Potential of *Kochia Prostrata* and Perennial Grasses for Rangeland Rehabilitation in Jordan Jordan Component of the Sustainable Development of Drylands

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and

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Abstract

Six varieties of forage kochia [*Kochia prostrata* (L.) Shad.], two *Atriplex* shrubs native to cold deserts in the western United States, and four drought-tolerant perennial grass varieties were seeded and evaluated under arid rangeland conditions in Jordan. Varieties were seeded in December 2007 and evaluated in August 2008 and June 2009 for frequency and height at two sites in arid rangeland areas of southern and northern Jordan. Conditions were very dry with the southern site (Qurain) receiving 110 mm and 73 mm of annual precipitation, and the northern site (Tal Rimah) receiving 58 and 43 mm during the winters of 2007/2008 and 2008/2009,

respectively. Plants were more abundant and taller ($P < 0.001$) at the wetter Qurain site than the drier Tal Rimah site in 2008. Only a few Atriplex shrubs emerged (< 3 of each species). Forage kochia frequency was 48% and 30% in 2008 at Qurain and Tal Rimah, respectively. However, no seeded plants were observed at the Tal Rimah site in 2009. Apparently the conditions were too dry for the plants observed in 2008 to survive. In contrast, abundance of forage kochia at Qurain in 2009 was similar (P = 0.90) to that observed in 2008 and height of forage kochia increased ($P < 0.001$) from 2008 (14.4 ± 1.1 cm) to 2009 (38.4 4 ± 1.1 cm). Sahro-select and Otavny-select were most abundant of the forage kochia varieties (P < 0.05) suggesting that these experimental lines may be more adapted to Jordan than the commercially available cultivar Immigrant. Frequency of perennial grass varieties declined (P < 0.001) at Qurain between the first (82 ± 4%) and second (39 ± 4%) measurements and results suggested that Siberian wheatgrass was better adapted than crested wheatgrass, with Russian wildrye being intermediate. Based on this study, forage kochia appears to have great potential for establishing palatable perennial shrubs through broadcast seeding and minimal tillage in arid rangeland conditions of Jordan if annual precipitation is at least 70 mm. Arid-adapted perennial grass varieties may also be useful in rangeland restoration efforts if annual precipitation is over 100 mm.

Key Words: Forage kochia, Middle East, crested wheatgrass, Russian wildrye, Siberian wheatgrass

INTRODUCTION

The Hashemite Kingdom of Jordan is primarily rangeland (about 90%) of which the majority is arid with less than 200 mm of annual precipitation. These rangelands support a range livestock industry that allows rural communities to maintain a valued and traditional way of life. In addition to livestock production, Jordanian rangelands are the watersheds that receive rainfall and periodic snow, yield surface water and replenish groundwater.

A large proportion of the rangelands in Jordan has deteriorated and is in poor condition. Heavy stocking levels, continuous grazing near permanent water sources, plowing of land for dryland cultivation and drought are some of the reasons for the downward trend in rangeland condition in Jordan (Al-Tabini 2001). Irrespective of the cause of the deterioration, responsibility of reversing this trend falls to rangeland users. A recent study by Al-Tabini et al. (2008) found that the combination of water harvesting and transplanting native shrubs resulted in a 7-fold increase in forage production (130 kg/ha to 950 kg/ha). Except in extreme drought conditions, estimated economic payback periods for these restoration activities were 4 to 9 years. Results from this study demonstrate the value of shrub establishment in rangeland restoration. However, transplanting shrubs is not practical for expansive rangelands because of the lack of available nursery stock, labor for planting and accessibility of equipment. Direct seeding of rangeland vegetation is less expensive, more rapid, and requires much less labor.

Forage kochia [*Kochia prostrata* (L.) Shad.] is a perennial polymorphic low-shrub that is native to areas from the Mediterranean Basin to Siberia (Shiskin 1936). It is not native to Jordan. Forage kochia is highly adapted to arid conditions and cold temperatures and has been used successfully in rangeland restoration in the western United States (Blauer et al. 1993; Harrison et

al. 2000). Forage kochia can be direct seeded, and seeds do not need to be covered with soil (Harrison et al. 2000). Soil only needs to be slightly disturbed before seeding. In rangelands dominated with cheatgrass (*Bromus tectorum* L.) that burn frequently, forage kochia is one of the few plants that can be successfully seeded and potentially used as bridge for establishing native species (Stevens et al. 1985, Monaco et al. 2003).

