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

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
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$^{-1}$ (0.2–0.4 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$^{-1}$ (0.4 g m$^{-1}$ of row length). The effect of row spacing on tall fescue seed production has been investigated in the US and Canada (Young et al., 1998a, 1998b; Torskenaes and Jonassen, 1995). Row spacing studies have also 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., 2007; Zhang et al., 2012). The 30-year (1980–2010) 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.

**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.

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**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$_4$)$_2$HPO$_4$; N, 18%, P$_2$O$_5$, 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.
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

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.
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)             | *   | **   | **   | *   | **  | ns  |
| Seeding rate (Sr)    | ns  | ns   | ns   | ns  | ns  | ns  |
| Row spacing (r)      | **  | ns   | *    | ns  | **  | **  |
| Y × S                | **  | **   | **   | ns  | **  | **  |
| Y × Sr               | ns  | ns   | ns   | ns  | **  | ns  |
| Y × r                | **  | ns   | ns   | ns  | ns  | ns  |
| S × Sr               | ns  | ns   | ns   | ns  | ns  | ns  |
| S × r                | ns  | ns   | 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 | 2010          | 2011          | 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 $p < .05$. 

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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.
than at Tongliao. TSW was greater at Jiuquan for each of the three years (Table 8).

**Discussion**

**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 2013). The 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).

| Table 4. Tiller numbers determined in the late October, 2009 for Jiuquan and Tongliao. |
|---|
| **Row spacing** | Jiuquan | Tongliao |
| **Site** | **No. m⁻²** | **No. m⁻²** |
| cm | | |
| 30 | 603a | 813a |
| 50 | 413b | 482b |
| 70 | 301c | 320c |
| 90 | 201d | 243d |
| Average | 380B | 465A |

| Table 5. FTD as influenced by sites and row spacings for the three experimental years (2010–2012). |
|---|
| **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 | 168b | 189bc |
| 70 | 150c | 257c | 168c | 189bc |
| 90 | 134c | 199c | 130d | 157c |
| Average | 209B | 324A | 225B | 214B |

1. Means in each column, within each sites, followed by different letters are significantly different at p < .05.
2. Means in average row followed by different capital are significantly different at p < .05.
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 effect 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.

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
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 higher 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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quality. I. Seed germination and seedling vigor. *Canadian Journal of Plant Science*, 75, 821–829.

Griffith, S. M. (2000). Changes in dry matter, carbohydrate and seed yield resulting from lodging in three temperate grass species. *Annals of Botany*, 85, 675–680.

Han, Y., Wang, X., Hu, T., Hannaway, D. B., Mao, P., Zhu, Z., ... Li, Y. (2013). Effect of row spacing on seed yield and yield components of five cool-season grasses. *Crop Science*, 53, 2623–2630.

Hebblethwaite, P. D., Wright, D., & Noble, A. (1980). Some physiological aspects of seed yield in *Lolium perenne* L. (perennial ryegrass). In P. D. Hebblethwaite (Ed.), *Seed production* (pp. 71–90). London: Butterworths.

Heide, O. H. (1994). Control of flowering and reproduction in temperate grasses. *New Phytologist*, 128, 347–362.

Malhi, S., McBeath, D., & Baron, V. (1996). Effects of nitrogen application on yield and quality of bromegrass hay in central alberta. *Canadian Journal of Plant Science*, 66, 609–616.

Ryle, G. (1961). Effects of light intensity on reproduction in S.48 timothy (*Phleum pratense* L.). *Nature*, 191, 196–197.

Ryle, G. (1964). The influence of date of origin of the shoot and level of nitrogen on ear size in three perennial grasses. *Annals of Applied Biology*, 53, 311–323.

Simic, A., Vuckovic, S., Maletic, R., Sokolovic, D., & Djordjevic, N. (2009). The impact of seeding rate and inter-row spacing on Italian ryegrass for seed in the first harvest year. *Turkish Journal of Agriculture and Forestry*, 33, 425–433.

Su, Y. Z., Zhao, W. Z., Su, P. X., Zhang, Z. H., Wang, T., & Ram, R. (2007). Ecological effects of desertification control and desertified land reclamation in an oasis–desert ecotone in an arid region: A case study in Hexi Corridor, northwest China. *Ecological Engineering*, 29, 117–124.

Szczepanek, M. (2015). Emergence and seed yield of redtop as affected by row spacing and sowing rate. *Acta Agriculturae Scandinaea Section B-Soil and Plant Science*, 65, 537–543.

Szczepanek, M., & Katańska-Kaczmarek, A. (2012). Response of timothy (*Phleum pratense* L.) cultivars to growing in diversified row spacing. *Acta Scientiarum Polonorum Agricultura*, 11, 63–72.

Szczepanek, M., & Onofri, A. (2013). Chewing, strong, and slender creeping red fescue response to sowing time and method. *Crop Science*, 53, 2613–2622.

Torskenaes, E., & Jonassen, G. H. (1995). Seeding rate and row width in seed production of smooth bromegrass (*Bromis inermis* Leyss.). *Norsk Landbruksforsking*, 9, 59–64.

Trupp, C. R., & Carlson, I. T. (1971). Improvement of seedling vigor of smooth bromegrass (*Bromus inermis* Leyss.) by recurrent selection for high seed weight. *Crop Science*, 11, 225–228.

Vogel, K. P., Moore, K. J., & Moser, L. e. (1996). Bromegrasses. In L. e. Moser, D. R. Buxton, & M. D. Casler (eds.), *Cool-season forage grasses* (pp. 535–567). Madison, WI: ASA, CSSA, SSSA.

Vuckovic, S., Simic, A., Cupina, B., Stojanovic, I., & Stanisavljevic, R. (2003). The effect of vegetation area size on grass seed yield. *Journal of Agricultural Sciences, Belgrade*, 48, 125–134.

Wang, J. F., Xie, J. F., Zhang, Y. T., Gao, S., Zhang, J. T., & Mu, C. S. (2010). Methods to improve seed yield of *Leymus chinensis* based on nitrogen application and precipitation analysis. *Agronomy Journal*, 102, 277–281.

Young, W. C., III, Mellbye, M. e., & Silberstein, T. B. (1999). Residue management of perennial ryegrass and tall fescue seed crops. *Agronomy Journal*, 91, 671–675.

Young, W. C., III, Youngberg, H. W., & Silberstein, T. B. (1998a). Management studies on seed production of turf-type tall fescue: I Seed yield. *Agronomy Journal*, 90, 474–477.

Young, W. C., III, Youngberg, H. W., & Silberstein, T. B. (1998b). Management studies on seed production of turf-type tall fescue: II Seed yield components. *Agronomy Journal*, 90, 478–483.

Zhang, G., Dong, J., Xiao, X., Hu, Z., & Sheldon, S. (2012). Effectiveness of ecological restoration projects in Horqin Sandy Land, China based on SPOT-VGT NDVI data. *Ecological Engineering*, 38, 20–29.