semiarid, continental, monsoon climate (Su et al., 2007; Zhang et al., 2012). The 30-year (1980–2010) average annual precipitation in Jiuquan is 87 mm and in Tongliao is 362 mm (CDA and NMIC, 2013). Most precipitation occurs in June, July and August at both sites. Both sites are characterized as having cold winters (lowest 30-year average monthly temperature of −8.9 in Jiuquan and −13.1 in Tongliao, CDA and NMIC, 2013) and warm summers (highest 30-year average monthly temperature of 22.2 in Jiuquan and 24.1 in Tongliao, CDA and NMIC, 2013). The 30-year average annual sunshine duration is 3053 h for Jiuquan, with 1134 h during the growing season and 3003 h for Tongliao, with 1083 h during the growing season. Compared to Tongliao, Jiuquan has a dryer growing season. The 30-year average RH from April to July is 42 and 55% in Jiuquan and Tongliao, respectively.

Precipitation and average temperatures of both sites from August 2009 to 2012 are shown in Figure 1. The highest and lowest average monthly temperatures were observed in July and December or January, respectively, depending on the site and year. The highest average monthly temperature was comparable for the two experimental sites (23.0 °C in Jiuquan and 24.7 °C in Tongliao), while the lowest temperature was higher in Jiuquan than in Tongliao (−9.8 °C and −14.7 °C, respectively). Precipitation in June and July was much higher in Tongliao than in Jiuquan over three years. Monthly sunshine duration, defined as the sum of that sub-period for which the direct solar irradiance exceeds 120 W m^{-2}, and RH from 2010 to 2012 are provide in Figure 2. There are greater monthly sunshine duration and lower RH during growing season in Jiuquan than in Tongliao from 2010 to 2012.

Experimental design and treatments

For both locations, a randomized block design was used, with three seeding rates (.3, .5, and .7 g pure live seed m^{-1} of row length, that is 76, 128, and 179 live seeds per liner meter) and four row spacing treatments (30, 50, 70, and 90 cm). Individual plots were 3 × 6 m, with 1.0 m between adjacent plots. Treatments were replicated four times creating a total of 48 plots for each location.

Crop management

Smooth bromegrass cv. Carlton was used in this experiment. Field trials were established on August 15th, 2009 in Jiuquan and August 17th, 2009 in Tongliao. Prior to sowing, 40.5 kg ha^{-1} N and 104 kg ha^{-1} P [$(NH_4)_2HPO_4$; N, 18%, P_2O_5, 46%] were broadcast and incorporated into soil. Nitrogen was distributed by hand in the rows at a rate of 6 g m^{-1}, with one-third applied in the fall and the remainder applied in the spring of the following year. That is, there are 199, 120, 85, and 66 kg ha^{-1} N applied for row spacings of 30, 50, 70, and 90 cm treatment, respectively. In 2010, 30 kg ha^{-1} P was seeded by machine along rows on May 24th and again on August 28th in Jiuquan due to the low initial soil available P.

Table 1. Chemical characteristics of the 0–30 cm soil layer in Jiuquan and Tongliao in August, 2009.

Location	pH	Organic matter (g kg^{-1})	Available P (mg kg^{-1})	Available K (mg kg^{-1})	Available N (mg kg^{-1})
Jiuquan	8.24	9.0	5.67	83.40	26.90
Tongliao	8.20	19.3	45.60	104.59	51.10