Forage kochia is palatable and has been used by livestock in Kazakhstan and Uzbekistan and nearby areas during fall and winter for centuries (Waldron et al. 2005, Waldron et al. 200x). Waldron et al. (2006) reported that forage kochia maintained a relatively high forage quality during the winter (8% to 12% crude protein). These authors also found that grazing cattle on forage kochia was $\$0.24 \cdot cow^{-1} \cdot day^{-1}$ less expensive than feeding alfalfa hay in drylot pens.

The ability to readily establish with direct seeding, adaptability to arid conditions, relatively high nutritive quality and palatability makes forage kochia a potential candidate species for rangeland restoration in Jordan. Drought resistant varieties of perennial wheatgrasses native to Siberia and Eurasia and bred in the U.S. for increased seedling establishment have also been used successfully in arid areas of the western United States. These species are palatable, productive and require only minimal tillage during seeding. The objective of this study was to compare and evaluate germination and initial establishment of six varieties of forage kochia, , two introduced *Atriplex* shrub species native to cold deserts in the western United States and drought-tolerant perennial grass varieties under arid rangeland conditions in Jordan.

METHODS

Study Sites

The study was conducted at two sites, Qurain and Tal Rimah. The Qurain location is located in southern Jordan, approximately 35 km southwest of Maan (lat N30°6'27" and long E35°28'15"). The site is located on silty clay soils at an elevation of 1498 m. The area typically receives between 150 and 200 mm of annual precipitation during November to March. Tal Rimah is located approximately 70 km east of Al-Mafrak (lat N32°17'13" and long E36°53'55") at an elevation of 1096 m. The site is located on clay soil which is overlaid by a clay loam at the soil surface. The area typically receives between 100 to 150 mm of precipitation during November to March. Both sites were located on gentle terrain with nearly level slopes (< 1%).

Protocol

At each site, four replicate 30 m x 30 m blocks were established within a 65 m x 65 m fenced location. Net wire was used for fencing to exclude livestock grazing. Within each block, six forage kochia varieties, four perennial grass varieties and two *Atriplex* shrub species were seeded (Table 1). Three native shrub species were also seeded in each block, but they were used a demonstration and were not compared to the other species. Each block was divided into 15 subplots, which were randomly allocated to the 15 varieties. Each subplot (6 x 10 m) consisted of three 10-m rows. Rows were 2 m apart. Seeding was completed on 16 December 2007 in Tal Rimah and on 18 December 2007 in Qurain. Seeds were broadcast by hand within the row and were lightly covered with soil by hand raking. Forage kochia seeds were covered with 2 to 3 mm of soil, and grass seeds and other shrubs were covered with 3 to 6 mm of soil. No attempt was made to incorporate water harvesting in the study.

Variety Origin

Origin of the forage kochia and grass varieties is as follows. Immigrant, is the only current cultivar in the U.S. and was released in 1984 and originated from germplasm from Russia (Stevens et al. 1985). BC-118 is a selection from collections made by the USDA-ARS from Uzbekistan in 1990. KZ-6X is a select hexaploid population originating from collections made in Kazakhstan (Waldron et al. 2001). Otavny-select, Sahro-select, and Pustinny-select are populations developed by the USDA-ARS originating from the Uzbek varieties and collections described by Waldron (2005). Immigrant, BC-118, and Pustinny-select are diploid subspecies *virescens*; whereas, KZ-6X, Otavny-select, and Sahro-select are subspecies *grisea*, with the latter two being tetraploids. Hycrest crested wheatgrass (Asay et al. 1985a), Bozoisky Russian wildrye (Asay et al. 1985b), and Vavilov Siberian wheatgrass (Asay et al. 1995) were all released by the USDA for their improved seedling vigor and establishment characteristics. Kazak Siberian wheatgrass is a low growing, very drought tolerant population developed from pubescent collections from Kazakhstan described by Jensen et al. (2000).

