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VARIATION IN WINTER FORAGE PRODUCTION OF FOUR SMALL GRAIN SPECIES - OAT, RYE, TRITICALE, AND WHEAT

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Abstract

Small grains including oat, rye, triticale, and wheat are grown widely for winter forage production throughout the world, and they play an important role in sustainable agriculture related to animal production by providing high quality forage during winter season. To compare winter forage yield, the four species were evaluated during three growing seasons. Significant effects (P<0.0001) of the species, environment, and species by environmental interaction were detected for seasonal and mean forage yield. Rye produced the greatest mean forage yield, followed by triticale, wheat, and oat. Seasonally, rye produced greater forage yield through December to early March while oat, triticale and wheat produced greater forage beginning in March. An advanced rye breeding line, NF95319B, produced the greatest mean forage yield (2,873 kg ha^{-1}) while ForageMax wheat produced the least forage yield (1,573 kg ha^{-1}). This study identified significant differences in forage yield among the small grains species and germplasm within the species, which provides useful information for small grain breeding programs for winter forage production. The results of this study could provide useful guidelines for livestock producers to maximize seasonal forage production by optimizing growth and development using mixtures of small grain forages.

Keywords: Oat, rye, Small grains, Triticale, Wheat, Winter forage.

Introduction

Small grains (SGs) are widely grown as winter forage crops across the world because of their cold tolerance and productive forage yield. In the United States (US), SG species typically grown for winter forage production are oat (*Avena sativa* L.), rye (*Secale cereale*L.), triticale (×*Triticosecale* Wittmack), and wheat (*Triticum aestivum* L.). The SGs can be used as pasture, silage, or hay, and play an important role in sustainable agriculture related to animal production by providing forage from winter to spring when warm-season grass production is limited by freezing temperatures (Maloney *et al*., 1999; Watson *et al*., 1993).

Rye generally produces more forage than the others because of its greatest cold tolerance and rapid growth in the fall (Evers *et al*., 1998). Rye can be grown well on less productive and dry soils (Watson *et al*., 1993), damages less from fungal leaf diseases, and is resistant to Hessian fly [*Mayetiola destructor* (Say)] (Buntin & Chapin, 1990; Buntun & Raymer, 1989; Johnson *et al*., 1984). However, forage production of rye decreases rapidly by April or May because of its early maturity (Denman & Arnold, 1970).

In 2012, 41.3 million ha of winter wheat were planted in the US; 30% of which was planted in the southern Great Plains (SGP) (USDA-NASS, 2013). The considerable production in the SGP can be attributed to sufficient growing degree-days to produce wheat pasture for grazing (Holman *et al*., 2010) and it is common practice to graze winter wheat during the vegetative stage (Epplin *et al*., 2000). Wheat is generally more productive than the others in the late spring (Denman & Arnold, 1970).

Oat is more suitable to cut-and-carry feed systems than to grazing in cold environments (Suttie & Reynolds, 2004). Oat can germinate under limited moisture (Stichler, 1997) and maintain good forage quality and palatability as it matures (Evers *et al*., 1998). However, oat has poor winter hardiness and is susceptible to various leaf and crown diseases (Kim *et al*., 2014).

Triticale could be either grazed or stored as hay (Harmoney & Thompson, 2010). Yield and stress tolerances of triticale are typically greater than wheat. However, the high price of triticale seed is an obstacle to using it as a forage crop (Lekgari *et al*., 2008).

In general, the primary need for winter forage is not quality but quantity (Lekgari *et al*., 2008). From December to February, the majorlimiting factor of forage production is freezing temperatures. Rye can continue to grow at temperatures as low as 0ºC, whereas wheat requires about 2.8−4.4 ºC, and oat requires higher temperatures (>4.4ºC) (West *et al*., 1988). For these reasons, mean and seasonal forage yield of the SGs appear to differ. However, little information on forage yield of the SGs and germplasm within the species is available. Therefore, the objective of this study was to evaluate and compare mean and seasonal forage yield of different cultivars of four SG species over a range of environmental conditions common to the SGP.