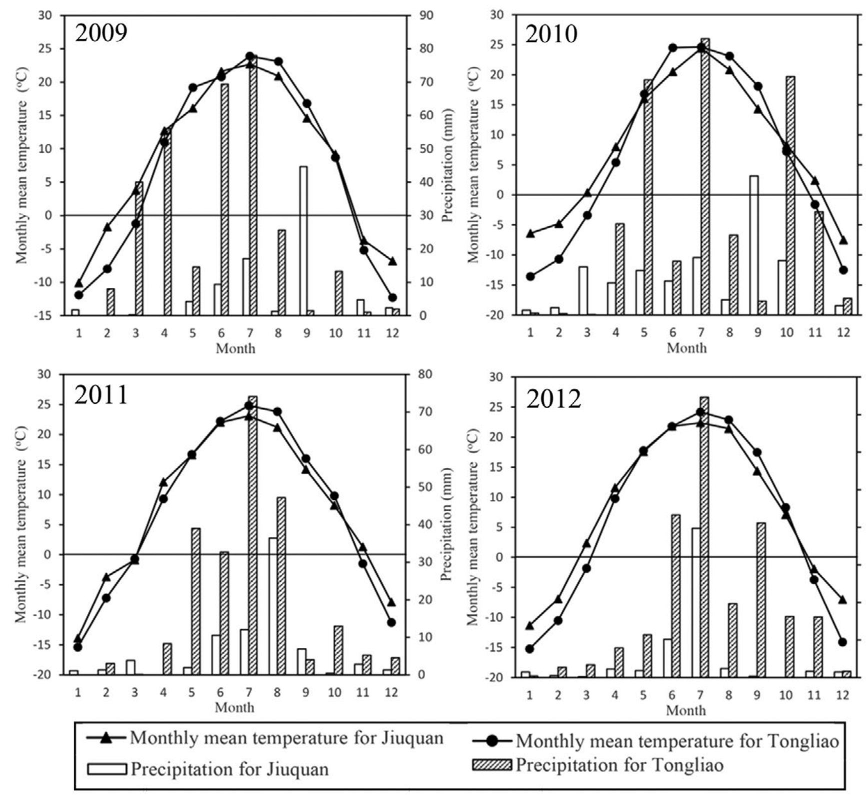

Figure 1. Monthly average temperature and precipitation in Jiuquan and Tongliao from January 2009 to December 2012.

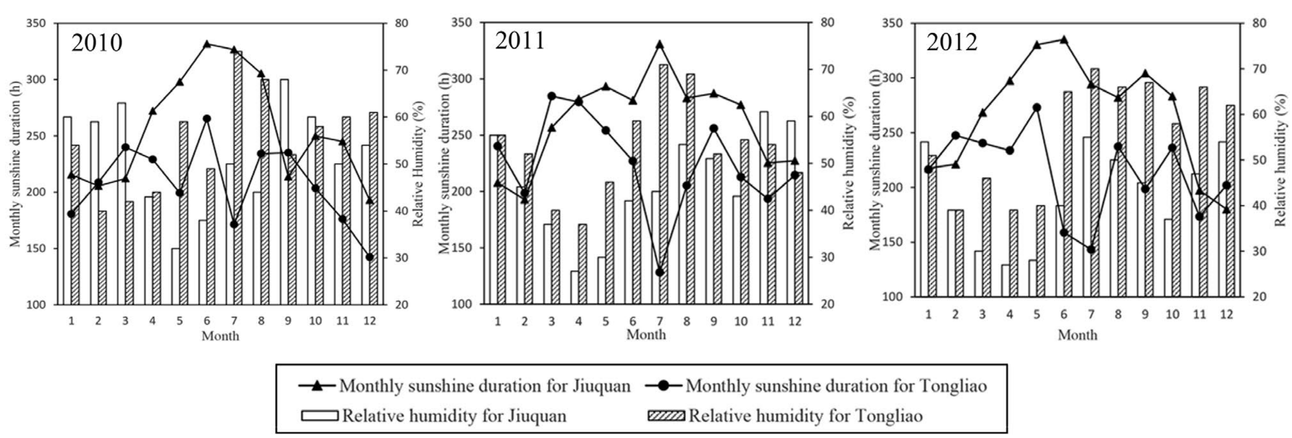

Figure 2. Monthly sunshine duration (h) and relative humidity (%) in Jiuquan and Tongliao form January 2010 to December 2012.

In 2009, plots were irrigated once immediately after sowing (90 mm) and again 2 wk later (90 mm) to ensure successful establishment. In the following years, plots were irrigated in early April, the middle of May, and early June with 90 mm in each time to provide adequate water for growth, and in late October or early November with 90 mm to ensure winter survival. In all experimental years, weeds were removed by cultivation in each row spacing at the five leaf stage and as needed thereafter.