Seeding Rates

The seeding rate for the forage kochia, four-wing saltbush, and shadscalewas 3.6 kg/ha pure lives seeds (PLS); whereas, the perennial grasses were planted at a rate of 6.5 kg/ha PLS Seeds from the three native shrubs were obtained from mature shrubs located within 100 km of the study sites. No attempt was made to determine the germination rates of the native shrub seeds (PLS values). Consequently, data from the native shrubs were not compared to the other shrub species.

Measurements

During mid August 2008 and late June 2009, frequency of the 15 varieties was measured in 30-cm diameter frames. Within each subplot the frame was placed at 90 equally distant locations along the three rows (30 frame placements per row). In addition, the height of the nearest plant (within 30 cm) was measured at 30 equally distant locations within a subplot (10 per row). Heights of plants measured within a subplot were averaged together.

Statistical Analyses

For 2008 observations, frequency and height data were analyzed using a statistical model that included site (Qurain or Tal Rimah), block, forage type (forage kochia, perennial grass or other shrubs), and variety within forage type and the site by variety within forage type interaction. The subplot was the experimental unit. The pdiff option of PROC MIXED was used for mean separation (SAS 1999). Varieties within a type were compared separately (i.e., only forage kochia varieties) using a model that included site, block within site, variety and site by variety interaction.

Analyses of the 2009 observations only included observations from Qurain. The statistical models approach for the analysis of the 2009 Qurain data was the same used in the 2008 analyses, except site and interactions with site were not included in the models.

In addition, data from 2008 and 2009 from the Quarin site were combined and evaluated using the repeated measures procedures of PROC MIXED (Littell et al. 1996). The model included block, forage type, variety within forage type, year, type by year interaction and the year by variety within forage type interaction. The subject was subplot. Compound symmetry, auto regressive 1 and unstructured approaches for modeling covariance between repeated records

were evaluated, and compound symmetry was used because it had the lowest Akaike Information Criterion value (Littell et al. 1996).

RESULTS AND DISCUSSION

Precipitation

Precipitation during the two years (October through April) following seeding was below expected levels at both sites during the study. No precipitation occurred before seeding (May 2007 to December 2007) at either site. After seeding (January 2008 to April 2008), Qurain received 110 mm and Tal Rimah received 58 mm. Expected annual precipitation levels are 150 to 200 mm and 100 to150 mm at Qurain and Tal Rimah, respectively. Rain rarely occurs in Jordan during summer (May to September). During the following year, Qurain received only 74 mm of annual precipitation and Tal Rimah received only 43 mm (December 2008 to April 2009). These levels of precipitation are much less than levels of 130 to 500 mm that forage kochia and other perennial grass species have been evaluated and recommended for in the western United States (Harrison et al. 2000).

2008 Frequency and Height

Frequency of forages observed at Qurain in August 2008 was higher ($P < 0.001$) than observed in Tal Rimah (Table 2). This is not surprising considering the higher level of precipitation that Qurain received compared to Tal Rimah. The frequency of the *Atriplex* shrubs was less ($P < 0.01$) than the forage kochia and perennial grasses. Only a few of *Atriplex* shrubs were observed during ocular observations in April 2008 and in frequency measurement recorded in August 2008. In addition, only a few native shrubs were observed. Quality of seeds of the native shrubs was not tested prior to seeding. The height of forage kochia was higher ($P < 0.001$) at Qurain than at Tal Rimah (Table 2) in August 2008. Similarly, grass heights at Qurain

were higher ($P < 0.001$) than at Tal Rimah. Higher precipitation levels at Qurain apparently allowed a greater abundance of plants to emerge (higher frequency) and allowed the plants that did emerge to grow taller. Establishment rankings of forage kochia varieties were similar at both sites (P = 0.90). Frequencies of KZ-6X, Otavny-select, and Sahro-select forage kochia were higher ($P < 0.05$) than for BC-118, Immigrant, and Pustinny-select in 2008 when evaluated over both sites. At the drier Tal Rimah site, KZ-6X, Otavny-select, and Sahro-select had an average establishment frequency of 40 to 53%; whereas, the average frequency of Immigrant, BC-118, and Pustinny-select was 10 to 21%. Conversely, at the wetter Qurain site, Otavny-select and Sahro-select had the highest establishment frequency (73 to 74%), KZ-6X was intermediate (55%), and the average establishment for Immigrant, BC-118, and Pustinny-select was 29% The ability of KZ-6X, Otavny-select and Sahro-select forage kochia to emerge and survive over the first summer with only 58 mm of precipitation (at the Tal Rimah site) suggests that forage kochia, particularly subspecies *grisea*, can germinate and survive one year in the extremely dry/harsh rangeland conditions of Jordan.

