PLANT-TYPE CHARACTERISTICS AND SEED YIELD OF PROSO MILLET (*PANICUM MILIACEUM* L.) RESPONSE TO PLANT DENSITY

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ABSTRACT

Yield of proso millet was usually low due to chaotic planting density in arid and semi-arid areas of China. To get high yield in proso millet, planting density and plant-type characteristics were explored. This study was carried out in the field to determine the effects of planting density (30, 45, 60, 75 and 90×10⁴ plants ha⁻¹) on plant-type characteristics and yield components. With an increment in planting density, panicle length, grain weight per panicle, grain density, total grain, plant height, panicle height, and stalk length increased. When planting density was increased 15×10⁴ plants ha⁻¹ at a time, rolling rate was increased by about 0.04, but leaf basic angle and dropping angle decreased by about 0.3° and 0.28°. Bender moment, anti-broken strength decreased with an increment in planting density, but anti-lodging index increased. Bender moment of three basic nodes decreased by about 1140, 1041, and 1024 cm g, and anti-broken strength of three basic nodes decreased by about 2240, 1664, and 907 g. The first node, the second node, and the third node increased lodging index by about 3.3, 3.5, and 4.8 cm g g⁻¹, respectively. Increase in planting density of proso millet could obtain the highest yield at 75×10⁴ plants ha⁻¹, and plant-type characteristics of high-yielding population was good for yield development.

KEY WORDS

Individual traits, different population, proso millet, optimal density.

Plant-type characteristics, including leaf basic angle, dropping angle, rolling rate, bender moment, anti-broken strength, and lodging index were the basic traits of a high yield population (Feng *et al.*, 2013). These traits could help to evaluate anti-lodging ability of crop populations. Some literatures (Hoshikawa and Wang, 1990; Ookawa and Ishihara, 1992) suggested effect of plant density on plant-type characteristics. Oilseed rapes could increase leaf area, branches, and pod numbers per plant at low densities, produce higher quantity of bigger fruit cluster branches at increasing plant density (Shujie *et al.*, 2012), and be susceptible to lodging and disease (Leach *et al.*, 1999). Moreover, higher density led to leaf senescence during the seed-filling stage (Egli *et al.*, 2005; Liu *et al.*, 2008), thinner maize stems (Tokatlidis *et al.*, 2010), taller but thinner banana plants (Ndabamenye *et al.*, 2013), shorter fruit length, fruit girth and bunch mass (Robinson, 1996), and detrimental effect on photosynthetic capacity and yield.

Proso millet (*Panicum miliaceum* L.) is one of the most important food grains and grown up to over an area of about 50 million ha as a dry-against crop in the northwest regions of China (Qu *et al.*, 2012, 2020). Proso millet was harvested at a production rate of 100 million Mg, and over 90 percent of proso millet was consumed by locals in this region (Chao *et al.*, 2014). Nowadays, lodging at higher densities and low yield at lower densities was happened commonly due to grower experience. Moreover, disordered plant density had passive effect on planting positive and yield of proso millet. Obtaining high crop economic yield per unit area depended on crop, environmental conditions, and agronomic traits (López-Bellido *et al.*, 2005; Hiltbrunner *et al.*, 2007; Dong *et al.*, 2010; Ciampitti and Vyn, 2011; Gisela *et al.*, 2012), and agronomic traits were impact on crop plant density. In this study, optimal planting density of proso millet with high yield and obtaining plant-type characteristics were explored for improving production management and yield.

The aim of this study was undertaken to a) evaluate proso millet yield and plant-type characteristics in different plant density; b) obtain optimal plant density of proso millet; c) obtain plant-type characteristics in high-yielding population through a field experiment during three growing seasons continually.

MATERIALS AND METHODS OF RESEARCH

Description of the experiment. Experiments were conducted at Fugu, Shaanxi province (39.09° N, 111.01° E and altitude 1000 m) in 2010-2012. Climate characteristics of experiments site were: annual mean precipitation of 366.2 mm, mean annual temperature of 9.1 °C, average annual pan evaporation of 1092.2 mm, average annual sunshine of 2890 h and 177 frostless days. Soil type is calcic cambisols and soil samples (0-20 cm) were collected before sowing. Then, analysis of the top soil obtained the following results: organic C content of 17.32 g kg⁻¹, nitrate N content of 1.5 g kg⁻¹, available P content of 6.7 mg kg⁻¹, available K content of 92 mg kg⁻¹, ammonium N (NH₄⁺+NO₃⁻) content of 46.3 mg kg⁻¹, and soil bulk density of 1.53 g cm⁻³.