Sampling and analyses

Data were collected from anthesis to seed harvest in 2010–2012. For SY estimation, three 1-m row samples were harvested by hand when 80% of the seed heads were ripe. Each sample was threshed, cleaned, weighed, and converted into SY (kg ha^{-1}) when seed moisture was approximately 10%. After weighing, seeds were stored in paper bags in a refrigeration at a temperature of 4 °C prior to determining thousand-seed weight (TSW).

For SY components, fertile tillers per square meter (FTD) were measured in three randomly selected .5 m row samples. Thirty fertile tillers and 30 spikelets were selected randomly to determine the number of spikelets per fertile tiller (SFT), florets per spikelet (FS), and seeds per spikelet (SS). Three randomly selected samples of cleaned seed were used from each plot to determine TSW values. To evaluate establishment, tillers per square meter were determined at both locations in late October, 2009.

Analysis of variance was conducted with SPSS Version 18 (SPSS, Chicago, IL). To avoid the potential for correlated errors for yearly repeated measurement data, a repeated measurement data analysis of variance was used to determine the effects of year, location, seeding rate, row spacing, and their interactions. In the combined analysis, year was treated as within-subjects variable, and other factors were considered between-subjects factors to determine their interactions. Duncan's new multiple range test ($p < .05$) was used to separate means with significant *F* values.

Results

Seed yield

Table 2 provides the variance test information for years, sites, seeding rates, row spacings, and their interactions. SY was influenced significantly by year, site, row spacing, and the interactions of years and sites, and years and row spacings, but was not affected by seeding rate in any year or site (data not shown).

In both sites, SY mostly decreased with increased row spacing over all experimental years, resulting in the highest

Table 2. Analysis of variance for years, sites, seeding rates, row spacings and their interaction effects on SY, FTD, SFT, FS, SS, and TSW.

Sources of variation	SY	FTD	SFT	FS	SS	TSW
Year (Y)	**	**	**	**	ns†	*
Site (S)	*	**	**	*	**	**
Seeding rate (SR)	ns	ns	ns	ns	ns	ns
Row spacing (R)	**	**	ns	*	**	**
Y × S	**	**	**	**	**	**
Y × SR	ns	ns	ns	ns	ns	ns
Y × R	**	**	ns	ns	*	ns
S × SR	ns	ns	ns	ns	ns	ns
S × R	ns	**	ns	ns	**	**
SR × R	ns	ns	ns	ns	ns	ns
Y × S × R	*	ns	ns	ns	*	ns

*$p < .05$; **$p < .01$.
†ns, not significant.

Table 3. SY as influenced by row spacings for the three experimental years (2010–2012).

Site	Row spacing	Year 2010	Year 2011	Year 2012	3-year average SY
	cm	kg ha^{-1}			
Jiuquan	30	1597a†	835a	981a	1138a
	50	1422ab	825a	842a	1030b
	70	1198bc	513b	655b	789c
	90	1103c	484b	456c	681c
	Average	1330A‡	664B	734A	909A
Tongliao	30	1946a	1336a	854a	1379a
	50	1400b	1306a	494b	1067b
	70	969c	1156ab	363c	829c
	90	837c	924b	292c	684c
	Average	1288A	1180A	501B	990A

†Means in each column, within each sites, followed by different low letters are significantly different at $p < .05$.
‡Means in average row followed by different capital letters are significantly different at $p < .05$.

three-year average SY obtained with the 30 cm row spacing (Table 3). However, SY for the 30 and 50 cm row spacing treatments was not significantly different over three years in Jiuquan. For Tongliao, increasing row spacing from 30 to 70 cm had no effect on SY in 2011. Row spacings greater than 70 cm had little influence on SY at either site.

The three-year average SYs were comparable in Jiuquan and Tongliao (Table 3). SY declined sharply in 2011 at Jiuquan and in 2012 at Tongliao, and at Jiuquan, SY was comparable in 2011 and 2012.

