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ASSESSMENT OF YIELD, AGRONOMIC TRAITS AND NUTRITIVE VALUE OF SORGHUM VARIETIES GROWN ON HIGHLY SALINE-ALKALI SOIL

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Abstract

Soil salinity is a crucial abiotic stress severely affecting crops production worldwide. Dual-purpose sorghum (Sorghum bicolor (L.) Moench) is a major source of livestock feed and has great potential for phytoremediation of saline soils. Eight sorghum varieties (N5D61, A60, 4264, 2562, GT2012, F438, 2168 and F968) were evaluated based on their agronomic traits and forage nutritive values as a phytoremediation strategy in a highly saline-alkali soil of the Hetao Irrigation District. Yield, biomass, plant height, stem diameter, leaf number, leaf area as well as crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF) contents varied significantly among varieties at different growth stages. The grain yield of A60 (2.16 Mg ha^{-1}) was higher (p<0.05) than that of 4262, 2562, F438, 2168, and F968. The maximum plant biomass was observed in F968 (15.3 Mg ha^{-1}) and 2562 (14.9 Mg ha^{-1}) varieties compared with other seven varieties at heading and harvest stages, respectively. The CP contents of A60 (6.51%) and N5D61 (4.07%) were higher than other varieties (2.51-3.63%) at the heading stage. The accumulation levels of CP (3.59%) at the heading stage were higher than that (3.25%) at harvest. The variety N5D61 had higher NDF (68.53%) and ADF (37.76%) contents at heading, whereas, at harvest, the response of A60 (NDF, 63.53%; ADF, 35.18%) was best, compared to other varieties. The highest relative forage value (RFV) was observed for Guotian2012 (118.4 and 126.6 at heading and harvest). Ultimately, the production of salt-tolerant crops, such as sorghum, is possible with the use of subsurface pipes in the Hetao Irrigation District.

Key words: Sorghum varieties; Soil salinity; Growth stage; Agronomic traits; Forage nutritive value; Subsurface pipe.

Introduction

Saline-alkali land covers a substantial amount of the potential arable land resources (Huang *et al*., 2019). Soil salinization affects over 8.3 × 10^{8} ha of the world's soil (Zhu *et al*., 2018), which covers over 25% of total land area and 40% of irrigated land (Huang *et al*., 2018), and the area is continuously increasing every year. This problem is more prevalent in arid and semiarid regions across the globe due to the intense evaporation and insufficient rainfall in these areas and has been considered the major cause of declining crop productivity (Dai *et al*., 2011; Juhaimi *et al*., 2019). The Hetao Irrigation District of northwest China is usually characterized as saline, which has been a major constraint to the agricultural productivity in this region (Tong *et al*., 2015). The shallow depth (~1.2-2.6 m) and saline groundwater (salinity 1.5-1.8 g L^{-1}) was determined for this site (Zhao *et al*., 2016). This also increases the risk of secondary soil salinization, likely via capillary rise (Yin *et al*., 2015). These lands can be used for cultivation by considering hyper accumulative crop like sorghum, which is crucial for maintaining soil health and addressing food security and fulfilling forage needs.

Sorghum is a cereal crop well known for its high sugar and starch content and grown to produce food, feed, and biofuel in many regions throughout the world (Glamoclija *et al*., 2011; Juhaimi *et al*., 2019). China is rich in sorghum cultivar sources, with over 1500 varieties (Fan *et al*., 2013). However, some sorghum varieties have low yield and biomass production, thus restricts their utilization. Several studies have reported that sorghum has high digestible nutrients, which are beneficial in dairy production (Ward *et al*., 2001; Amer *et al*., 2012; Alix *et al*., 2019). Resent research has shown that forage dry matter yields for sorghum (17.5 Mg ha^{-1}) are comparable to those of corn (*Zea mays* L.) (15.9 Mg ha^{-1}) (Dos *et al*., 2014; Alix *et al*., 2019).

Sorghum is also a salt, cold and drought-tolerant crop that can easily adapt to low-input environmental conditions (Kaplan *et al*., 2019). Sorghum is rated as moderately salt tolerant compared with other cereals (Lamm *et al*., 2007; Merrill *et al*., 2007; Lyons *et al*., 2019), with a soil EC threshold of 6.8 dS m^{-1} (Lewis *et al*., 2019), and can produce notable yields due to its well-developed root system (Li *et al*., 2010; Tari *et al*., 2013). Therefore, sorghum is recognized as a potential phytoremediation plant for saline-alkali soils and has been introduced on saline lands in North China (Han *et al*., 2011). According to Han *et al*., (2011), sorghum cultivation is considered a significant biological measure for improving saline-alkali lands. Moreover, significant differences were observed in the sorghum tolerance to high salinity due to genotypic differences among varieties (Gill *et al*., 2003; Almoderes *et al*., 2007; Fan *et al*., 2013). Thus, sorghum may be a candidate plant for the restoration of salinized regions. The cultivation of sorghum on saline soils with minimal inputs and maximum yields is currently the best way to relieve land source crises and forage scarcities (Han *et al*., 2011). However, sorghum yield is lower on highly saline lands. Therefore, modification of the soil salt content is necessary for sorghum cultivation and land utilization. So far, there is insufficient information on the agronomic traits and forage nutritive value of sorghum under subsurface pipe cultivation in highly saline-alkaline soils (Haj & Bouri, 2018).