Materials and Methods

Plant materials: The plant materials tested in this study included advanced breeding lines from the Samuel Roberts Noble Foundation, commercial cultivars, and commonly available varieties from other public and private breeding programs. In 2008–2009 (referred to the 2008 season) growing season, 66 entries were evaluated in total; this included 30 wheat, 14 rye, 12 triticale, and 10 oat germplasms. During 2009–2010 (2009 season), 26, 15, 13, and eight germplasms of wheat, rye, triticale, and oat were evaluated, respectively. During 2010–2011 (2010 season), 22 entries of wheat, 10 rye, seven triticale, and four oat germplasms were tested.

Table 1. Mean forage yield (kg ha^{-1}) of 30 small grain germplasms that were tested during the three growing seasons.

Species	Germplasm	Mean forage yield†
Rye	NF95319B	2,873A‡
Rye	NF97326	2,793AB
Rye	MatonII	2,758AB
Rye	NF95307A	2,714ABC
Rye	NF95307B	2,653ABCD
Triticale	NF96213	2,621ABCDE
Rye	Maton	2,571ABCDE
Triticale	NF96210	2,566ABCDE
Rye	WinterGraze70	2,528ABCDE
Rye	BatesRS4	2,506ABCDEF
Rye	Elbon	2,459ABCDEFG
Rye	Oklon	2,451ABCDEFG
Triticale	Tamcale5019	2,315ABCDEFGH
Wheat	NF95134A	2,166ABCDEFGH
Wheat	NF96107A	2,158ABCDEFGH
Wheat	NF96131	2,124ABCDEFGH
Wheat	NF97117	2,118ABCDEFGH
Wheat	Duster	2,037BCDEFGH
Wheat	Fannin	2,024BCDEFGH
Wheat	Endurance	1,928CDEFGH
Wheat	OK Bullet	1,921DEFGH
Oat	NF27	1,873DEFGH
Wheat	Deliver	1,836EFGH
Wheat	Jackpot	1,737FGH
Wheat	Doans	1,727FGH
Oat	NF95418	1,702GH
Wheat	Overley	1,692GH
Wheat	Jagger	1,641H
Wheat	KingGrazer	1,611H
Wheat	ForageMax	1,573H
P>*F*§		0.0023

†Multiple comparisons among the variety means were performed using the least significant difference (LSD) test in PROC MIXED. The LSMEANS were separated assigned using the macro PDMIX 800 (Saxton, 1998) at P=0.05 probability level.

‡Means followed by the same letters in each column are not significantly different at P=0.05 probability level.

§Significance level of the effect.

Ten rye germplasms including cultivars Elbon (PI 534961), Maton (CIse 521; Bates, 1979), MatonII (PI 643433; Baker *et al*., 2008), Oklon (PI 565085), Winter Graze70 (CIse 38), and advanced breeding lines developed by the Noble Foundation (NF)including NF95307A, NF95307B, NF95319B, NF97326, and Bates_RS4,were tested in all three seasons, and four cultivars were tested for two seasons (Table 1). For oat, advanced breeding linesNF27 and NF95418 were tested during all seasons and five cultivars were tested during two seasons (Table 1). Triticale breeding linesNF96210, NF96213, and cultivar TAMcale 5019 (PI 641801) were tested during all seasons (Table 1) and nine cultivars were tested during two seasons. Fifteen wheat lines including Deliver (PI 639232), Doans (PI 654419), Duster (PI 644016), Endurance (PI 639233), Fannin (PI 639231), ForageMax (PI 643139), Jackpot (PI 658007), Jagger (PI 593688), King Grazer, NF95134A, NF96107A, NF96131, NF97117, OK Bullet (PI 642415), and Overley (PI 634974) were evaluated across all three seasons (Table 1) and seven lines were tested across two seasons.

Field trials

Small grain trials took place during the 2008, 2009, and 2010seasons at two locations in southern Oklahoma. In the 2008 and 2010 seasons, field trials were conducted at the Noble Foundation Dupy (Dupy) farm near Gene Autry, OK and at the Red River Demonstration and Research (RR) farm near Burneyville, OK. In the 2009 season, the trials were conducted at the RR farm and the Noble Foundation Headquarters (HQ) farm near Ardmore, OK. The Dupy farm is classified as a Dale silt loam soil, the HQ farm is classified as a Wilson silt loam soil, and the RR farm soil is classified as a Minco fine sandy loam. Soil pH (ranged from 6.0 to 6.9), minerals (K, Ca, and Mg), and sodium concentrations in the experimental sites were adequate for wheat production based on the soil tests (Table 2). Weather information on precipitation and temperature in the research fields during the three seasons was based on records from the Oklahoma Mesonet (http://www.mesonet.org).

