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Research Note

Potential of *Kochia prostrata* and Perennial Grasses for Rangeland Restoration in Jordan

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Abstract

Six varieties of forage kochia (*Kochia prostrata* [L.] Schrad.), two *Atriplex* shrubs native to North America, 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 2008 and 2009 at two sites. Conditions were dry with Qurain receiving 110 mm and 73 mm and Tal Rimah receiving 58 mm and 43 mm of annual precipitation during the winters of 2007/2008 and 2008/2009, respectively. Plants were more abundant and taller ($P < 0.001$) at Qurain than Tal Rimah in 2008. Forage kochia frequency was 48% and 30% in 2008 at Qurain and Tal Rimah, respectively. However, no seeded plants were observed at Tal Rimah in 2009, suggesting that 58 mm and 43 mm of annual precipitation are insufficient to allow plants to persist over multiple years. At the wetter site, forage kochia abundance in 2009 was similar ($P = 0.90$) to that observed in 2008 and plant height increased ($P < 0.001$) from 2008 (14.4 cm \pm 1.1 SE) to 2009 (38.4 cm \pm 1.1 SE). Sahro-select and Otavny-select were the most abundant forage kochia varieties ($P < 0.05$), suggesting that these experimental lines could be more adapted to the environmental conditions of Jordan than the commercially available cultivar Immigrant. Frequency of perennial grass varieties declined ($P < 0.001$) at Qurain from 82% \pm 4 SE to 39% \pm 4 SE between 2008 and 2009, respectively. Among grasses, Siberian wheatgrass had better stands than crested wheatgrass, with Russian wildrye being intermediate. Based on this study, forage kochia appears to have great potential for establishing palatable perennial shrubs in arid rangeland conditions in Jordan if annual precipitation is at least 70 mm. Arid-adapted perennial grass varieties might also be useful in rangeland restoration if annual precipitation is over 100 mm.

Resumen

Seis variedades de “kochia” forrajera (*Kochia prostrata* [L.] Schrad.), dos arbustos de *Atriplex* nativos de Norte América, y cuatro variedades de pastos perennes tolerantes a la sequía se sembraron y se evaluaron bajo condiciones de pastizales áridos en Jordania. Las variedades se sembraron en diciembre del 2007 y se hizo la evaluación en 2008 y 2009 en dos sitios. Las condiciones fueron secas, recibiendo 110 mm y 73 mm en Qurain y 58 mm y 43 mm de precipitación anual en Tal Rimah durante los inviernos de 2007/2008 y 2008/2009, respectivamente. Las plantas fueron más abundantes y altas ($P < 0.001$) en Qurain que en Tal Rimah en el 2008. La frecuencia de “kochia” forrajera fue 48% y 30% en 2008 en Qurain y Tal Rimah, respectivamente. Sin embargo, no se observaron plantas sembradas en Tal Rimah en 2009 sugiriendo que 58 mm y 43 mm de precipitación anual es insuficiente para permitir que las plantas persistan durante varios años. En el sitio más húmedo la abundancia de “kochia” forrajera en el 2009 fue similar ($P = 0.90$) al observado en el 2008 y el tamaño de la planta incrementó ($P < 0.001$) del 2008 (14.4 cm \pm 1.1 SE) a (38.4 cm \pm 1.1 SE) en el 2009. “Sahro-select” y “Otavny-select” fueron las variedades más abundantes de “kochia” forrajera ($P < 0.05$) sugiriendo que las líneas de este experimento pueden adaptarse mejor a condiciones medioambientales de Jordania que el cultivar “Immigrante” disponible comercialmente. La frecuencia de las variedades de los pastos perennes aminoró ($P < 0.001$) en Qurain de un 82% \pm 4 SE a 39% \pm 4 SE entre 2008 y 2009, respectivamente. Entre pastos, “Siberian wheatgrass” tuvo mejores poblaciones que “Crested wheatgrass,” siendo intermedio “Russian wildrye.” Con base en este estudio “kochia” forrajera parece tener un gran potencial para el establecimiento de un arbusto perenne palatable en condiciones de pastizales áridas en Jordania, si la precipitación anual es por lo menos 70 mm. Variedades de pastos perennes adaptados a la sequía pueden ser también útiles en la restauración de pastizales si la precipitación anual es menos a 100 mm.