Generally, crude protein, acid detergent fibre and neutral detergent fibre are indices of forage quality (Chen *et al*., 2015; Liu *et al*., 2016; Jia *et al*., 2017; Ameen *et al*., 2019). All of these are crucial factors for the production of sorghum forage. To develop the cultivation of sorghum under highly saline-alkali soil, farmers have focused on yield and forage quality. Developing new varieties of sorghum with high dry matter and neutral detergent fibre contents has become an important agronomic target. However, agronomic traits, yield and forage nutrition for sorghum varieties are influenced by geographical positions and climate condition. In this study, we planted eight sorghum varieties in the heavy saline-alkali land of Hetao Irrigation Region, Wuyuan City, China, in order to select the efficient varieties for food and feed for this area. The postulated hypothesis was that different sorghum varieties differ in agronomy traits and nutritive values impact on highly saline-alkali soil. Therefore, the objectives of this study were to evaluate the effects of variety and growth stage on (1) agronomic traits and biomass yield and (2) forage nutritive value of sorghum.

Materials and Methods

Research region and site characterization: The Hetao Irrigation District (latitude N40°11′~41°23′, longitude E106°10′~109°30′), one of the three largest irrigation districts, is situated in the western areas of the Inner Mongolia Autonomous Region, China. The total land area is near 1.1×10^6 ha, of which approximately 5.7×10^5 ha is under irrigation, and 5.3×10^5 ha could be utilized for cropland. Approximately 73.6% of the irrigated land is characterized by saline-alkali soil. The irrigation water supplied by the Yellow River and the annual water diversion volume was approximately 5×10^9 m^3 (Zhao *et al*., 2016). The area is classified as having a typical arid continental climate, with cold winters and dry summers. The mean annual temperature in the region is 8.1°C. The annual precipitation and evapotranspiration are approximately 150 mm and 2100 mm, respectively (Fig. 1).

The field experiment site had a sorghum monocropping system and was situated in Wuyuan Country, Inner Mongolia, China. The groundwater table was at 1.4 m, with an average salt concentration of 5.3 ms cm^{-1}. The soil at the experimental site was silty loam with an initial pH of 8.6 and contained 10.3 g kg^{-1} of organic matter, 56.2 mg kg^{-1} of available N, 81.7 mg kg^{-1} of available P and 8.4 mg kg^{-1} of available K in the 0-20 cm soil layer (Table 1).

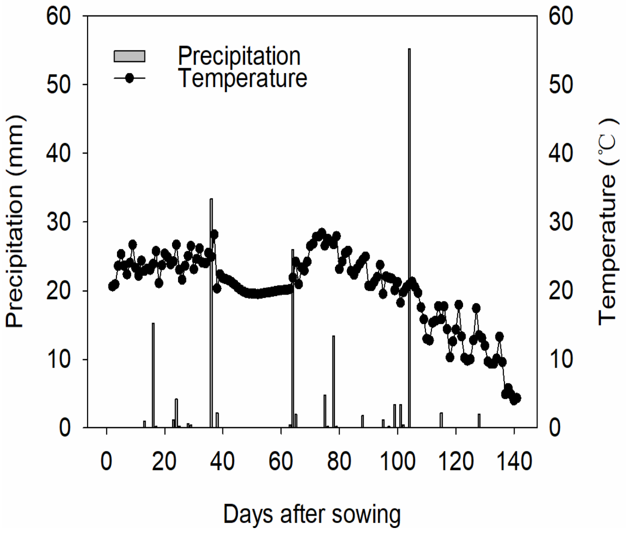

Fig. 1. Daily precipitation and temperature during the sorghum growing period in 2018.

Experimental setup and field management: A surface pipe system was installed at the field experiment site to control irrigation and drainage and thus decrease the salinity in June 2017 (Fig. 2). The drain with a surface pipe length of 80 m and a 0.7‰ slope was installed at depths of 1.4 and 1.8 m. The perforated pipe had a diameter of 100 mm. To prevent clogging with sediment, the filter material was embedded. The experimental plots received 375 kg ha^{-1}, 300 m^3 ha^{-1}, 22.5 Mg ha^{-1}, 600 kg ha^{-1}, and 15 Mg ha^{-1} of humic acid, fine sand, manure, compound fertilizer, and desulphurization gypsum before ploughing. The soil was ridged with a deep vertical rotary tillage machine to a depth of ~50 cm. Then the soil was covered in high density polyethylene film. The saline-alkali soil was irrigated with 400 mm of irrigation water from the Yellow River before planting, and never irrigation during the sorghum growing season except rainfall.

The field experiment was conducted in June 2018 using eight sorghum varieties, N5D61, A60, 4264, 2562, GT2012, F438, 2168 and F968, and a randomized complete block design. The N5D60, A60 and Guotian2012 varieties exhibited early maturity (100 days). The 4264, 2562, F438, 2168 and F968 varieties exhibited late maturity (114 days) (Table 2). Each sorghum variety had four replications, so that a total of 32 subplots were assigned in the study. Each subplot covered an area of 8 m × 4 m. Plants were sown on June 7 in 2018. Basal fertilizer of 225 kg ha^{-1} diammonium phosphate was applied before sowing. 315 kg ha^{-1} urea was applied at the jointing stage. Sorghum was sown at a row spacing of 60 cm and a density of 83333 plants per hectare (Fig. 2).

Table 1. Soil physiochemical characteristics.