Across the seasons, the experimental plots were arranged in a randomized complete block design (RCBD) with three replications at each location. For the 2008season, 66 entries were planted on October 1 and September 29 at the Dupy and RR farms, respectively. For the 2009season, 62 entries were seeded in a clean-tilled seedbed on September 29at the HQ farm and October 1 at the RR farm. For the 2010season, 43 entries were planted on September 20 at the Dupy farm and September 21 at the RR farm. Depending on the species and germplasm within the species, approximately 100 to 134 kg of pure live seed (PLS) was planted per ha, which corresponded to 800,000 kg PLS ha^{-1}. Each entry was drilled in 1.5 by 3.0 m plots, in 0.18 m rows, at 2.5cm planting depth with a HEGE 500 drill (Wintersteiger, Salt Lake City, UT). Fertilization consisted of pre-plant incorporation of 45 to 90 kg actual Nha^{-1}according to the location and year. The difference in N rates was due to differences in residual N in the soil at each location. Plots also received a top dressed application of 90 kg actual N ha^{-1}in February of each growing season. In order to control aphid populations, 910 g of Cobalt™ ha^{-1}was applied for the 2009 and 2010seasons. Annual ryegrass was also controlled by application of39.2 g of Amber® ha^{-1} in September or October of all years.

Forage samples were harvested whenever there was adequate forage mass for harvest. Harvesting intervals varied each growing season according to the amount of precipitation and inclement weather conditions such as colder temperature and snow. Plots were harvested with a HEGE sickle bar forage plot harvester at a 7.5 cm height. In the 2008 season, forage samples were collected on January 23, March 2, April 22, and June 2 at the Dupy farm, and on February 10, March 26, May 5, and June 6 at the RR farm. At the HQ farm during the 2009 season, forage samples were harvested on January 27, March 15, April 12 and May 19, and at the RR farm they were harvested on February 18, March 22, April 13 and May 17. In the 2010 season, forage samples were harvested at the Dupy farm on December 2, February 22, March 23, and April 28, and for the RR farm trials were harvested on December 6, February 22, March 15, and April 12.

Statistical analysis

To calculate a least significant difference (LSD) for mean forage yields of the SG species, PROC GLM function of SAS 9.3 was used with *P*=0.05 (SAS Institute, 2011). Each location by year combination was considered a separate environment in the analysis (Kim & Diers, 2009). An across-environment analysis was done with the species, environments, replications within environments, and the species by environment interaction treated as random effects.

Analysis of variance for the forage yield of 30 germplasms (10 rye, two oat, three triticale, and 15 wheat) tested during all three seasons was conducted by PROC MIXED function. Germplasm was considered as a fixed effect while the others including replication (nested within location), location, year, harvest-date (Dec. to May), and all possible interactions were treated as random effects in the analysis. Multiple comparisons among the germplasm from the SG species were performed using the LSD test in PROC MIXED function with the PDIFF option of the LSMEANS statement. The LSMEANS were separated using the macro PDMIX 800 (Saxton, 1998) at *P*=0.05 probability level.

The general linear mixed model (MIXED procedure in SAS) was used to estimate seasonal forage yield of the SG species. To meet statistical assumptions, the square root of forage yield of the four species at each clipping was calculated. To evaluate the most appropriate functional relationship (i.e., linear, log-transformed, quadratic, or cubic) for describing temporal forage production of the SG species, an information theoretic approach was used (Burnham & Anderson, 2002). The most appropriate functional relationship for each species using Akaike's information criterion (AIC) corrected for small sample size (Burnham & Anderson, 2002) was selected. Year, location, year by location, germplasm, and replication by year by location were considered as random effects to account for these sources of variation and to better model the seasonal relationship over time.

Results

Across the six environments, mean forage yield of the SG species was 2,026 kg ha^{-1}. Across the species, the 2010 season was the most productive, producing 2,533 kg ha^{-1} of forage (Table 3). During the 2008 season, mean forage production was 2,282 kg ha^{-1}and only 1,396 kg ha^{-1} of forage was produced in the 2009 season (Table 3).