There were no differences ($P = 0.31$) in height among the six varieties of forage kochia. Many of the forage kochia plants at Tal Rimah were small seedlings less than 1 cm tall. This is consistent with other observations, where forage kochia has emerged, but remained as very small seedlings throughout one or two growing seasons during extended drought periods (Horton 2004).

Frequency of establishment did not differ ($P > 0.10$) among the perennial grass species when evaluated across sites or at Qurain (Table 3). Similarly, no differences ($P > 0.10$) in height were observed among the perennial grass varieties when evaluated across sites or at Qurain (Table 4).

2009 Frequency and Height

Tal Rimah Study Site. At Tal Rimah, no forage kochia plants nor perennial grasses seeded in December 2007 were observed in late June 2009. Apparently, the two consecutive years of extreme dry conditions (58 mm of annual precipitation in 2007/2008 and 43 mm in 2008/2009) were too severe for the plants to survive. In a separate study (unpublished data), Immigrant forage kochia, Siberian wheatgrass, and crested wheatgrass were seeded in early January 2009 at the Tal Rimah study site. However, none of these seeded varieties were observed in June 2009 further confirming that the conditions were too dry for these seeds to germinate and survive.

Qurain Study Site. The frequency of forage kochia did not change ($P = 0.61$) at the Qurain site from 2008 to 2009 (Table 3). Similar to 2008, in 2009 we observed that Sahro-select and Otavny-select were most abundant of the forage kochia varieties (Table 3). KZ-6X, Immigrant, and Pustinny-select were intermediate in frequency, and BC-118 was the least abundant of the forage kochia varieties (Table 3). The forage kochia grew well at Qurain and roughly doubled in height ($P < 0.001$) from 2008 to 2009. Sahro-select, Pustinny-select, Otavny-select, and BC-118 were all developed as larger-startured forage kochia lines, and in this study were all significantly taller than the cultivar Immigrant (Table 4).

In contrast, the frequency of the perennial grasses was lower ($P < 0.001$) in 2009 (39 ± 4%) than in 2008 (82 ± 4%) as many of the small seedlings from 2008 did not survive. Frequency trends from 2009 suggested that the Siberian wheatgrass (49.5%) may be more adapted to, and have a greater chance of survival, on the Jordan rangeland than Russian wildrye (36%) or crested wheatgrass (22%) (Table 3). The height of the perennial grasses ($P = 0.04$) increased from 2008 to 2009 at Qurain, but were still shorter than the forage kochia (Table 4).

Additional observations will be needed to determine the ability of these grasses to persist in this environment.

The frequency of *Atriplex* shrubs, which was minimal in 2008, did not change ($P = 0.62$) from 2008 to 2009 at the Qurain site.

MANAGEMENT IMPLICATIONS

Forage kochia appears to be an excellent forage resource for restoring perennial vegetation in arid rangelands of Jordan. Forage kochia emerged and survived the summer in drought conditions (70 to 110 mm) that were drier than precipitation levels of 150 to 500 mm recommended by rangeland managers for this species in the western United States. However, in conditions where annual precipitation is less than 70 mm, forage kochia may not survive.

Forage kochia can be broadcast seeded with minimal soil preparation, which will dramatically reduce restoration costs compared to transplanting nursery raised stock (Harrison et al. 2000). Many of Jordanian rangelands are remote, and operation of machinery can be difficult because of rugged terrain or large rocks on the soil surface. The Sahro-select and Otavny-select varieties performed better than the other forage kochia varieties in the drought conditions of 2008 and 2009. However, at present, these varieties have not been released as commercially available cultivars. The commercially available Immigrant variety also performed reasonably well.