Experimental design. In this study five planting densities were used, as: M1 (30×10⁴ plants ha⁻¹), M2 (45×10⁴ plants ha⁻¹), M3 (60×10⁴ plants ha⁻¹), M4 (75×10⁴ plants ha⁻¹), and M5 (90×10⁴ plants ha⁻¹). The experiments were laid out in a factorial completely randomized design with three replications, and plot area was 10 m² (2 m×5 m). The entire experimental area was ploughed after all fertilizers (34.5 N kg ha⁻¹, 9.0 P₂O₅ kg ha⁻¹) were incorporated into the soil surface (Plough depth: 20 cm), and fertilizing amount was controlled by a conventional method. The cultivar “Yumi 2” of proso millet were sown on 11 June and harvested on 25 September in 2010, sown on 12 June and harvested on 23 September in 2011, and sown on 15 June and harvested on 27 September in 2012, respectively. During three growing seasons, proso millet was managed according to a conventional way from growers, no irrigation.

Sampling and harvest. In mature, plants of each plot (1 m², 1 m×1 m) were sampled to determine the yield components and seed yield per plant. Then following measurements and observations on individual traits were done, as: panicle length, primary branch, secondary branch, grain weight per panicle, and total grains. Especially, culm and sheath were oven-dried at 70 °C for 72 h and measured their dry weight. The residual plants of each plot were carefully harvested to access seed yield.

In panicle stage, size and leaf posture of the top-most three leaves from 20 plants plot⁻¹ randomly was measured. Leaf basic angle is the angle between main stem and leaf base, and leaf dropping angel is the angel between main stem and the line of pulvinus and leaf tip. Then, the formula of dropping angel follows:

$$\text{Dropping angel (}^{\circ}\text{)} = \text{Leaf dropping angel (}^{\circ}\text{)} - \text{Leaf basic angle (}^{\circ}\text{)}$$

The width of top-most three leaves was measured at flattening and natural of leaf. And the formula of rolling rate follows:

$$\text{Rolling rate} = \text{the width of leaf flattening (cm)} / \text{the width of leaf natural (cm)}$$

Plant height, culm length, internodes length, culm wall thickness and culm diameter of low-most three nodes were measured at the milk stage, and anti-broken strength was evaluated according to the report by Li *et al.* (2009). Then, formula of lodging index follows:

$$\begin{aligned} \text{Bender moment (cm g)} &= \text{the length between internodes base and plant top (cm)} \times \text{the fresh weight} \\ &\quad \text{between internodes base and plant top (g)} \\ \text{Lodging index (cm g g}^{-1}\text{)} &= \text{Bender moment (cm g)} / \text{Anti-broken strength (g)} \end{aligned}$$

All data were presented as the mean value of three replicates. Variance and differences of treatments were separated using the test of Tukey's multiple range at $P \leq 0.05$.

RESULTS OF STUDY

Panicle and yield. Panicle length, grain weight per panicle, grain density, and total grain decreased when grown with proso millet at high densities, and these traits decreased by about 0.5 cm, 0.5 g, 1.3 grain cm⁻¹, and 32 grains panicle⁻¹ per increment 15×10⁴ plants ha⁻¹. Branch, No. of primary branch, secondary branch, and seed-setting rate was decreased with increment in planting densities (Table 1). Seed yield of proso millet first increased then declined with increment at planting densities in different growing seasons (Table 1). Although rainfall was difference in tested seasons, yield at 75×10⁴ plants ha⁻¹ was higher than that of other densities. Increasing 15×10⁴ plants ha⁻¹ at a time increased seed yield by about 202.6 kg ha⁻¹ within 75×10⁴ plants ha⁻¹.