There was a significant (p<0.0001) effect of species on mean forage yield across the environments. Rye produced the greatest forage yield followed by triticale, wheat, and oat (Table 3). There were also significant (p<0.0001) effects of environment and species by environment interactions on forage yield. In the 2008 season, rye at the RR farm produced the greatest amount of forage (3,345 kg ha^{-1}) while oat at the Dupy farm produced the least amount (1,504 kg ha^{-1}) (Table 4). At the RR farm in the 2009 season, triticale produced the greatest forage yield (2,233 kg ha^{-1}) while oat produced the least yield (806 kg ha^{-1}) (Table 5). During the 2010 season, forage yield of rye and triticale at the Dupy farm were the greatest (3,945 kg ha^{-1}) while wheat at the RR farm produced the least amount (1,111 kg ha^{-1}) (Table 6).

There were significant (p<0.0001) effects of year and location, but the environmental effect was not significant on oat forage yield. The mean forage yield of oat across the seasons was 1,475 kg ha^{-1} and the average yields of environments ranged from 806 kg ha^{-1} at the RR farm in the 2009 season to 2,345 kg ha^{-1} at the Dupy farm in the 2010 season (Tables 5and 6). Forage yield of rye in the 2008 and 2010 seasons was significantly greater (*P*=0.05) than that in the 2009 season (Table 3).

Table 2. Soil characteristics of three experimental locations during the three growing seasons.

Season	Location	pH	N	P	K	Ca	Mg	Na	Soluble Salts
			(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(kg ha^{-1})	(ppm)
2008	Dupy	6.0	73.9	228.4	300.1	1858.8	826.4	118.6	0.0
	RR	6.2	30.2	120.9	331.4	1422.1	369.5	38.0	0.0
2009	HQ	6.9	2.9	24.6	53.7	291.1	6288.7	2192.5	204.8
	RR	6.6	58.2	82.8	288.9	1522.9	463.5	17.9	121.6
2010	Dupy	6.1	61.5	76.1	591.2	3549.7	1478.1	369.5	243.2
	RR	6.2	5.5	138.8	378.4	1256.4	340.4	22.3	38.4

Table 3. Mean forage yield (kg ha^{-1}) and standard error of four small grain species.

Species	2008 season	2009 season	2010 season	Across seasons
	kg ha^{-1}			
Oat	1,912±100C†	892±58C	1,801±202C	1,475±65D
Rye	3,167±87A	1,612±73A	3,033±152A	2,520±65A
Triticale	2,356±104B	1,606±72A	2,985±194A	2,213±72B
Wheat	1,963±63C	1,341±37B	2,293±101B	1,861±42C
Across species	2,282±44b‡	1,396±29c	2,533±74a	

† Means within a column followed by the same uppercase letter do not significantly differ by the least significant difference test (P=0.05).

‡Means within a row followed by the same lowercase letter do not significantly differ by the least significant difference test (P=0.05).

Across the three seasons, year, location, and environment had significant effects (P<0.0001) on rye forage yield. The mean forage yield of rye across the environments was 2,520 kg ha^{-1} (Table 3) and the average yields of the environments ranged from 1,013 kg ha^{-1} at HQ farm in the 2009 season to 3,945 kg ha^{-1} at Dupy farm in the 2010 season (Tables 5 and 6). The average yield of rye for the 2008 and 2010 seasons was significantly greater (P=0.05) than that in the 2009 season (Table 3).

Environmental effect on triticale forage yield was not significant, but effects of year and location were significant (P<0.0001). The mean forage yield of triticale across the environments was 2,213 kg ha^{-1} and the average yields ranged from 1,604 kg ha^{-1} at HQ farm in the 2009 season to 3,945 kg ha^{-1} at the Dupy farm in the 2010 season (Tables 5 and 6). The average yield of triticale in 2010 season was significantly greater (P=0.05) than that in 2008 and 2009 seasons (Table 3).

There were significant (p<0.0001) effects of year, location, and environments for forage production of wheat. The mean forage yield of wheat across the environments was 1,861 kg ha^{-1}(Table 3), and the average yields for the environments ranged from 1,111 kg ha^{-1} at the RR farm to 3,475 kg ha^{-1} at the Dupy farm in the 2010 season (Table 6). The average yield of wheat for the 2010 season was significantly (P=0.05) greater than in the 2008 season; likewise, forage yield of the 2008 season yield was significantly greater than that of the 2009 season (Table 3).

