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Full Length Research Paper

Establishment of high-elevation fourwing saltbush (*Atriplex canescens* Pursh Nutt.) ecotypes in Northern Mexico´s oak-bunchgrass rangelands

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In Mexico, fourwing saltbush grows in shrubland ecosystems where the highest elevation is approximately 1,500 m, while in the United States of America (USA) it is found up to 2,400 m elevations. The objective was to evaluate the growth and survival of the Sandoval, Grants and Trinidad ecotypes in Mexico's oak-bunchgrassland, as well as to characterize the soils of two high-elevation sites in southwest United States where fourwing saltbush grows. The ecotypes were collected at elevations of about 1,800 m in the USA. Based on the habitat-specific-seed data, two ranches in Chihuahua, México were selected for evaluation of the ecotypes; the Santa Monica ranch (RSM) and El Saucito ranch (RES). Fourwing saltbush plants were grown in a nursery and then transplanted in August 2005 when the plants reached about 20 cm in height. An analysis of variance was performed considering a random block design and mean separation was done using a Duncan test. Two years after transplanting, in the Santa Monica ranch plants reached 103, 91 and 75 cm height, while survival was 73, 66, and 73% for Sandoval, Grants, and Trinidad ecotypes, respectively. Soil texture and weed competition were the main variables affecting fourwing saltbush. At the El Saucito ranch, plants reached 29, 25 and 28 cm in height with survival of 24, 55 and 55% for the same ecotypes. Soil depth and intense grazing probably affected fourwing saltbush performance. The three ecotypes may be used in some specific environmental ecosystems; nevertheless, soil characteristics and management should be considered to reduce uncertainty and increase success.

Key words: Fourwing saltbush, plant height, survival, altitude, soil texture.

INTRODUCTION

Winter supplementation is one of the main components in production costs for cattle ranches in northern Mexico. In high-elevation valleys, rangeland forage fulfills nutrient requirements for cattle during the rainy season of mid-summer and autumn. However, grasses and forbs offer few nutrients during the winter and spring seasons, so feed supplementation is necessary from December through early June. In some regions, especially in valleys with up to 1500 m elevations, fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.) and other similar plants are widespread. These shrubs can provide a high intake by livestock during the winter season with high protein and phosphorus contents (Van Niekerk et al., 2004; USDA, 2010) and are able to minimize or even eliminate the supplementation needs (Casson et al., 1996).

Up to date, technology for fourwing saltbush propagation in shrubland regions is available (FAO, 2006). Unfortunately, the distribution of this shrub in Northern Mexico is restricted to lower-elevation arid and

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semi-arid zones (Romero-Paredes and Ramirez, 2003) and to pheozem and regozol calcareous soils with sand, sandy loam, sandy clay, clay, and clay loam textures (CONAFOR, 2007; Molina, 1992; CONAFOR, 1999). Therefore, seed for higher elevation cattle raising regions with oak-bunchgrass vegetation is not obtainable. Since several fourwing saltbush ecotypes from southwest United States regions with elevations above 1,800 m are available, it was hypothesized that those ecotypes can be established in regions with oak-bunchgrass vegetation and transition zones in the state of Chihuahua, Mexico. Thus, the objective was to evaluate the survival and growth of three high-elevation fourwing saltbush ecotypes in oak-bunchgrass rangelands of Northern Mexico, as well as to characterize the soils of two high-elevation sites in southwest United States where fourwing saltbush grows. The results will be of great value to cattle stakeholders in oak-bunchgrass vegetation zones.

MATERIALS AND METHODS

Ecotypes origin

Three fourwing saltbush ecotypes were evaluated in two experimental sites. Two of the ecotypes were collected in New Mexico, USA (Grants, collected near the City of Grants in Cibola County, and Sandoval, collected in Sandoval county) and one in Colorado, USA (Trinidad, collected in Trinidad county). Seeds of the Grants and Trinidad ecotypes were collected from native plants near 1,800 m elevation, while seeds from the Sandoval ecotype were obtained from a commercial distributor, who guaranteed establishment on sites with elevations higher than 2,000 m. In addition to seed collection, composite soil samples were taken at three depths (0 to 10, 10 to 20 and 20 to 30 cm) and analyzed for the following variables; pH, electrical conductivity, carbonates, texture, and subsequent elements: sodium (Na), potassium (K), arsenic (As), calcium (Ca), copper (Cu), iron (Fe), nickel (Ni), zinc (Zn), manganese (Mn), and magnesium (Mg). Soil analysis was completed according to standard soil analysis. The soil elements were analyzed with a complete digestion of the soil sample with nitric acid, refrigerated at 4°C and utilizing an Inductively coupled plasma optical emission spectrometer (ICP-OES) Perkin Elmer, 2100.