Key Words: alternate forage sources, crested wheatgrass, forage kochia, Middle East, Russian wildrye, Siberian wheatgrass

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INTRODUCTION

The Hashemite Kingdom of Jordan is roughly 90% rangeland, 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. A large proportion of Jordanian rangeland has deteriorated and is in poor condition. Heavy stocking levels, continuous grazing near permanent water sources, dryland cultivation, and drought are some of the reasons for the downward trend in rangeland condition in Jordan (Al-Tabini 2001). Al-Tabini et al. (2008) found that the combination of water harvesting and transplanting native shrubs resulted in a seven-fold increase in forage production ($130 \text{ kg} \cdot \text{ha}^{-1}$ to $950 \text{ kg} \cdot \text{ha}^{-1}$) with an estimated economic payback period of 4–9 yr with normal or favorable precipitation. 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 is less expensive, more rapid, and requires much less labor.

Forage kochia (*Kochia prostrata* [L.] Schrad.) is a perennial polymorphic low shrub that is native to areas from the Mediterranean Basin to Siberia (Shishkin 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 through broadcasting directly on the soil surface without soil cover (Harrison et al. 2000). The soil needs to be slightly disturbed before seeding. Forage kochia is palatable, retains its quality during the winter (8% to 12% crude protein), and has been used for livestock in Kazakhstan and Uzbekistan as fall forage and winter forage for centuries (Waldron et al. 2005, 2006, 2010). 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 perennial wheatgrasses native to Siberia and Eurasia and bred for increased seedling establishment also have 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 the western United States and drought-tolerant perennial grasses under arid rangeland conditions in Jordan.

METHODS

Study Sites

The study was conducted at two sites, Qurain and Tal Rimah. Qurain is located in southern Jordan, approximately 35 km southwest of Maan (lat $30^{\circ}6'27''\text{N}$ and long $35^{\circ}28'15''\text{E}$). The site is located on silty clay soils at an elevation of 1 498 m and receives between 150 mm and 200 mm of annual precipitation. Tal Rimah is located in northern Jordan approximately 70 km east of Al-Mafraq (lat $32^{\circ}17'13''\text{N}$ and long $36^{\circ}53'55''\text{E}$) at an

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

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

elevation of 1 096 m. The site is located on clay soils overlaid by clay loam and receives between 100 mm to 150 mm of precipitation. Both sites were located on gentle terrain with nearly level slopes ($< 1\%$).

Protocol

At each site, four replicate $30 \text{ m} \times 30 \text{ m}$ blocks were established within a $65 \text{ m} \times 65 \text{ m}$ paddock fenced with net wire to exclude livestock. Within each block, six forage kochia varieties, four perennial grass varieties, and two *Atriplex* shrub species were seeded (Table 1). Three native shrub species also were seeded in each block, but due to uncertainty about seed viability, they were used as a demonstration and were not compared to the other species. Each block was divided into 15 subplots, which were randomly allocated to the 15 seed types. Each subplot ($6 \times 10 \text{ m}$) consisted of three 10-m rows placed 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 2–3 mm of soil, and grass seeds and other shrubs were covered with 3–6 mm of soil. No attempt was made to incorporate water harvesting in the study.

Variety Origin

Origin of forage kochia and grass varieties is as follows: Immigrant, the only current cultivar in the United States, was released in 1984 and originated from germplasm from Russia (Stevens et al. 1985). BC-118 is a selection from collections made by the US Department of Agriculture–Agricultural Research Service (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 et al. (2005). Immigrant, BC-118, and Pustunny-select are diploid *Kochia prostrata* subsp. *virescens* Prat.; whereas KZ-6X, Otavny-select, and Sahro-select are *K. p.* subsp. *grisea* Prat., with the latter two being tetraploids. Hycrest crested wheatgrass (*Agropyron desertorum* [Fisch. ex Link] Schult. \times *Agropyron cristatum* [L.] Gaertn.; Asay et al. 1985a), Bozoiisky Russian wildrye (*Psathyrostachys junceus* [Fisch.] Nevski; Asay et al. 1985b), and Vavilov Siberian wheatgrass (*Agropyron fragile* [Roth] P. Candargy; Asay et al. 1995) all were released by the USDA for their improved seedling vigor and establishment characteristics. Kazak Siberian wheatgrass (*Agropyron fragile* [Roth] P. Candargy) is a low-growing, very drought-tolerant population developed from pubescent collections from Kazakhstan described by Jensen et al. (2000).