Across the environments, trend of mean forage yields of the 30 germplasms were consistent with means of the species (Tables 1 and 3). Rye and triticale germplasms produced greater forage yield than oat and wheat germplasms. The mean forage yield of an advanced rye breeding line, NF95319B, was the greatest (2,873 kg ha^{-1}) among the germplasm while the yield of Forage Max (wheat) was the least (1,573 kg ha^{-1}) (Table 1). The greatest forage yield (4,242 kg ha^{-1}) was produced by NF95307A (rye) at the DUPY farm in the 2008 season while the least yield (382 kg ha^{-1}) was recorded by Doans (wheat) at the RR farm in the 2008 season (data not shown).

Table 4. Seasonal and mean forage yield (kg ha^{-1}) of four small grain species in the 2008 season.

#†	Species	Red River Farm				Dupy Farm			
		Planting date 09/29/08				Planting date 10/01/08			
		02/20/09‡	03/26/09	05/05/09	Mean	01/23/09§	03/02/09	04/22/09	Mean
8	Oat	169B¶	3,013C	1,331B	1,504B	1,479B	1,804C	3,677A	2,320C
15	Rye	3,244A	4,071A	1,654A	2,990A	3,365A	4,038A	2,630B	3,345A
13	Triticale	276B	3,440B	1,589A	1,769B	1,892B	4,102A	2,937B	2,977B
26	Wheat	204B	3,447B	911C	1,520B	1,774B	3,356B	2,091C	2,407C

† # represents the number of varieties of each species tested.
‡ Dates represent harvest dates at Red River Farm during the 2008 season.
§ Dates represent harvest dates at Dupy Farm during the 2008 season.
¶ Means followed by the same letters in each column do not significantly differ by the least significant difference test (P=0.05).

Table 5. Seasonal and mean forage yield (kg ha^{-1}) of four small grain species in the 2009 season.

#†	Species	Red River Farm					Headquarters Farm				
		Planting date 10/01/09					Planting date 09/29/09				
		02/18/10‡	03/22/10	04/13/10	05/17/10	Mean	01/27/10§	03/17/10	04/12/10	05/19/10	Mean
10	Oat	0D¶	347C	1,411B	649A	806C	496B	623D	2,333A	1,213A	1,166B
14	Rye	3,600A	2,078A	1,552B	0B	2,196A	508B	1,754A	1,489C	302C	1,013B
12	Triticale	2,900B	2,140A	1,945A	0B	2,233A	476B	1,168C	2,069B	544B	1,604B
30	Wheat	663C	1,712B	1,447B	0B	1,317B	1,786A	1,517B	2,121AB	142D	1,392A

† # represents the number of varieties of each species tested.
‡ Dates represent harvest dates at Red River Farm during the 2009 season.
§ Dates represent harvest dates at Headquarters Farm during the 2009 season.
¶ Means followed by the same letters in each column do not significantly differ by the least significant difference test (P=0.05).

Table 6. Seasonal mean and mean forage yield (kg ha^{-1}) of four small grain species in the 2010 season.

#[†]	Species	Red River Farm					Dupy Farm				
		Planting date 09/21/10					Planting date 09/20/10				
		12/06/10[‡]	02/22/11	03/15/11	04/12/11	Mean	12/02/10[§]	02/22/11	03/26/11	04/28/11	Mean
10	Oat	1,934B[¶]	1,606B	662B	826A	1,257B	6,510BC	1,116C	474B	1,282A	2,345B
14	Rye	4,535A	2,396A	957A	594B	2,121A	6,140C	6,379A	2,817A	446B	3,945A
12	Triticale	4,667A	2,370A	799AB	395B	2,109A	8,010A	4,725B	2,727A	319BC	3,945A
30	Wheat	1,673B	1,249C	940A	582B	1,111B	6,990B	4,442B	2,305A	163C	3,475A

[†] # represents the number of varieties of each species tested.
[‡] Dates represent harvest dates at Red River Farm during the 2010 season.
[§] Dates represent harvest dates at Headquarters Farm during the 2010 season.
[¶] Means followed by the same letters in each column do not significantly differ by the least significant difference test (P=0.05).