Table 1 – Yield and panicle traits of population with different densities

Year	Density	PL (cm)	GWPP (g)	GD (grain/cm)	TG	Primary branch			Secondary branch			Yield (kg ha ⁻¹)	Lodging (Yes/No)
						NB	TGpb	SSR (%)	NB	TGsb	SSR (%)		
2010	M1	33.3 b	8.7 b	31.7 c	1087.0 e	13.5 a	743.0 a	94.0 a	31.0 a	344.0 e	86.3 a	4266.9 e	No
	M2	34.9 a	9.0 a	31.9 c	1125.0 d	13.8 a	745.0 a	93.7 a	31.7 a	380.0 d	86.1 a	4533.6 d	No
	M3	35.5 a	9.2 a	34.4 b	1150.0 c	13.9 a	747.0 a	93.1 a	32.0 a	403.0 c	85.7 a	4666.9 c	No
	M4	35.7 a	9.5 a	34.5 b	1173.0 b	13.8 a	751.0 a	92.7 a	32.1 a	422.0 b	85.1 a	4934.6 a	No
	M5	35.9 a	9.7 a	35.2 a	1212.0 a	13.9 a	754.0 a	91.2 a	32.4 a	458.0 a	84.2 a	4733.6 b	Yes
2011	M1	30.3 a	6.7 b	27.6 d	837.0 e	9.7 b	642.0 b	90.2 a	24.8 a	195.0 e	84.3 a	1836.8 b	No
	M2	30.9 a	7.2 b	29.1 c	900.0 d	10.2 a	645.0 b	89.3 a	25.0 a	255.0 d	83.2 a	2016.8 a	No
	M3	31.0 a	7.5 b	29.9 c	926.0 c	10.8 a	647.0 b	89.1 a	25.7 a	279.0 c	82.1 a	2073.5 a	No
	M4	31.4 a	7.8 b	31.1 b	975.0 b	11.0 a	652.0 a	88.9 a	26.0 a	323.0 b	81.4 a	2093.1 a	No
	M5	31.7 a	9.0 a	35.5 a	1125.0 a	11.6 a	658.0 a	88.0 a	26.4 a	467.0 a	81.0 a	2033.4 a	Yes
2012	M1	40.0 b	9.1 b	27.7 b	1137.0 b	10.8 b	802.0 b	94.1 a	30.0 a	335.0 c	87.5 a	3906.9 e	No
	M2	40.8 ab	9.7 a	30.0 a	1198.0 a	10.9 a	804.0 b	93.3 a	30.2 a	394.0 b	86.4 a	4270.2 d	No
	M3	41.3 ab	10.0 a	30.5 a	1219.0 a	10.9 a	807.0 b	92.4 a	30.6 a	412.0 a	86.1 a	4883.6 c	No
	M4	42.6 ab	10.2 a	30.7 a	1229.0 a	11.2 a	812.0 ab	91.2 a	30.7 a	417.0 a	85.2 a	5473.6 a	No
	M5	43.7 a	10.5 a	30.9 a	1240.0 a	11.4 a	819.0 a	91.0 a	30.9 a	421.0 a	83.6 a	4910.3 b	Yes

Note. Means with different letters are statistically difference at 0.05 probability level. PL, panicle length; GWPP, grain weight per panicle; GD, grain density; TGpb, total grains of primary branch; TGsb, total grains of secondary branch; NB, No. of branches; SSR, seed-setting rate.

Morphological characteristics of top-most three leaves and leaf number. Significant interaction was found between leaves per plant and plant density (Table 2). After heading, leaves per plant decreased gradually. In rainy growing season (2010 and 2012), the number of leaves plant⁻¹ at high densities was higher than that of low densities. In dry growing season (2010), the number of leaves plant⁻¹ at high densities was lower than that of low densities.

Table 2 – No. of green leaves in main stem at different days after heading in different yield populations

Years	Density	Heading	10DAH	20DAH	30DAH	Maturity
2010	M1	8.0	7.0	5.2	3.1	2.9
	M2	8.0	7.2	5.6	3.3	3.0
	M3	8.0	7.3	5.9	3.6	3.2
	M4	8.0	7.6	6.1	3.7	3.3
	M5	8.0	7.8	6.3	4.0	3.5
2011	M1	8.0	6.0	4.6	3.0	2.5
	M2	8.0	6.1	4.8	3.2	2.7
	M3	8.0	6.4	5.1	3.4	2.9
	M4	8.0	6.5	5.3	3.8	3.0
	M5	8.0	6.7	5.8	4.0	3.1
2012	M1	8.0	6.8	5.0	3.2	2.7
	M2	8.0	7.0	5.1	3.3	3.0
	M3	8.0	7.1	5.6	3.7	3.1
	M4	8.0	7.4	5.9	3.9	3.4
	M5	8.0	7.8	6.1	4.1	3.7

Note. DAH: days after heading.