Soil depth (cm)	Soil bulk density (g cm^{-3})	Olsen P (mg kg^{-1})	Available K (mg kg^{-1})	Available N (mg kg^{-1})	Soil organic matter (g kg^{-1})	Ion content (mg kg^{-1})							
						pH	Na^+	K^+	Mg^{2+}	Ca^{2+}	HCO_3^{2-}	Cl^-	SO_4^{2-}
20	1.67	8.9	256.7	39.8	12.7	7.55	4050	40.3	517.2	540.1	420	420	4160
40	1.69	7.8	201.7	33.8	11.0	7.68	3851	28.9	599.7	385.5	460	460	4730
60	1.40	7.4	164.5	19.9	8.5	7.72	1365	15.8	128.8	150.1	450	450	1350
80	1.43	6.8	141.7	25.2	8.1	7.48	1267	15.5	128.3	176.5	460	460	1260

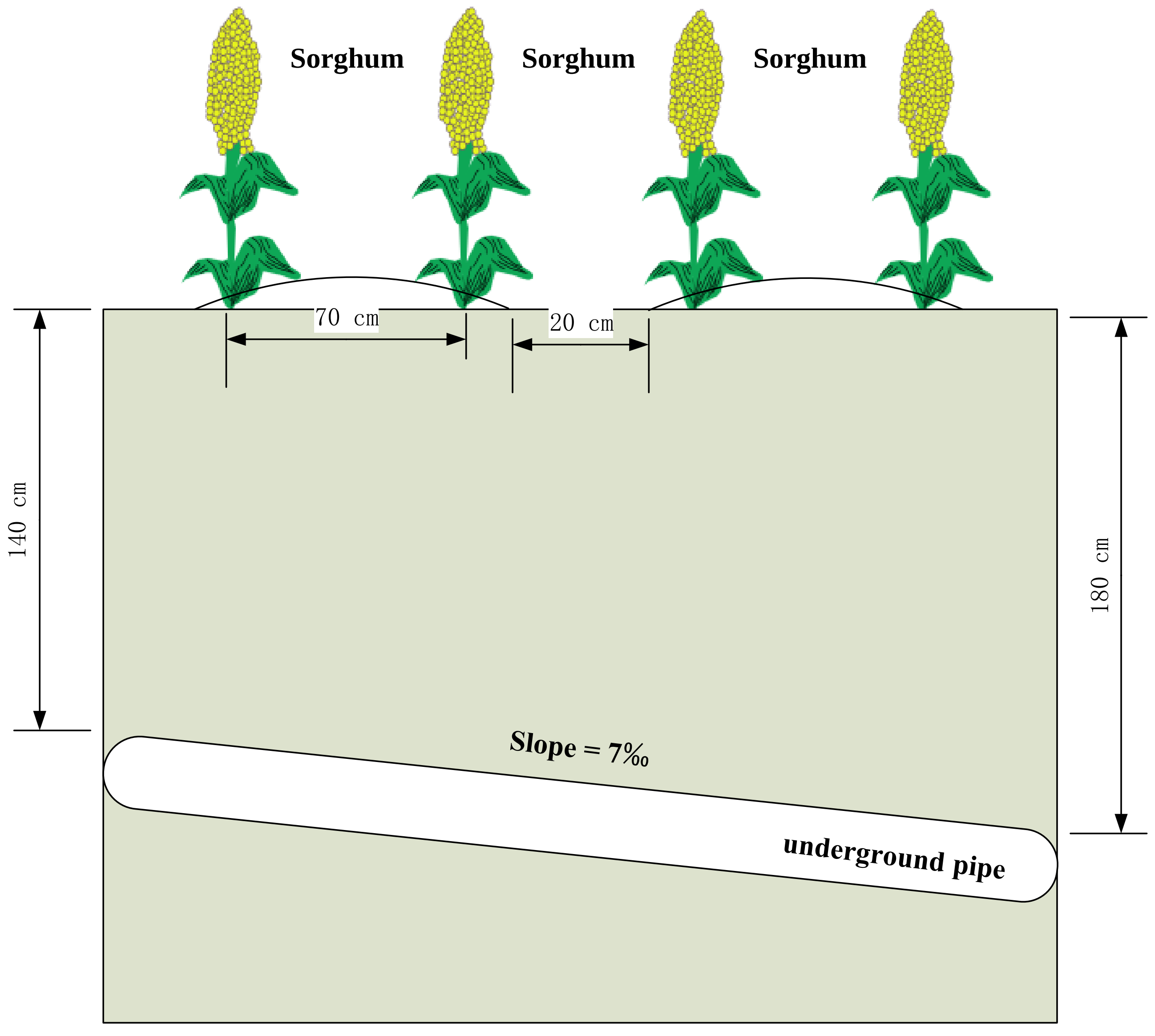

Fig. 2. A sketch of the plot with the underground pipe.

Table 2. Growth period of different varieties of sorghum.

Variety	Seeding date	Seeding	Jointing	Heading	Maturity	Growth period (day)
N5D61	2018.06.07	2018.06.20	2018.07.07	2018.08.13	2018.09.15	100
A60	2018.06.07	2018.06.20	2018.07.07	2018.08.13	2018.09.15	100
4264	2018.06.07	2018.06.20	2018.07.07	2018.09.05	2018.09.29	114
2562	2018.06.07	2018.06.20	2018.07.07	2018.09.05	2018.09.29	114
Guotian2012	2018.06.07	2018.06.20	2018.07.07	2018.08.20	2018.09.15	100
F438	2018.06.07	2018.06.20	2018.07.07	2018.09.05	2018.09.29	114
2168	2018.06.07	2018.06.20	2018.07.07	2018.09.15	2018.09.29	114
F968	2018.06.07	2018.06.20	2018.07.07	2018.09.05	2018.09.29	114

Sampling and measurements: The aboveground parts of six sorghum plants were collected from each plot after 40, 60 and 80 days. Each plant was divided into roots, stems, leaves and panicles for biomass analysis in 2018. Each aboveground plant portion was cut into 10 cm long pieces. The plant samples were oven dried at 70°C for 24 h to a constant weight for calculation of their biomass. Then, they were ground through a 1 mm sieve for composition analysis.

To observe the changes in plant growth between sorghum varieties, six plants were chosen from each plot, and their height was measured using a steel ruler on days 40, 60 and 80. The stem diameter was measured using a digital Vernier caliper, and the chlorophyll content in the leaf was measured using a SPAD Chlorophyllmeter (SPAD-502Plus; Minolta, Japan). Soil physiochemical characteristics were determined with conventional methods (Anon., 1995).