Field research

The ecologic requirements of the ecotypes were obtained based on the characteristics of the sites where the ecotypes were collected, including elevation, vegetation, and soil types. Then, similar geographic areas in Chihuahua with high potential for plant adaptation were identified. Two sites were selected in the transition zones between bunchgrass rangelands and Juniper-Oak (*Juniperus* spp.-*Quercus* spp.) communities. The study was conducted from August, 2005 to September, 2007 on two ranches of the state of Chihuahua, northern Mexico.

The first ranch, called El Saucito (RES), is located near the municipality of Balleza, in the southeastern part of the state of Chihuahua. The second ranch, named Santa Monica (RSM), is located near the municipality of Buenaventura, in the northern part of the state. Both ranches are representatives of the oak-bunchgrass rangelands of northern Mexico. Soil sampling and analysis in the field study sites were done in the same manner as in the seed collection sites. Prior to the study, fourwing saltbush was not present in either ranch, so survival and growth of three ecotypes collected in the USA were evaluated. Seedbed preparation consisted on contour furrowing.

Plant production

The field study was established by transplanting fourwing saltbush seedlings that were grown under nursery conditions. Three to five scarified seeds were placed in plastic bags of 8 cm diameter and 20 cm depth in May 2005. Transplanting to the tops of furrows was done in the field 3 months after planting seeds in the bags (August). This period coincides with the middle of the rainy season in both sites in the state of Chihuahua. Experimental plots were excluded from grazing for 2 years after transplanting. A total of approximately 18,000 plants were transplanted on each ranch.

The plant survival variable was determined by counting live and dead plants. This variable was classified as categorical. The plant height variable was estimated by measuring length from the plant base to the tip of the furthest leaf or stem. This variable was assessed 2 years after transplanting and analyzed as continuous. A random block design was used with four replications in the Santa Monica ranch while three replications were used at the El Saucito ranch. An analysis of variance (ANOVA) was performed at a 0.05 level of significance, mean while the Duncan test was used for mean separation.

RESULTS AND DISCUSSION

Characteristics of the sites where seeds were collected are shown in Table 1, while characteristics of the sites where the field study was conducted are shown in Table 2. One of the relevant factors between study sites was soil properties. At the El Saucito ranch, soil was shallow and rocky, while soil in the Santa Monica ranch was deeper and with higher production potential. Mineral contents of soils from both sites of seed collection and field study sites are shown in Table 3. Some differences were found at the Grant site where there were high concentrations of Ca, Cu, Fe, Mn and Mg. It is generally agreed that these elements have little effect on soil salinity. Concentrations of other elements in the soil, including Na, which has a direct effect on soil salinity, were low and comparable among seed collection and study sites. At the El Saucito ranch, mineral concentrations tended to be higher in the upper, flatter parts of the site than in the low, hilly parts. Contrariwise, mineral content in the soil at the Santa Monica ranch was more consistent throughout the site, except for the element Fe, which showed some variation among blocks. Physical and chemical characteristics of the soil showed little differences between seed collection and study sites (Table 4). Soil pH levels ranged from 7.3 to 8.0, and levels of Ca CO_3 ranged from 1.0 to 5.0 mg kg^{-1} dry soil. Soils are slightly alkaline and calcareous with very low electrical conductivities. The dominant textures were sandy and clay loam in sites of seed collection, and silty clay at the El Saucito ranch and clay in the Santa Monica ranch.

Table 5 shows ecotype plant heights in the Santa

Table 1. General characteristics of the sites of seed collection.

Characteristic	Ecotypes	
	Grants, NM	**Trinidad, CO**
Geographic Position	N 35° 07' 45" W 107° 52' 13"	N 37º 19' 32" W 104º 32' 52"
Elevation (m)	1,971	1,830
Climate	Annual mean temperature: 10°C, Minimum mean temperature: 0.2°C Maximum mean temperature: 20.6° Annual precipitation mean: 276 mm[a]	Annual mean temperature: 12°C Minimum mean temperature 2.9°C Maximum mean temperature: 20.1°C Annual precipitation mean: 409 mm[b]
Soil	Calcareous, shallow depth (<50 cm).	Deep (>1 m), good fertility
Vegetation	Bunchgrass rangeland (*Bouteloua gracilis*, *Atriplex* spp. and *Juniperus* spp.)	Bunchgrass rangeland (*Bouteloua gracilis*, *Atriplex* spp. and *Juniperus* spp.)