SY components

In late October, 2009, the highest tiller number was obtained at 30 cm row spacing treatment and decreased with increased row spacing in two experimental sites. There was high tiller number in Tongliao than Jiuquan (Table 4). FTD decreased with increased row spacing at both sites for all years (Table 5). FTD were higher at Jiuquan than Tongliao over all experimental years except 2011. Higher SFT values were obtained at Tongliao for all years; 52.6, 81.1, and 41.3% higher than at Jiuquan in 2010, 2011, and 2012, respectively (Table 6).

FS and SS increased with increased row spacings at both locations, although the responses were not significant at Tongliao (Table 7). SS values were higher at Jiuquan than at Tongliao. TSW was greater at Jiuquan for each of the three years (Table 8).

Disscussion

Seed yield

SYs have different response to year under two climates. The variation of SY with years in Jiuquan (a desert climate) was similar to results reported by Canode (1968) in which SY decreased sharply in the second seed production year but was maintained in subsequent years. However, the three-year average SYs were comparable at Jiuquan and Tongliao (Table 3). A very strong, positive correlation between SY and FTD as well as between SY and SFT was shown in many studies on growing grass for seed (Szczepanek and Onofri, 2013). The equal SY may be partly attributed to the higher FTD in Jiuquan and higher SFT in Tongliao (Tables 5, 6). Furthermore, the effect of low precipitation in Jiuquan could be offset by irrigation in growing season.

Row spacing has been shown to be an important component of optimal SY of many grasses. Simic et al. (2009) reported that in the first seed production year, a row spacing of 40 cm was optimal for SY of Italian ryegrass (*Lolium multiflorum* Lam.). For timothy (*Phleum pratense* L.), a row spacing of 24 cm had more favorable effect on forming fertile shoots and SY than 36 cm treatment (Szczepanek

Table 4. Tiller numbers determined in the late October, 2009 for Jiuquan and Tongliao.

	Site	
Row spacing	Jiuquan	Tongliao
cm	No. m^{-2}	
30	603a†	813a
50	413b	482b
70	301c	320c
90	201d	243d
Average	380B‡	465A

†Means in each column, within each sites, followed by different letters are significantly different at $p < .05$.
‡Means in average row followed by different capital are significantly different at $p < .05$.

Table 5. FTD as influenced by sites and row spacings for the three experimental years (2010–2012).

		Year			
Site	Row spacing	2010	2011	2012	Average
	cm	No. m^{-2}			
Jiuquan	30	678a†	498a	571a	618a
	50	492b	402b	382b	425b
	70	346c	284c	277c	302c
	90	270d	267c	240c	258c
	Average	474A‡	363A	368A	364A
Tongliao	30	488a	482a	385a	390a
	50	265b	358b	217b	274b
	70	150c	257c	168c	189bc
	90	134c	199c	130d	157c
	Average	209B	324A	225B	214B

†Means in each column, within each sites, followed by different letters are significantly different at $p < .05$.
‡Means in each column followed by different capital are significantly different at $p < .05$.

Table 6. Number of SFT in Jiuquan and Tongliao for the three experimental years (2010–2012).

Site	Year 2010	2011	2012	Average
	No. tiller^{-1}			
Jiuquan	34.4b†	27.5b	34.3b	32.1b
Tongliao	52.5a	49.8a	48.5a	50.3a

†Means in each column, within each index, followed by different letters are significantly different at $p < .05$.

Table 7. Number of FS and SS as influenced by row spacing in Jiuquan and Tongliao average from 2010–2012.

	Site		Site	
	Jiuquan	Tongliao	Jiuquan	Tongliao
Row spacing	FS	FS	SS	SS
cm	No. spikelet^{-1}			
30	5.8c†	5.6a	2.9b	3.4a
50	5.8bc	5.8a	3.7a	3.2a
70	6.2a	5.8a	3.9a	3.4a
90	6.1ab	5.9a	3.9a	3.5a
Average	6.0A	5.8A	3.6A	3.4A

†Means in each column followed by different letters are significantly different at $p < .05$.
‡Means in average row followed by different capital are significantly different at $p < .05$.

and KataĚska-Kaczmarek, 2012). In our experiment, three-year SY decreased with increased row spacing at both locations. This agrees with previous results that average SY decreased with increased row spacing for 11 grasses (including bromegrass) (Darwent et al., 1987).