The contents of crude protein (CP), acid detergent fibre (ADF) and neutral detergent fibre (NDF) in the plant samples obtained at the heading and harvest stages were determined. The CP content was assayed by the Kjeldahl method (Anon., 1980). The ADF and NDF contents were determined following the procedure of Van Soest *et al*., (1991).

The relative feed value (RFV) was calculated by Rohweder *et al*., (1978) using the following formula:

$$\text{DMI} = \frac{120}{\text{NDF}} \quad (1)$$

$$\text{DDM} = 88.9 - 0.779 \times \text{ADF} \quad (2)$$

$$\text{RFV} = \text{DMI} \times \frac{\text{DDM}}{1.29} \quad (3)$$

where *DDM* refers to the digestible dry matter (%), *DMI* refers to the dry matter intake (%); *NDF* refers to the neutral detergent fibre (%), and *ADF* refers to the acid detergent fibre (%).

Data analysis

All the data were initially collected and analysed with Excel 2016. Statistically significant differences between treatments were determined by least significant difference (LSD) tests at $P = 0.05$ in the analysis of variance (ANOVA) procedure using SAS 8.0 for Windows (SAS Institute, Cary, NC). All graphical material was prepared using Sigmaplot 12.5 (Systat Company, USA). Student's t-tests were used to compare the sorghum biomass variables among the different varieties and growth stages using JMP 10 statistical software (Anon., 2012).

Results

Changes in agronomic traits: The cumulative trends of the sorghum growth parameters (plant height, stem diameter and SPAD) at 40, 60 and 80 days after planting showed significant difference (Fig. 3). The variety 4264 (66 cm, 15.9 mm, 8 and 219.0 cm^2) showed a markedly ($p<0.05$) higher plant height, stem diameter, leaf number and leaf area than the other four varieties (A60, F438, 2168 and F968) at the jointing stage. However, F968 showed minimum values than the other three varieties (N5D61, 4262 and 2562). In addition, 4262 had the highest stem diameter at the heading (22.0 mm) and harvest stages (21.8 mm).

The highest chlorophyll contents of 38.8 were observed for 2562 at the jointing stage (Fig. 4), and minimum were observed in N5D61. Chlorophyll contents continuously decreased from the jointing stage onward. Additionally, significant differences were observed among all varieties at each growth stage. From heading to harvesting, sharp decrease in SPAD contents was observed.

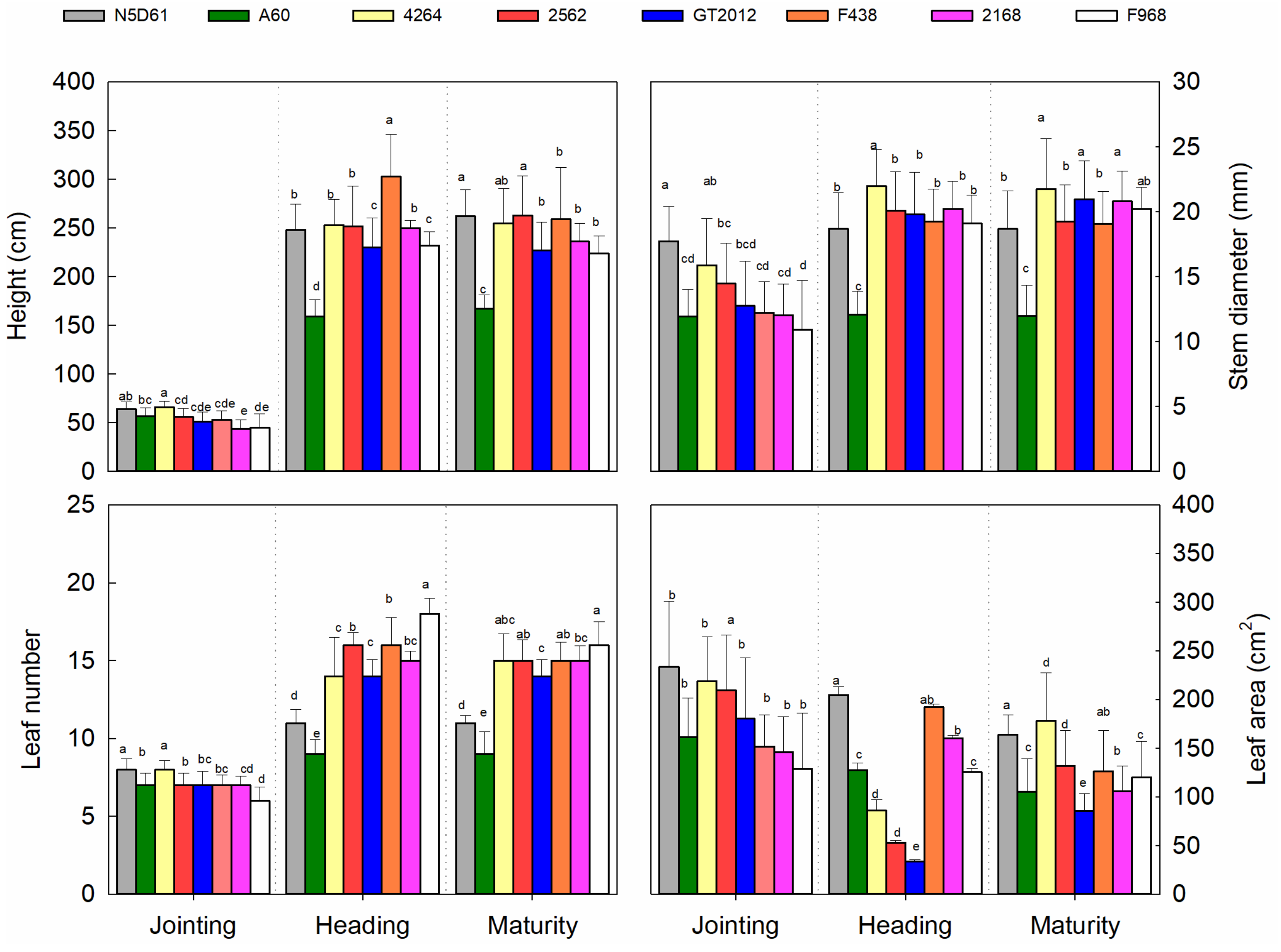

Fig. 3. Dynamic changes in plant height, stem diameter, leaf number and leaf area of eight cultivars at different sampling times in 2018. Different lowercase letters indicate significant differences among varieties at $p<0.05$. The vertical bars denote the standard deviation.