Length of top-most three leaves increased with the increment in plant density of proso millet, but leaves width decreased (Table 3). Rolling rate increased when plant density increased, increasing 15×10⁴ plants ha⁻¹ at a time increased rolling rate by about 0.04, and leaf basic angle and dropping angle decreased by about 0.3° and 0.28°.

Culm traits. Increment in planting density was found to have a significant effect on culm traits. Plant height, panicle height, and stalk length increased when plant density rose up.

Height of gravity center and relative gravity center for high density had a rise trend compared with that of low density (Table 4a), and both traits increased by about 1 cm and 0.7% with increment in plant density. Top internodes length, including the first node, the second node, and the third node, increased when plant density of proso millet increased. PNIPH and NISL had a similar trend in the same condition (Table 4b) and increased by about 0.8% and 1.5% with increment 15×10^4 plants ha^{-1} at a time. Dry weight of culm, sheath, and per unit internodes had a reducing trend when plant density increased (Table 5).

Table 3 – Size and leaf posture of the top-most three leaves in different densities

Leaf position	Density	Length (cm)	Width (cm)	Rolling rate	Leaf basic angle ($^{\circ}$)	Dropping angle ($^{\circ}$)
The first leaf to top	M1	42.4 c	1.8 e	1.3 c	8.5 a	2.8 a
	M2	43.2 bc	2.2 d	1.4 b	8.2 a	2.3 b
	M3	43.9 bc	2.5 c	1.4 b	7.9 a	2.1 b
	M4	44.2 b	2.8 b	1.4 b	7.4 ab	1.9 bc
	M5	45.1 a	3.1 a	1.5 a	7.1 b	1.7 c
The second leaf to top	M1	35.6 c	1.5 a	1.3 b	11.2 a	4.4 a
	M2	35.8 c	1.7 ab	1.3 b	11.0 a	4.1 b
	M3	36.2 ab	2.1 ab	1.4 a	10.7 b	3.8 c
	M4	36.5 ab	2.3 ab	1.4 a	10.2 b	3.7 c
	M5	37.0 a	2.5 a	1.4 a	10.0 b	3.6 c
The third leaf to top	M1	43.2 c	1.9 c	1.27 c	13.5 a	5.4 a
	M2	44.1 ab	2.1 b	1.30 abc	13.1 a	5.1 a
	M3	44.6 a	2.5 ab	1.32 ab	12.8 b	4.9 b
	M4	45.1 a	2.7 a	1.36 a	12.5 b	4.5 bc
	M5	45.8 a	2.8 a	1.40 a	12.1 b	4.1 c

Table 4a – Culm traits in different densities

Years	Density	Plant height (cm)	Panicle height (cm)	Stalk length (cm)	Gravity center height (cm)	Relative gravity center height (%)
2010	M1	140.8 e	106.1 d	74.1 c	78.2 c	44.5 c
	M2	141.7 d	108.1 c	74.4 c	78.5 c	44.6 b
	M3	144.7 c	110.2 b	75.7 b	79.3 b	45.2 ab
	M4	146.8 b	111.6 b	76.4 b	79.4 b	45.9 a
	M5	151.6 a	114.0 a	77.4 a	81.2 a	46.4 a
2011	M1	95.3 e	65.9 d	36.5 a	51.4 c	46.1 c
	M2	96.4 d	66.5 d	36.6 a	51.8 bc	46.3 bc
	M3	98.4 c	67.4 c	36.4 a	52.1 b	47.1 b
	M4	101.2 b	68.9 b	36.9 a	52.4 b	48.2 a
	M5	105.2 a	70.9 a	37.6 a	54.6 a	48.3 a
2012	M1	152.4 e	121.4 e	89.4 b	85.2 d	44.1 c
	M2	157.1 d	123.1 d	90.1 ab	87.5 c	44.3 c
	M3	167.8 c	127.8 c	90.8 ab	89.9 b	46.4 b
	M4	169.4 b	130.5 b	91.6 a	90.5 ab	46.6 ab
	M5	174.4 a	132.4 a	92.2 a	91.7 a	47.4 a