Seeding Rates

Seeding rates for forage kochia and *Atriplex* were 3.6 kg \cdot ha⁻¹ pure live seeds (PLS), whereas, perennial grasses were planted at a rate of 6.5 kg \cdot ha⁻¹ PLS. Seeds from the three native shrub species (*Achillea fragrantissima* Sch. Bip, *Atriplex halimus* L., and *Salsola vermiculata* L.) were collected within 100 km of the study sites. No attempt was made to determine germination rates of native shrub seeds (PLS values).

Measurements

During mid-August 2008 and late June 2009, frequency (presence or absence) 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, 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.

Statistical Analyses

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

Due to low survivorship in Tal Rimah, analyses of the 2009 observations only included Qurain data. Statistical models for 2009 Qurain data were the same used in 2008 analyses, except that site and interactions with site were not included.

Data from 2008 and 2009 from Qurain were combined and evaluated using 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. Subplot was the subject and compound symmetry was used for modeling covariance between repeated records.

Table 2. Mean frequency and height (SE¹) of seeded forages at the Qurain and Tal Rimah sites in 2008 (year 1).

Forage type	Site	Frequency (%)	Height (cm) ²
Pooled forages	Qurain	44 (2) a ³	10.7 (0.6) a
	Tal Rimah	15 (2) b	2.2 (0.7) b
Forage kochia	Qurain	48 (3) a	14.7 (0.8) a
	Tal Rimah	30 (3) b	0.9 (0.8) b
Perennial grasses	Qurain	82 (3) a	6.8 (1.0) a
	Tal Rimah	13 (3) b	3.5 (1.0) b
<i>Atriplex</i> shrubs	Qurain	3 (3)	—
	Tal Rimah	1 (3)	—

¹Pooled standard error.

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

³Site means within a forage type with differing letters differ ($P < 0.05$).

RESULTS AND DISCUSSION

Precipitation

Precipitation during the 2 yr (October through April) following seeding was below long-term expected levels at both sites. 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. Rain rarely occurs in Jordan during the 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 130–500 mm that have been recommended for forage kochia and other perennial grass species that have been evaluated and recommended in the western United States (Harrison et al. 2000).

2008 Seedling Establishment Frequency and Height

Frequency of forage plants observed at Qurain in August 2008 was higher ($P < 0.001$) than observed at Tal Rimah (Table 2). This is not surprising, considering the higher level of precipitation that Qurain received compared to Tal Rimah. Frequency of *Atriplex* shrubs was less ($P < 0.01$) than forage kochia and perennial grasses. Only a few *Atriplex* and native shrubs were observed in August 2008. Quality of native seeds might have been poor. Seed quality always is an important consideration, especially when planting native seeds that were collected during drought conditions (Harrison et al. 2000). Other than seeded species, few other plants (e.g., weeds) were observed in study plots.

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 plants that did emerge to persist and grow taller. Seedling establishment rankings of forage kochia varieties were similar at both sites (site \times variety interaction, $P = 0.90$). Frequencies of KZ-6X, Otavny-select, and Sahro-select forage kochia were higher ($P < 0.05$) than for BC-118, Immigrant, and Pustunny-select in 2008 when evaluated at both sites. At the drier Tal Rimah site, KZ-6X, Otavny-select, and Sahro-select had an average establishment frequency of 40–53%; whereas

Table 3. Mean frequency and height (\pm standard error of the mean) of seeded forages at the Qurain site during 2008 and 2009.