Canode (1968) concluded that the influence of row spacing on smooth bromegrass SY was primarily in the first crop, with highest SY obtained over the three experimental years with a 60-cm row spacing. This difference from previous research reports may be partly explained by the weather-related yield components. For example, Canode (1968) reported that FTD was not influenced by row spacing, and hundred seed weight was highest with the 90-cm row spacing. In our experiment, however, FTD decreased with increased row spacing in both experimental sites (Table 5) and TSW was not influenced by row spacing (data not shown). Furthermore, the cultivation we used to control weed may have negative effect on new rhizome-formed seedlings between rows (more new seedlings appeared in wider row spacing than narrower), which may reduce SY in wider row spacing treatment.

SY components

Management practices such as row spacing, nitrogen fertility, and post-harvest residue management affect FTD (Chastain et al., 2011; Young et al., 1998b; Young et al., 1999). In this experiment, FTD decreased with increased row spacing in both experimental climates. This differs from the conclusion of Canode (1968) that row spacing did not have a significant affect on FTD. We seeded same number of seeds per liner meter in each row spacing density, as a result of which, plants per square meter was higher at narrow row spacing treatment. This is the direct reason for higher FTD in narrow row spacing treatment. FTD were higher in Jiuquan than in Tongliao in two of the three experimental years. This may be attributed to the higher winter temperature in Jiuquan than Tongliao (Figure 1), allowing more primary-induced tillers to survive over winter. For example, tiller numbers were higher at Tongliao than Jiuquan in October, 2009 (Table 4), while in 2010, Jiuquan had higher FTD than Tongliao (Table 5).

Nutrition (especially nitrogen) is important for grass spikelet development (Ryle, 1964). Our results for SFT indicate there may have been nutrition effects on smooth bromegrass spikelet development. All initial soil nutrient levels were higher at Tongliao than Jiuquan (Table 1), which may have positive effect on SFT development in Tongliao.

FS showed an increase trend with increased row spacing. This may be attributed to increased competition for assimilates between floret sites at higher tiller density resulting in reduced assimilates available for floret development (Hebblethwaite et al., 1980). Significant lodging occurred during the flowering stage at the 30 row spacing treatments at Jiuquan. This may have had a negative affect on seed development (Griffith, 2000), resulting in the decrease of SS with increased row spacing. The lower SS in Tongliao may have been due to the greater precipitation in June and July (Figure 1). This rainfall may have interfered with pollination and have caused heavy lodging during seed development, resulting in seed abortion.

Table 8. TSW as influenced by site for the three experimental years (2010–2012).

Site	Year 2010	2011	2012	Average
	g			
Jiuquan	4.06a[†]	4.28a	4.01a	4.12a
Tongliao	3.14b	3.11b	3.18b	3.14b

[†]Means in each column followed by different letters are significantly different at $p < .05$.

High seed quality is associated with higher seed weight (Grass and Burris, 1995; Trupp and Carlson, 1971). Although the three-year SY for smooth bromegrass was comparable for Jiuquan and Tongliao, TSW for seed produced at Jiuquan was significantly higher than that produced at Tongliao. This may be explained by the greater sunshine duration (574 h; average value from 1980 to 2010) and lower RH (48%) in June and July in Jiuquan compared with Tongliao (527 h and 66% RH; average values from 1980 to 2010). Thus, seed produced in Jiuquan may be of higher quality than that from Tongliao.

Conclusions

Compared with Tongliao, there is comparable SY and higer TSW in Jiuquan. Increasing the seeding rate within each row spacing treatment had no influence on smooth bromegrass SY. Seeding rates of .3 g m^{-1} pure live seed and 30 cm row spacing were sufficient for highest SY in these research locations and in similar ecological regions around the world.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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