Table 4b – Culm traits in different densities

Years	Density	Top internodes length (cm)			PNIPH (%)	NISL (%)
		First node	Second node	Third node		
2010	M1	14.6 d	20.5 e	24.7 d	47.4 b	43.2 d
	M2	14.9 c	21.3 d	24.9 d	47.5 b	45.2 c
	M3	15.1 bc	22.3 c	25.6 bc	47.7 b	45.5 c
	M4	15.4 b	22.8 b	25.9 b	48.0 a	46.1 b
	M5	15.7 a	23.4 a	26.7 a	48.9 a	47.3 a
2011	M1	14.1 c	19.8 e	23.4 d	61.7 d	80.5 e
	M2	14.3 bc	20.3 d	23.2 d	62.0 c	81.7 d
	M3	14.6 b	21.1 c	24.6 c	63.0 b	85.2 c
	M4	14.9 a	22.1 b	24.9 b	63.5 b	86.7 b
	M5	15.1 a	22.7 a	25.2 a	64.3 a	88.6 a
2012	M1	14.8 d	21.3 e	25.6 d	41.3 d	35.8 e
	M2	15.1 cd	22.3 d	25.8 d	42.6 c	36.6 d
	M3	15.4 c	23.2 c	26.0 c	45.9 b	40.7 c
	M4	15.7 b	23.6 b	26.3 b	45.9 b	42.5 b
	M5	16.1 a	24.5 a	26.7 a	47.1 a	43.6 a

Note. PNIPH, sum of panicle and neck internodes/ plant height; NISL, neck internode/stalk length.

Table 5 – Dry weight in different densities

Years	Density	Dry weight of culm (g stem ⁻¹)	Dry weight of sheath (g stem ⁻¹)	Dry weight per unit internodes (g cm ⁻¹)
2010	M1	3.81 e	1.38 e	0.0700 b
	M2	3.91 d	1.51 d	0.0728 b
	M3	4.20 c	1.62 c	0.0769 b
	M4	4.43 b	1.78 b	0.0813 a
	M5	4.91 a	1.94 a	0.0885 a
2011	M1	2.63 e	1.12 e	0.1027 d
	M2	2.82 d	1.25 d	0.1112 c
	M3	3.10 c	1.41 c	0.1239 b
	M4	3.51 b	1.68 b	0.1407 a
	M5	3.69 a	1.84 a	0.1471 a
2012	M1	4.12 e	1.68 c	0.0649 c
	M2	4.43 d	1.76 b	0.0687 c
	M3	4.89 c	1.91 ab	0.0749 b
	M4	5.12 b	2.01 a	0.0778 b
	M5	5.34 a	2.13 a	0.0810 a

Lodging index. Increment in plant densities had a significant impact on culm length, culm diameter, and culm wall thickness. When plant density increased, culm length increased, but culm diameter and culm wall thickness decreased (Table 6).

Figure 1 – Bender moment, anti-broken strength, and lodging index in different densities

Table 6 – Physical lodging characteristics of the basal internodes in different densities
(Mean values of test years)

	Density	First node	Second node	Third node
Culm length (cm)	M1	4.80 b	9.80 e	14.60 c
	M2	5.10 ab	10.20 d	15.10 bc
	M3	5.30 ab	11.30 c	15.80 b
	M4	5.50 a	12.10 b	16.10 a
	M5	5.60 a	13.20 a	16.40 a
Culm diameter (cm)	M1	1.15 a	1.12 a	1.12 a
	M2	1.10 b	1.08 b	1.05 b
	M3	1.00 c	0.94 c	0.94 c
	M4	0.98 d	0.95 c	0.94 c
	M5	0.95 e	0.93 c	0.91 d
Culm wall thickness (mm)	M1	1.04 a	1.00 a	0.99 a
	M2	0.97 b	0.95 b	0.94 b
	M3	0.96 bc	0.95 b	0.92 c
	M4	0.94 bc	0.92 bc	0.90 d
	M5	0.92 c	0.90 c	0.88 e

Bender moment decreased with moving up in plant densities, and bender moment of the first node was the highest than that of others, and then that of the second node (Fig.1a). Bender moment decreased by about 1140, 1041, 1024 cm g with three basic nodes of the first, the second, and the third, respectively when plant density increased 15×10^4 plants ha^{-1} at a time. Anti-broken strength had a similar trend with that of bender moment (Fig.1b) and decreased by about 2240, 1664, 907 g with three basic nodes of the first, the second, and the third, respectively. Lodging index reduced when plant density increased, and lodging index of the first node was the lowest than that of others, and then that of the second node (Fig.1c). When plant density increased 15×10^4 plants ha^{-1} at a time, the first node, the second node, and the third node increased lodging index by about 3.3, 3.5, 4.8 cm g g^{-1} , respectively.