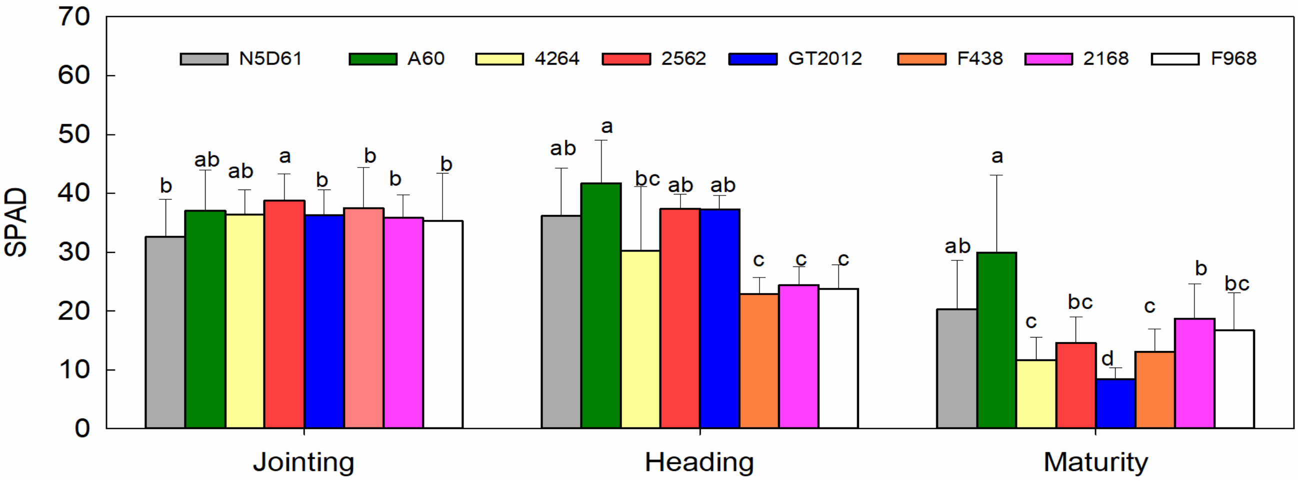

Fig. 4. Dynamic changes in the SPAD values of eight cultivars at different sampling times in 2018. Different lowercase letters indicate significant differences among varieties at $p<0.05$. The vertical bars denote the standard deviation.

Table 3. Sorghum seed and biomass (above ground) yields as affected by variety and growth stage (t ha^{-1}).

Variety	Seed	Biomass		
		Jointing stage	Heading stage	Harvest stage
N5D61	1.95 ± 0.57a	1.37 ± 0.39a	7.64 ± 1.58d	6.45 ± 1.15cd
A60	2.16 ± 0.68a	1.03 ±0.42a	4.35 ± 0.51e	4.83 ± 0.74d
4264	0.82 ± 0.26b	1.40 ± 0.49a	12.96 ± 3.01ab	12.31 ± 2.13ab
2562	0.78 ± 0.21b	1.32 ± 0.28a	10.87 ± 1.50bc	14.89 ± 3.34a
Guotian2012	1.81 ± 0.21a	1.08 ± 0.24a	10.75 ± 1.01bc	14.03 ± 3.25a
F438	0.73 ± 0.25b	0.83 ± 0.17a	12.00 ± 2.24b	12.61 ± 2.75ab
2168	0.56 ± 0.33b	0.78 ± 0.38a	8.97 ± 3.47cd	9.41 ± 2.97bc
F968	0.594 ± 0.28b	0.76 ± 0.29a	15.32 ± 1.49a	12.89 ± 3.68ab
ANOVA				
Cultivars (C)			NS	
Growth stage (G)			*	
C*G			NS	

Values with different lowercase letters within the same column differ significantly at $p<0.05$
NS, non-significant.
* Significant at the 0.05 level of probability

Table 4. Nutritive value of eight sorghum varieties at two growth stages (%).

Variety	Heading			Harvest		
	CP	NDF	ADF	CP	NDF	ADF
N5D61	4.07 ± 0.75b	68.53 ± 1.00a	37.76 ± 2.31a	4.47 ± 1.00 a	56.69 ± 4.18 b	27.36 ± 2.19 b
A60	6.51 ± 1.06a	57.49 ± 4.19bc	35.43 ± 0.99ab	3.20 ± 0.75 ab	63.53 ± 4.32 a	35.18 ± 1.05 a
4264	3.63 ± 0.37bc	60.01 ± 4.96b	32.56 ± 2.21abc	3.23 ± 0.51 ab	60.43 ± 2.78 ab	34.60 ± 1.05 a
2562	3.09 ± 0.28cd	62.91 ± 3.99b	32.74 ± 7.86abc	2.56 ± 0.42 b	60.66 ± 3.80 ab	34.11 ± 2.37 a
Guotian2012	3.04 ± 0.27cd	51.73 ± 3.01c	29.83 ± 0.93bc	4.21 ± 1.89 ab	50.03 ± 0.89 c	26.76 ± 1.04 b
F438	2.51 ± 0.19d	60.69 ± 1.28b	33.59 ± 0.78abc	2.66 ± 0.52 b	59.62 ± 2.86 ab	33.05 ± 2.62 a
2168	2.54 ± 0.24d	52.89 ± 1.30c	28.80 ± 0.67c	2.95 ± 0.34 ab	56.59 ± 3.56 b	29.32 ± 1.53 b
F968	3.33 ± 0.22bcd	54.13 ± 2.25c	31.07 ± 0.25bc	2.70 ± 0.40 b	61.35 ± 3.36 ab	33.48 ± 3.10 a
Average	3.59 ± 1.29	58.55 ± 5.66	32.72 ± 2.93	3.25 ± 0.72	58.61 ± 4.17	31.73 ± 3.39
CV	35.9	9.7	8.9	21.2	7.1	10.7