Table 2. General characteristics of the study sites in Chihuahua, Mexico.

Characteristics	El Saucito ranch	Santa Monica ranch
Geographic Position	N 26° 48' 56" W 106º 25' 06"	N 29° 28' 23" W 107° 02' 26"
Elevation (m)	1,890	1,898
Climate	Annual mean temperature: 17.8°C Minimum mean temperature: 8.3°C Maximum mean temperature 27.3°C Annual mean precipitation: 491 mm[1].	Annual mean temperature: 16.2°C Minimum mean temperature: 8.1°C Maximum mean temperature 24.3°C Annual mean precipitation: 319 mm[1].
Soil	Shallow depth(< 30 cm), rocky, some areas with bedrock exposure	Deep (> 2 m), high fertility soil
Vegetation	Juniperus-oak rangeland with bunchgrasses.	Originally was an oak woodland at the time of the study it was an abandoned field with *Amaranthus* and *Chenopodium* spp.

Table 3. Mineral content of soils in the sites of seed collection and study sites in Chihuahua, Mexico.

Site	Element (mg/kg of dry soil)									
	Na	**K**	**As**	**Ca**	**Cu**	**Fe**	**Ni**	**Zn**	**Mn**	**Mg**
Trinidad CO, USA	457	668	2.1	121.3	6.9	2.338.0	1.4	22.0	55.3	392.8
Grants NM, USA	451	657	4.5	15.778.0	18.6	5.163.6	8.3	35.8	190.4	17.161.0
El Saucito block 1	480	626	0	138.7	2.1	447.8	0	40.8	34.4	64.0
El Saucito block 2	487	616	0	39.8	0	161.9	0	0	10.2	20.8
El Saucito block 3	483	646	0	2.3	0	37.6	0	0	1.2	5.5
Santa Mónica block 1	466	663	0	na	0.160	222.9	0.967	0	3.5	38.7
Santa Mónica block 2	436	714	0	na	0.069	219.0	0.173	0.095	4.5	40.5
Santa Mónica block 3	470	695	0	na	0.057	212.8	0.174	0.832	4.7	47.9
Santa Mónica block 4	451	707	0	na	0.053	177.2	0.118	3.7	4.3	46.4

Na =Not analyzed.

Table 4. Physical and chemical soil properties in the sites of seed collection and the study sites in Chihuahua, Mexico.

Site	Soil properties								
	pH	$CaCO_3$ (mg/kg of soil)		Electrical conductivity (mmhos/cm)		Sand (%)	Silt (%)	Clay (%)	Texture
Trinidad CO, USA	7.5	2.2	Slightly calcareous	0.359	Very low	57.7	14.7	27.6	Sandy clay loam
Grants NM, USA	8.0	5.0	Moderately calcareous	0.521	Very low	49.6	17.0	33.4	Sandy clay loam
El Saucito block 1	7.3	1.0	Slightly calcareous	0.180	Very low	41.3	27.6	31.1	Silty clay
El Saucito block 2	7.4	1.0	Slightly calcareous	0.215	Very low	43.0	27.5	29.5	Silty clay
El Saucito block 3	7.5	1.0	Slightly calcareous	0.244	Very low	46.0	24.9	29.1	Sandy clay loam
Santa Monica block 1	7.8	1.0	Slightly calcareous	0.144	Very low	41.1	27.5	31.4	Silty clay
Santa Monica block 2	7.4	1.0	Slightly calcareous	0.132	Very low	23.7	34.6	41.7	Clay
Santa Monica block	7.7		Slightly calcareous	0.125	Very low	23.7	25.2	51.1	Clay
Santa Monica block 4	7.5	1.0	Slightly calcareous	0.202	Very low	19.7	33.9	46.4	Clay

Table 5. Plant height (cm) of three ecotypes of fourwing saltbush in the Santa Monica ranch. August 2000

Ecotype	Blocks				Mean
	1	2	3	4	
Sandoval NM	87.94	108.83	114.04	98.35	102.3 a[1]
Grants NM	75.67	87.33	105.07	98.31	91.6 [b]
Trinidad CO	67.76	73.47	93.03	73.22	76.9 [c]

[1]Height means with different letters are significantly different ($p<0.05$).