DISCUSSION OF RESULTS

Yield components. Yield components were affected by an increment in planting densities, especially individual level. Some increments, as panicle length and total grains, could increase the final seed yield per unit area with optimum planting population (Ciampitti and Vyn, 2011). Panicle length, grain weight per panicle, grain density, and total grain of present study decreased with increment in planting density, and plant density of 75×10^4 plants ha^{-1} obtained high seed yield lastly. Some literatures (Momoh and Zhou, 2001; Kwa *et al.*, 2005) showed that some traits of individual level decreased with increment in planting density but increase in yield with maximum planting population per unit area. In another study, increase seed yield might be attributed to the greater number of main stems per unit area (Hiltbrunner *et al.*, 2007), root stems (Mohd *et al.*, 2013) or pod number of oilseed rape (Yasari *et al.*, 2008). In this study, yield components of proso millet were decreased by a few ranges when plant density increased, but high yield was obtained at optimal plant density. The reason was that increase density to some extent was an effective means to increase the seed yield of proso millet by greater number of main stems per unit area (Dong *et al.*, 2010; Lin *et al.*, 2009) and suitable level per plant productivity.

Characteristics of culm and leaves. Characteristics of culm were difference with increment in plant density (Tahir *et al.*, 2015). Plant height of proso millet increased with increasing in plant density, and similar results were applied in panicle height and stalk length. In this study, increment in plant height and decrement in culm diameter and culm wall thickness at high density attributed to sunlight, water and nutrition competition of individual level within the population (Amanullah *et al.*, 2009; Awan *et al.*, 2014). Leaves per plant after heading evaluated photosynthetic (Chauhan *et al.*, 2011), and leaves per plant diminished with increment in planting density in this study. But if rainfall was enough, as in 2010 and 2012, leaves per plant at high densities were higher than that of low densities. This result indicated that decrease soil evaporation at high plant density might save soil water enough from limited

rainfall in arid and semi-arid regions (Eberbach *et al.*, 2005; Chen *et al.*, 2010), especially in rainy seasons, which was benefit on proso millet growth and yield development; if not, high densities might be premature senescence resulted from competition from soil water.

Anti-lodging ability. Anti-lodging ability was the basic of population of high yield (Norberg *et al.*, 1988). The coordination of individual level and population size was necessary for obtaining a high yield. In this study, plant-type characteristics, as leaf basic angle, dropping angel and rolling rate, evaluated individual level of proso millet with increment in plant density. Then anti-lodging ability, as gravity center height, bender moment, anti-lodging strength and anti-lodging index, evaluated characteristics of population lodging in different planting densities. At high plant density, higher gravity center height, bender moment, anti-lodging strength and lodging index indicated that anti-lodging ability of proso millet decreased with increment in plant density, suggested increment of lodging risk due to unhealthy root growth or weak stem (Cardwell, 1982; Esechie, 1992). Moreover, higher rolling rate, lower leaf basic angle, and dropping angle indicated that plant-type of proso millet at high density was slim and upper leaves as a response to light and nutrition competition within the population (De Raïssac *et al.*, 2004).

Plant density and environment. The optimal plant density with high yield population relied on cultivars (Tokatlidis, 2013) and environments (Tokatlidis *et al.*, 2011). In this study, proso millet was planted in arid and semi-arid regions of China, and rainfall was a key factor for the increment in yield. The plant density of 90×10^4 plant ha^{-1} was lodging continuously in tested seasons, but yield at 75×10^4 plant ha^{-1} was higher than that of others and no lodging. This reason might be that high plant density within some range increased mulching of soil surface, reduced soil surface radiation (Papadopoulos and Pararajasingham, 1997), improved crop evapotranspiration, and reduced soil water evaporation. Moreover, plant height of 140-160 cm, panicle height of 100-110 cm, leaf basic angle of $8-10^\circ$, and 75 plants m^{-2} might be a rational plant-type structure with a high yield of proso millet in semi-arid and arid areas.

CONCLUSION

P. miliaceum yield was the highest at a plant density of 75×10^4 plants ha^{-1} with a rational plant-type structure of plant height of 140-160 cm, panicle height of 100-110 cm, leaf basic angle of $8-10^\circ$, and 75 plants m^{-2} .

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