Values with different lowercase letters within the same column differ significantly at $p<0.05$. CP, NDP and ADP are crude protein neutral detergent fiber and acid detergent fiber, respectively, from sorghum at different growth periods

Sorghum yield: Sorghum biomass showed significant variation among varieties during the three growing seasons (Table 1). In 2018, the changes in the sorghum biomass were small till the jointing stage, ranging from 0.76 to 1.40 Mg ha^{-1}. Thereafter, the biomass increased rapidly until harvest, especially in F968 and 2562. These differences were significant. The biomass of A60 was minimum compared to other sorghum varieties, and the differences were significant at the harvest stage, except for the variety N5D51.

The highest seed yield of sorghum was observed for the A60 variety (2.16 t ha^{-1}) (Table 3). The seed yield of 2168 was the lowest. Compared to the 4264, 2562, F438, 2168 and F968 varieties, the seed yield of N5D61 increased 58.0%, 60.2%, 62.7%, 71.2%, respectively. The seed yield of A60 was 62.1%, 64.1%, 66.3%, 74.0% and 72.5% higher than yields from 4264, 2562, F438, 2168 and F968, respectively. However, there were no significant differences in the seed yields among the varieties N5D61, A60 and Guotian2012, respectively.

Feed value of sorghum: Maximum and minimum CP contents were found at heading stage in A60 (6.51%) and F438 (2.51%), respectively. At harvest stage, F438 and N5D61 had the lowest CP (2.66%) and highest CP (4.47%) contents, respectively.

Maximum NDF values were observed in N5D61 variety. At the heading stage, the NDF values of N5D61, A60, 4264, 2562, Guotian2012, F438, 2168 and F968 were 68.65%, 57.49%, 60.01%, 62.91%, 51.73%, 60.69%, 52.89% and 54.13%, respectively, and at harvest, the corresponding values were significantly decreased to 4.47%, 3.20%, 3.23%, 2.56%, 4.21%, 2.66%, 2.95% and 2.70%, respectively.

The four sorghum varieties showed significantly different ADF contents. Maximum ADF contents recorded in N5D61 were 37.76%, which were much higher than those of Guotian2012 (7.93%), 2168 (8.96%) and F968 (6.69%), at the heading stage. At harvest, the ADF content of A60 was higher than that of N5D61, Guotian2012 and 2168. Guotian2012 had the lowest ADF content (26.76%). The ADF content of 4262 was 4.77%, 5.80% and 3.53 higher than those of N5D61, Guotian2012 and 2168, respectively.

The levels of CP, NDF, and ADF were higher at the heading stage than at the harvest stage (Figs. 5-7). The CP contents of A60 (0.64%) and N5D61 (0.40%) were significantly (p<0.05) higher than those of the other five varieties at the heading stage, except for that of 4262. Afterwards, N5D61 also showed a significantly higher CP accumulation (p<0.05) than F968, F438, and 2562. The accumulation of NDF in N5D61 was 1.09-1.33 times higher than that in the other seven varieties at the heading stage (p<0.05). The highest accumulation of NDF was observed for the A60 variety at harvest. N5D61 had the highest ADF accumulation (3.73%), being significantly higher than that in the other varieties, except for that of F968 and F438 at harvest.

Relative forage value: Significant differences were found among varieties for DMI, DDM, and RFV from heading to harvest (Table 5). The DMI and RFV of Guotian2012 were the highest compared with those of the other varieties at heading and harvest stages. However, for the DDM, 2168 (66.5%) showed significantly (p<0.05) higher values than N5D61 and A60 at heading stage. The DDM of Guotian2012 at harvest was significantly higher than that of A60, 4264, 2562, F438, and F968. The highest RFV was observed for Guotian2012.