Discussion

This study revealed significant differences in both mean and temporal forage yield among oat, rye, triticale, and wheat under variableenvironments that are charactersticof the SGP. Among the species, rye and triticale produced greater forage yield than wheat and oat for each season and across the seasons. Generally, rye produces significantly greater forage yield than the others, especially in cold-stress environments, because of its relatively low minimum temperature requirements for growth as well as great cold tolerance (Bruckner & Raymer, 1990; Macoon *et al*., 2002). Forage yield of rye increased cubicallywith maturity and it produced greater forage yield than the other species especially during January and February. However, forage production of rye rapidly declined entering mid- or late-April and leaf proportion was usually less than that of the others at each stage of growth (Bruckner & Raymer, 1990).Watson *et al*., (1993) reported that cattle gains are normally greateron wheat and triticale pasture during grazing because rye becomes stemmy and less palatable to livestock earlier in the spring than other SGs.

Although oat produces less forage during January and February, and stands of the various winter oat varieties are often severely depleted due to winter kill, a unique advantage of oat as winter forage crop is its later maturity than the other SGs, producing the majority of forage from April to May. This temporal forage production of oat was also significant in the present study, especially in the 2009 and 2010 seasons.

We estimated the most appropriate functional relationship for describing the distribution of seasonal forage production from January to mid-May (Fig. 1). Although the seasonal production curves differed in magnitude throughout the seasons, all four SG species were best described by cubic relationships, showing two peaks of production and two troughs in production throughout the year (Fig. 1). Temporally, rye produced greater forage yield earlier in the season (December to early March) until oat, triticale and wheat began producing greater forage beginning in March, with oat having the greatest production from mid-April through mid-May (Table 6 and Fig. 1). The most critical season, in terms of changing production patterns, tended to occur from early March to mid-April; as production decreased for some species, production of other species increased. Based on the points of intersection, rye production in mid-March dropped whereas production of triticale and wheat began to increase (Fig. 1). Last, oat passed production of rye in late March, and production of triticale and wheat in mid-April, resulting in greater late season production.

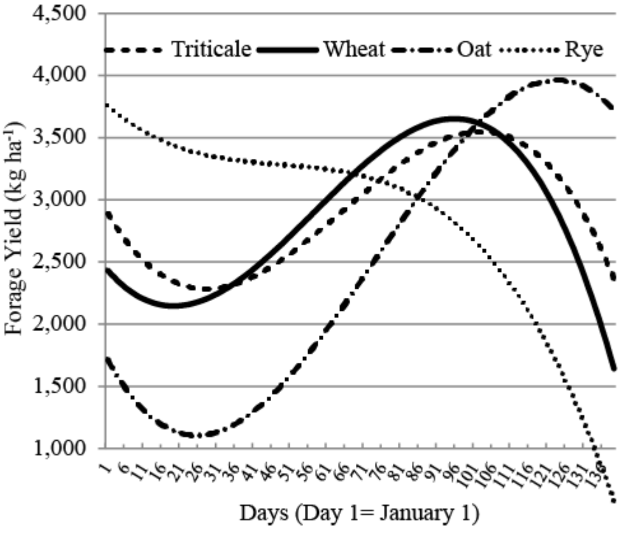

Fig. 1. Estimation of seasonal forage production (from January to mid-May) of the four small grain species.

The differences in annual forage production may be explained partially by variable environmental conditions (Table 7). Major environmental factors limiting winter forage production in SGP were drought and freezing temperatures. However, forage production during the mid-growing season, especially January and February, was dependent on temperature requirements for growth, the least in rye and greatest in oat (Bruckner & Raymer, 1990; Helsel & Thomas, 1987). In the 2008 season, although total rainfall was slightly less than the 30-year average, most of the rainfall occurred during spring, especially through April and May 2009 (Table 7). Severe drought conditions in the fall and freezing temperatures caused no harvestable forage growth during November to next January. There was no harvestable forage during early winter of the 2009 season due to low rainfall in

November and freezing temperatures in December. In the 2010 season, better than average growing conditions during early growing season, particularly during September, helped the plants grow better and provided December harvest. However, both of the locations received less than 60% of their average monthly rainfall during the remainder of the growing season. During January and March in 2011, the total monthly rainfall was almost negligible and the lack of rainfall in the later part of the growing season reduced forage yield. Other factors that need to be considered for choice of SGs for winter forage production might be the environmental conditions including insect/disease problems, and the capacity of the species or varieties to recover rapidly from stress conditions including grazing. However, there were no disease or insect problems during the present study.