Variety	Frequency (%)		Height (cm)	
	2008	2009	2008	2009
Forage kochia				
Immigrant	34 \pm 4 ab ¹	41 \pm 3 b	13.9 \pm 4.6	31.4 \pm 5.6 a
Sahro-select	73 \pm 10 c	67 \pm 9 c	15.3 \pm 3.2	42.2 \pm 6.7 c
BC-118	22 \pm 7 a	18 \pm 7 a	13.6 \pm 2.6	39.3 \pm 3.7 bc
Otavny-select	74 \pm 16 c	71 \pm 12 c	19.9 \pm 4.9	41.3 \pm 2.4 c
Pustiny-select	31 \pm 13 ab	29 \pm 11 ab	15.9 \pm 2.6	42.5 \pm 3.4 c
KZ-6X	55 \pm 12 bc	55 \pm 8 bc	9.4 \pm 2.5	34.6 \pm 2.7 ab
Grass species				
Kazak Siberian wheatgrass	88 \pm 4	56 \pm 13 a	7.3 \pm 0.7	10.8 \pm 2.0
Valivov Siberian wheatgrass	80 \pm 5	43 \pm 6 ab	7.5 \pm 0.5	11.5 \pm 1.0
Hycrest crested wheatgrass	84 \pm 4	22 \pm 3 b	7.0 \pm 0.6	9.0 \pm 0.7
Bozoisky Russian wildrye	77 \pm 5	36 \pm 10 ab	5.6 \pm 0.3	9.3 \pm 1.0
Atriplex shrubs				
Four-wing saltbush	11 \pm 6	6 \pm 3	— ²	—
Shadscale	0	1 \pm 1	—	—
Native shrubs				
<i>Atriplex halimus</i>	2 \pm 2	1 \pm 1	—	—
<i>Salsola vermiculata</i>	1 \pm 1	0	—	—
<i>Achillea fragrantissima</i>	1 \pm 1	0	—	—

¹Varieties within a type (forage kochia or grass) during a given year (2008 or 2009) with different letters differ ($P < 0.05$).

²There were not enough *Atriplex* and native shrubs to get an accurate measurement of height.

the average establishment frequency of Immigrant, BC-118, and Pustiny-select was 10–21%. Conversely, at the wetter Qurain site, Otavny-select, and Sahro-select had the highest seedling establishment frequency (73–74%), KZ-6X was intermediate (55%), and the average seedling establishment for Immigrant, BC-118, and Pustiny-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 Tal Rimah) suggests that forage kochia, particularly *K. p. subsp. grisea*, can germinate and survive 1 yr in the extremely dry/harsh rangeland conditions of Jordan.

There were no differences ($P = 0.31$) in height among forage kochia varieties. 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 seedling establishment did not differ ($P > 0.10$) among perennial grass species when evaluated across sites or at Qurain (Table 3). Similarly, no differences ($P > 0.10$) in height were observed among perennial grass varieties when evaluated across sites or at Qurain (Table 3).

2009 Seedling Establishment Frequency and Height

Tal Rimah. At Tal Rimah no forage kochia plants or perennial grasses seeded in December 2007 were observed in 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 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. None of these seeded varieties was observed in June 2009, further confirming that conditions were too dry for these seeds to survive.

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

In contrast, frequency of perennial grasses was lower ($P < 0.001$) in 2009 (39 \pm 4%) than in 2008 (82 \pm 4%) because many of the small seedlings from 2008 did not survive. Frequency trends from 2009 suggested that Siberian wheatgrass (49.5%) might be more adapted to, and have a greater chance of survival on, Jordan rangeland than crested wheatgrass (22%) with Russian wildrye being intermediate (Table 3). Height of perennial grasses ($P = 0.04$) increased from 2008 to 2009 at Qurain, but were still shorter than forage kochia (Table 3). Additional observations will be needed to determine the ability of these grasses to persist in this environment.

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 mm to 110 mm). If annual precipitation is less than 70 mm, forage kochia might not survive. Sahro-select and Otavny-select varieties performed better than other forage kochia varieties; however, these varieties have not yet been released as commercially available cultivars. The commercially available Immigrant variety also performed reasonably well.

Perennial grass varieties evaluated in this study 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 might be slightly more productive than Hycrest crested wheatgrass and Bozoisky Russian wildrye in the arid conditions of Jordan.

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