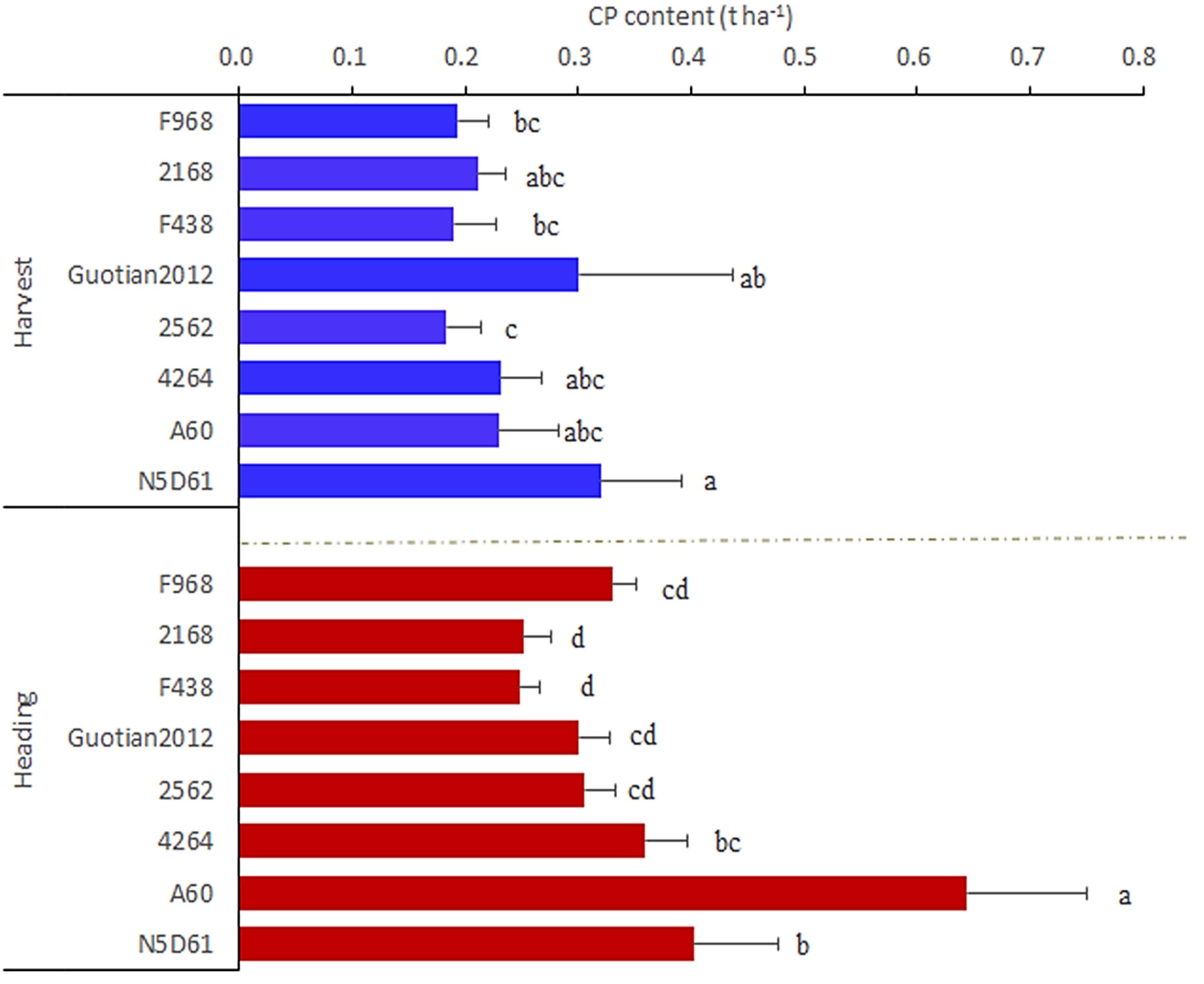

Fig. 5 Dynamic changes in SPAD among eight cultivars at different sampling times in 2018. Different lowercase letters indicate significant differences among varieties at p<0.05. The vertical bars denote the standard deviation.

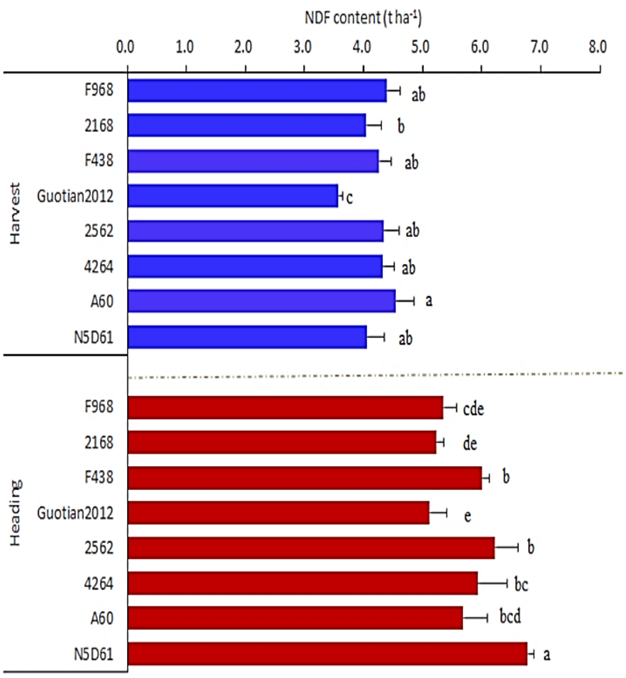

Fig. 6 Dynamic changes in SPAD among eight cultivars at different sampling times in 2018. Different lowercase letters indicate significant differences among varieties at p<0.05. The vertical bars denote the standard deviation.

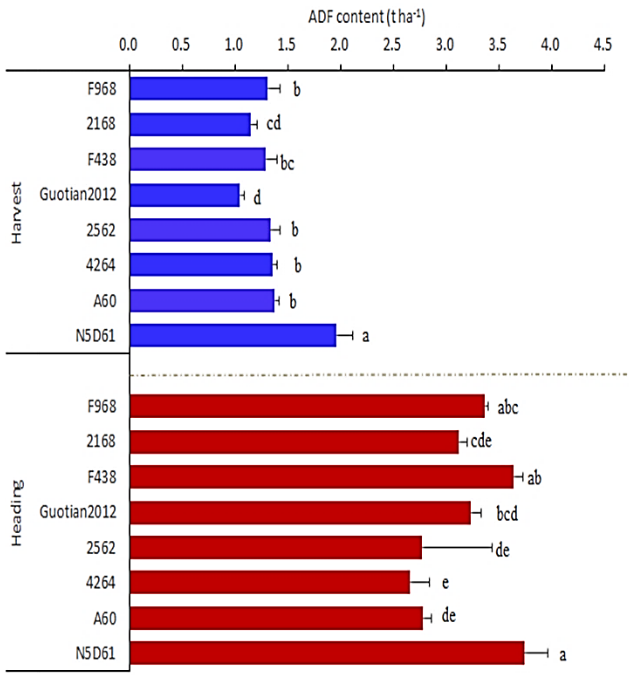

Fig. 7. Dynamic changes in SPAD among eight cultivars at different sampling times in 2018. Different lowercase letters indicate significant differences among varieties at p<0.05. The vertical bars denote the standard deviation.