Uneven production of forage would be a major obstacle limiting livestock production in the US. However, due to their ability to grow under cold temperatures during winter season, SG species can successfully extend the grazing season from winter to the following spring. In addition to total forage yield, seasonal production of winter forage is an important factor because the choice to grow a particular SG species is largely affected by the period the forage is critically needed rather than total forage yield. However, choice of a cultivar is more dependent on its forage yield (Denman & Arnold, 1970; Lekgari *et al*., 2008).

Table 7. Average precipitation, high/low temperatures, and 30-year average precipitation at the experimental locations.

Month	2008 season		2009 season		2010 season		30-yr Avg.†		
	Dupy	RR	HQ	RR	Dupy	RR	Dupy	RR	HQ
Sept.	47.8 (29/16)‡	36.3 (29/15)	133.9 (27/17)	181.1 (28/16)	155.7 (30/19)	173.2 (31/18)	105.9	101.6	105.9
Oct.	34.8 (25/10)	32.0 (26/10)	194.8 (21/9)	203.7 (20/9)	59.2 (26/10)	73.7 (26/8)	112.5	111.5	112.5
Nov.	12.7(19/4)	12.9 (20/3)	5.3 (20/7)	6.1 (21/6)	46.0 (19/6)	34.8 (19/5)	68.6	69.3	68.6
Dec.	4.6 (13/-1)	6.9 (14/-3)	71.6 (8/-2)	92.7 (9/-3.3)	51.6 (13/1)	51.3 (13/-1)	58.9	60.5	58.9
Jan.	14.7 (13/-2)	8.9 (14/-3)	42.7 (9/-1)	46.0 (10/-2)	6.9 (11/-3)	21.8 (11/-4)	47.0	43.9	47.0
Feb.	35.6 (18/4)	39.6 (18/3)	68.3 (9/-1)	70.9 (8/-1)	49.5 (13/1)	46.2 (14/0)	55.6	54.4	55.6
Mar.	30.2 (19/7)	48.0 (20/7)	49.3 (17/5)	71.4 (18/4)	1.5 (21/7)	6.6 (21/7)	81.3	85.6	81.3
Apr.	157.2 (23/10)	390.1 (23/9)	86.9 (23/12)	74.4 (23/10)	47.2 (27/12)	72.1 (27/11)	81.0	84.6	81.0
May	269.2 (25/14)	124.5 (26/14)	87.6 (27/16)	107.2 (28/16)	146.6 (27/15)	133.1(27/15)	129.0	128.8	129.0
Total	606.8	699.3	740.4	853.4	564.1	612.9	739.9	740.2	739.9

†30-yr Avg. represents average of precipitation (mm) at the experimental locations during the last 30 years.
‡Average high/low temperatures (ºC) from September to May in each experimental location.

Conclusions

Identification of valuable germplasm is the most important starting point in all crop breeding programs. Several breeding lines tested in the present study presented great forage yields and might have a great potential to be used as important sources forbreeding programs. Some of the germplasm might be released soon due to their great winter forage production. Analysis of the inheritance and dissection of the genetic components of forage yield in the germplasm might be required. Additional field trials would be needed to check the nutritive characteristics of forage germplasm. Assessment of genetic diversity using molecular markers could be the next step to associate the phenotypic variation and genetic diversity.

One of the great advantages of the SG species as winter forage crops is the diversity of forage production characteristics existing among the species and cultivars (Bruckner & Raymer, 1990). In addition to early planting, increasing the seeding rate and application of additional nitrogen might improve winter forage yield of the SG species (Edwards *et al*., 2011; Lyon *et al*., 2001). Mixtures of the SG species could potentially extend the grazing period and reduce the tendency for a strong peak growth period in the spring. However, future studies might be needed to determine unintended effects from mixtures because some species are more competitive than the others and seeding rates might need to be adjusted for each species to obtain the desired mix of components. The results of the present study will provide useful guidelines for livestock producers for the choice of the SG species for winter forage production in SGP and other regions under the similar climatic conditions across the world. Further studiesexploring the capacity to recover rapidly from grazing and clipping as well as animal growth evaluation would be valuable to develop new SG cultivars for winter forage production.

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