Perennial grass varieties evaluated in this study originated from Eurasia and were selected for arid and semi-arid conditions in the western United States. These grass varieties also have potential to be used in reseeding Jordanian rangelands, especially in areas receiving more

than 100 mm of precipitation. The Kazak and Vavilov Siberian wheatgrass varieties may be slightly more productive than Hycrest crested wheatgrass and Bozoisky Russian wildrye in the arid conditions of Jordan.

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Table 1. Varieties of forage kochia, perennial grasses and other shrubs evaluated during the study.

Forage type	Variety	Scientific name
Forage kochia	BC-118	*Kochia prostrata* (L.) Scrad.
	Immigrant	
	KZ-6X	
	Otavny-select	
	Pustinny-select	
	Sahro-select	
Perennial grass	Bozoisky Russian wildrye	*Psathyrostachys junceus* (Fisch.) Nevski
	Hycrest crested wheatgrass	*Agropyron desertorum* (Fisch. ex Link) Schult X *Agropyron cristatum* (L.) Gaertn.
	Kazak Siberian wheatgrass	*Agropyron fragile* (Roth) Candargy
	Vavilov Siberian wheatgrass	*Agropyron fragile* (Roth) Candargy
Atriplex	Four-wing saltbush	*Atriplex canescens* (Pursh) Nutt.
	Shadscale	*Atriplex confertifolia* (Torr. & Frém.) S. Watson
Native shrubs		*Achillea fragrantissima* (Forssk) Sch. Bip
		Atriplex halimus L.
		Salsola vermiculata L.

Table 2. Frequency and heights of seeded forages at the Qurain and Tal Rimah sites in 2008 (year 1).

Forage type	Site	Frequency, %	SE[1]	Height, cm[2]	SE[1]
Pooled forages	Qurain	44[a]	2	10.7 [a]	0.6
	Tal Rimah	15[b]	2	2.2 [b]	0.7
Forage kochia	Qurain	48[a]	3	14.7 [a]	0.8
	Tal Rimah	30[b]	3	0.9 [b]	0.8
Perennial grasses	Qurain	82[a]	3	6.8 [a]	1.0
	Tal Rimah	13[b]	3	3.5 [b]	1.0
Atriplex shrubs	Qurain	3	3	--	
	Tal Rimah	1	3	--	

[1] Standard error.

[2] There was not a sufficient number of *Atriplex* shrubs to measure for an accurate evaluation of plant height.

[a,b] Site means within a forage type with differing superscripts differ ($P < 0.05$).

Table 3. Frequency of seeded forages at the Qurain sites during 2008 and 2009.

	2008		2009	
Variety	Frequency, %	SE[1]	Frequency, %	SE[1]
Forage kochia				
Immigrant	34[ab]	8	41[b]	7
Sahro-select	73[c]		67[c]	
BC-118	22[a]		18[a]	
Otavny-select	74[c]		71[c]	
Pustinny-select	31[ab]		29[ab]	
KZ-6X	55[bc]		55[bc]	
Grass species				
Kazak Siberian wheatgrass	88	4	56[a]	7
Valivov Siberian wheatgrass	80		43[ab]	
Hycrest crested wheatgrass	84		22[b]	
Bozoisky Russian wildrye	77		36[ab]	
Atriplex shrubs				
4-wing saltbush	11	3	6	1
Shadscale	0		1	
Native shrubs				
Atriplex halimus	2		1	
Salsola vermuclata	1		0	
Achillea fragrantissima	1		0	

[1] Standard error.

Table 4. Height of seeded forages at the Qurain sites during 2008 and 2009.

	2008		2009	
Variety	Height, cm	SE[1]	Height, cm	SE[1]
Forage kochia				
Immigrant	13.9	3.3	31.4a	3.1
Sahro-select	15.3		42.2c	
BC-118	13.6		39.3bc	
Otavny-select	19.9		41.3c	
Pustinny-select	15.9		42.5c	
KZ-6X	9.4		34.6ab	
Grass species				
Kazak Siberian wheatgrass	7.3	0.5	10.8	2.0
Valivov Siberian wheatgrass	7.5		11.5	
Hycrest crested wheatgrass	7.0		9.0	
Bozoisky Russian wildrye	5.6		9.3	

[1] Standard error.

Disclaimer

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