Table 5. Relative forage value of seven sorghum varieties.

Variety	Heading			Harvest		
	DMI (%)	DDM (%)	RFV	DMI (%)	DDM (%)	RFV
N5D61	1.8 ± 0.0d	59.5 ± 1.8c	80.8 ± 3.6d	2.1 ± 0.2b	67.6 ± 1.7a	111.5 ± 11.1b
A60	2.1 ± 0.2bc	61.3 ± 0.8bc	99.6 ± 8.5bc	1.9 ± 0.1c	61.5 ± 0.8b	90.4 ± 7.4d
4264	2.0 ± 0.2c	63.5 ± 1.7abc	99.1 ± 10.9bc	2.0 ± 0.1bc	61.9 ± 0.8b	95.5 ±5.7cd
2562	1.9 ± 0.1cd	63.4 ± 6.1abc	94.4 ± 15.1cd	2.0 ± 0.1bc	62.3 ± 1.8b	96.0 ± 8.9cd
Guotian2012	2.3 ± 0.1a	65.7 ± 0.7ab	118.4 ± 8.2a	2.4 ± 0.0a	68.1 ± 0.8a	126.6 ± 3.8a
F438	2.0 ± 0.0c	62.7 ± 0.6abc	96.2 ± 3.0bc	2.0 ± 0.1bc	63.2 ± 2.0b	98.8 ± 7.9bcd
2168	2.3 ± 0.1ab	66.5 ± 0.5a	117.0 ± 3.8a	2.1 ± 0.1b	66.1 ± 1.2a	109.0 ± 8.8bc
F968	2.2 ± 0.1ab	64.7 ± 0.2ab	111.3 ± 5.0ab	2.0 ± 0.1bc	62.8 ± 2.4b	95.6 ± 8.9cd

Values with different lowercase letters within the same column differ significantly at p<0.05. DDM, DMI, and RFV are digestible dry matter, dry matter intake, and relative feed value, respectively, from sorghum at different growth periods

Discussion

Salinity stress usually suppresses crop growth, which in turn limits sorghum biomass, yield and nutritional value in saline soils (Han *et al*., 2011). Therefore, to increase sorghum yield, it is important to improve saline-alkali soil conditions. On this basis, sorghum is an effective phytoremediation species with great potential to improve soil salinity. Furthermore, in recent years, the shortage of forage has been a limiting factor for the rapid development of animal husbandry in our study region (Ferraretto *et al*., 2013). Sorghum also had high biomass yield and forage quality, comparable to those of corn (*Zea mays* L.) (Han *et al*., 2011, Qu *et al*., 2014). Additionally, sorghum has shown greater salt tolerance at germination than other crops (Lewis *et al*., 2019).

In the present study, significant differences in sorghum yield were found among the eight varieties (Table 3). We found that the late maturing sorghum variety 4262 had a higher plant height, stem diameter and leaf area than other varieties. F968 is also a late variety. This characteristic allows F968 to produce enough dry matter, giving it an advantage over the early maturing A60. This finding was also observed by many other researchers (Qu *et al*., 2014). Therefore, F968 was quite tolerant to soil salinity with regard to forage yield in a highly saline soil. The Hetao Irrigation District has 285000 ha of saline-alkali land (Lei *et al*., 2011). If 50% of this land were planted in sorghum in, each hectare would produce 1.4 tons of grains (Table 3). Therefore, controlling salt accumulation in highly saline-alkali areas can be effective for increasing crop yields in the saline soils of the Hetao Irrigation District (Zhao *et al*., 2016).

In this study, significant differences were found among the eight sorghum varieties for CP, NDF and ADF depending on the growth stage (Table 4). The highest NDF and ADF for the early maturing varieties were found at the heading stage. Thus, there is a need for timely harvest of sorghum biomass to maximize its nutritional value as forage (Han *et al*., 2011; Lyons *et al*., 2019; Machicek *et al*., 2019). Similarly, previous studies showed that the growth stage influences forage nutritive value (Han *et al*., 2011; Ameen *et al*., 2019). In this study, the CP, NDF, and ADF contents (3.6%, 58.5%, and 32.7% at the heading stage) were lower than those reported in a previous study (4.9%, 58.5%, and 35.6%) (Kaplan *et al*., 2019). These lower CP, NDF, and ADF values in our study were likely due to the lower soil environment. However, the CP content corresponded to fourth-level forage grass according to the classification criterion of gramineous forages in America (Qi *et al*., 2008; Chen *et al*., 2015; Liu *et al*., 2016; Jia *et al*., 2017; Ren *et al*., 2019). The NDF and ADF contents ranked at first and third levels, respectively, for forage grass. In our study, the highest accumulation of CP was found for A60, and the accumulation levels of NDF and ADF were the highest for N5D61. Thus, sorghum has the potential to make good forage.

Conclusions

Our results reinforce that sorghum has high potential as a forage crop because of its nutritional value and adaptability to grow well in highly saline-alkali soil under limited rainfall. However, the agronomic traits and forage properties of sorghum were affected by variety, growth stage and maturity, as well as their interactions. The 4264 variety was superior in terms of agronomic traits. The seed yield of the early maturing varieties was significantly higher than that of late maturing varieties. Across nutritive parameters, early varieties exhibited increases from elongation to sorghum maturity, and the late varieties showed the opposite trend. This was critical to produce sorghum as a salt-tolerant crop, to be used as a phytoremediation strategy for the optimization of harvest in highly saline soils.

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