Monica ranch. The Sandoval ecotype was the tallest, followed by Grants and Trinidad. Evidently, soil texture affected ecotype plant height. Higher plants were observed in block 3 with clay soil (51% clay) than in blocks 1, 2 and 4 with less clay content (31, 42 and 46%, respectively, Table 4). Taking into account the place of origin of the seeds, Sanderson and McArthur (2004) reported that these fourwing saltbush ecotypes belong to Atriplex canescens variety *occidentalis* (Torr. and Frem.) S.L. Welsh and Stutz. These authors observed that this variety is mainly distributed in hills and valleys with silt-like, clay soils. Glenn et al. (2001) also reported that *Atriplex canescens* variety *angustifolia* (Torr.) S Watson showed higher survival and growth than the *occidentalis* variety in sandy soils under irrigation conditions. Apparently, chemical properties did not influence plant height in the ecotypes of the Santa Monica ranch.

Survival of the three fourwing saltbush ecotypes in the Santa Monica ranch is shown in Table 6. Unlike plant height, plant survival did not show a relationship to soil texture. In general, all ecotypes showed the highest survival in block 1 and the lowest in block 2. Two factors greatly influenced fourwing saltbush ecotypes survival and growth in the Santa Monica ranch. First, a high density of the weed A*maranthus* spp. is suspected of restricting growth and survival of all ecotypes. Second, rain distribution also affected survival and growth of the ecotypes as most of the 250 mm of the rain received during the summer fell from early July to early September. Since the transplanting was done in early August, approximately 30 of the 60 days that are relevant for fourwing saltbush seedling germination and growth occurred with few rain events.

Table 7 shows plant height and survival of all

Table 6. Survival of three fourwing saltbush ecotypes in the Santa Monica ranch. August 2007.

Ecotypes	Survival (%)
Sandoval NM	73 a[1]
Grants NM	73[a]
Trinidad CO	66[b]

[1]Height means with different letters are significantly different (p<0.05).

Table 7. Plant height and survival of three fourwing saltbush ecotypes in the El Saucito ranch. August 2007.

Ecotype	Height (cm)	Survival (%)
Trinidad CO	27.8 [a1]	55[a]
Sandoval NM	27.9[a]	24[b]
Grants NM	25.2[a]	55[a]

[1]Heigth and survival means with different letters are significantly different (p<0.05).

ecotypes at the El Saucito ranch. Survival of Trinidad with 55% and Grants with 54% was higher than the Sandoval ecotype with 24%. Despite a good, rainy summer season with 500 mm, plant survival was low, which is partially attributed to shallow and low fertility soil. This could have affected soil water retention and fourwing saltbush root growth. According to Science Views (2007), fourwing saltbush tolerates soils as shallow as 25 cm, although it is mainly distributed in moderately deep to deep soils.

Shallow, rocky soils also probably negatively affected plant heights of all ecotypes at the El Saucito ranch. Taller plants were observed in the Sandoval ecotype, followed by the Trinidad and Grants ecotypes (Table 7). Similar results were reported by Echavarría et al. (2005) who evaluated fourwing establishment in cultivated soil and in shallow, rangeland soil, both with a medium texture. They observed that forage production of the plants was higher in the cultivated soil with 1.2 kg plant^{-1} than in the rangeland soil with 0.25 kg plant^{-1}. In adition to adverse soil conditions, intensive cattle and horse grazing, which accidently occurred approximately 12 months before the final measurements, probably also affected plant height and survival of all ecotypes in El Saucito ranch study.

Previous studies concerning fourwing saltbush adaptation in regions far from its origin showed good results, not only in restored areas within its natural habitat but also in areas with absence of fourwing saltbush plants, like those dominated by *Artemisia* spp. and pinyon-oak rangelands (Monsen and Shaw, 1995; Ott et al., 2003). Sanderson and McArthur (2004) and Fitzsimmons et al. (1998) concluded that fourwing saltbush ecotypes distributed in northern latitudes adapt much better in southern latitudes. In this regard, cold resistance is a good trait, although plant growth is adversely affected. From these authors, the general recommendation is that seeds should be collected from the same site where they are to be transplanted and transplanting sites should be not higher than 660 m of elevation from the site of seed collection.

Conclusion

The Sandoval, Grants and Trinidad ecotypes showed ample potential to survive and grow in the oak-bunchgrass rangelands. The best sites for fourwing saltbush transplanting are those with deep, rock-free soils with clay loam and sandy**,** clay loam soils. A validation study of these three fourwing saltbush ecotypes is proposed as an alternative for conversion of abandoned fields to productive lands in the transition grassland-forest and central valleys of northern Mexico.

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