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Effects of cutting and burning on regeneration of *Alhagi sparsifolia* Shap. on the southern fringe of the Taklamakan Desert, North-west China

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Abstract. Indigenous vegetation such as *Alhagi sparsifolia* Shap. (Fabaceae) has been severely damaged in recent years because of the growing population and increasing land use on the southern margin of the Taklamakan Desert. *Alhagi sparsifolia* plays an important role in supporting the fragile ecosystem in the oasis foreland as it has multiple ecological and economic functions. Cele Oasis, located on the southern rim of the Taklamakan Desert, was used to investigate the impact of human disturbance on regeneration of *A. sparsifolia* in the oasis–desert ecotone. Observations of *A. sparsifolia* in response to cutting and burning were conducted in 2010 and 2011. The results showed that burning in spring significantly decreased height and biomass in comparison to cutting in the fall. Moreover, biomass was decreased by spring burning more than by spring cutting. Burning in spring is no advantage for the growth and survival of *A. sparsifolia*. Cutting in fall appears to be a useful treatment for increasing the production from and survival of *A. sparsifolia* that could facilitate the sustainable development of the Cele Oasis.

Additional keywords: aboveground biomass, Cele Oasis, growth characteristics.

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Introduction

Disturbances, such as fire and cutting, can interfere with plant renewal and growth (Turner 1997; Kong *et al*. 2003). The effects of burning and cutting can be favourable for some species while adverse for others. For example, the regeneration of *Molinia caerulea* (Brys *et al*. 2005) and Scots pine, *Pinus sylvestris* (Hancock *et al*. 2009), were promoted after fire, but *Hypericum perforatum* (Clark and Wilson 2001) and *Salix caroliniana* (Michx.) (Lee *et al*. 2005) were hindered. Gaisler *et al*. (2004) reported that *Trifolium repens* increased in upland meadows in the Czech Republic with cutting and/or mulching, whereas regeneration of *Rhizophora mucronata* (a mangrove) appeared to be reduced with cutting in the Philippines (Walters 2005). The effects of fire and cutting on plants appear to vary from one region to another (Alhamad *et al*. 2012). For instance, cutting inhibits the regeneration capacity of plants in tropical forests (Pearce et al. 2003) whereas cutting did not strongly affect the survival of the trees in semiarid caatinga in Brazil (Figueirôa *et al*. 2006). Information, however, on how cutting and burning affects natural plants of arid rangeland, especially in the southern fringe of the Taklamakan Desert of North-west China, is rather limited.

Indigenous vegetation in the transition zone between oasis and sandy desert on the southern fringe of the Taklamakan Desert in Xinjiang, North-west China is dominated by a few perennial plant species, including *Alhagi sparsifolia* Shap. (Fabaceae) (Qong *et al*. 2002; Bruelheide *et al*. 2003). It was estimated that the distribution of *Alhagi* covers ~1.73×10^6 ha in Xinjiang, accounting for 3.0% of the total area of rangeland in the region (Zeng *et al*. 2002*a*). Because of its wide distribution, *A. sparsifolia* plays an important role in supporting the fragile ecosystem in the oasis foreland (i.e. the transition zone between oasis and desert), stabilising sand dunes and functioning as a shelter against drifting sand (Li *et al*. 2002; Zeng *et al*. 2002*b*). As north-west winds continually move desert silt onto the oases, this ecosystem service is crucial (Xia *et al*. 1993; Siebert *et al*. 2004). In addition, *A. sparsifolia* has a high crude protein content and is of great socioeconomic significance as the main source of fodder for livestock in the oasis foreland (Thomas *et al*. 2000;

Zeng *et al*. 2002*a*). *Alhagi sparsifolia* vegetation is also an important component of the local agricultural system (Siebert *et al*. 2004), especially for the Cele Oasis.

Unfortunately, due to excessive harvest and grazing (Gries *et al*. 2005), this specialised species now faces large-scale extinction (Bruelheide *et al*. 2010). In autumn, *A. sparsifolia* is cut and stored for winter livestock forage by local people. Because of economic and population growth, more of the natural vegetation in the Cele Oasis–desert ecotone, including *A. sparsifolia*, has been cut and the ground prepared for growing crops in recent decades, an activity that primarily occurs in spring. The *A. sparsifolia* vegetation is destroyed, and few, if any, of these plants will re-sprout and survive the cutting and subsequent cultivation. Consequently, additional research to obtain information suggesting ways to promote more sustainable use of *A. sparsifolia*, and effectively protect vegetation cover in the oasis foreland, is important.

Moreover, controlled burning is also used for removing natural vegetation before cultivation, but no studies have been conducted on the effects of cutting and burning on *A. sparsifolia* in this region. Understanding how plants will respond to the disturbances mentioned above for natural vegetation regeneration management is a particular research need. Here, the focus is only on the response of *A. sparsifolia* vegetation recovery to different types of disturbance which involve cutting and burning, because these types of disturbance are all annually conducted by local subsistence farmers and their seasons of application are comparatively stable. These disturbances have been important in the process of 'oasification' in recent decades (Bruelheide *et al*. 2003; Gui *et al*. 2011).

The objectives were to determine (1) how cutting and burning affect subsequent renewal and aboveground biomass of *A. sparsifolia*, (2) whether aboveground biomass production of *A. sparsifolia* under disturbance can be estimated non-destructively, and (3) if disturbances introduced by local subsistence farmers provide sustainable management opportunities for *A. sparsifolia*.

Materials and methods

Study area

The study was carried out in an oasis–desert ecotone near the Cele Research Station of the Chinese Academy of Sciences, located between the northern edge of the Kunlun Mountains and the southern edge of the Taklamakan Desert (E 80°03′24″–E 82°10′34″, N 35°17′55″–N 39°30′00″). The climate of the study area is extremely dry with an annual average precipitation of 35.1 mm (rainfall is highly erratic) and a potential annual evaporation rate of 2600 mm (Li *et al*. 2010). Temperatures range between 41.9°C in summer and –23.9°C in winter. Vegetation cover in the Cele Oasis foreland is sparse, with an average cover of 5–20%, and is dominated by shrubby and sub-shrubby species such as *A. sparsifolia* and *Tamarix ramosissima* (Zeng *et al*. 2008). A 5–10-km-wide belt of natural vegetation in the foreland serves as a source of livestock feed as well as fuel (Qong *et al*. 2002), but large areas of *A. sparsifolia* vegetation have been destroyed by overuse, either through over-grazing by local animals or over-harvesting. The result is that the oasis is susceptible to shifting sand dunes (Siebert *et al*. 2004; Zeng *et al*. 2008). The depth of the ground watertable was observed in a well at nearly 17 m in a location 500 m to the south-east of the experimental site. Soil in the study site is very uniform. Silt is the predominant grain size fraction (>87%). No soil aggregates were found in any soil depth in the experimental plots (Gries *et al*. 2005).

Study species

Alhagi sparsifolia Shap. (Fabaceae) is a leguminous, spiny, perennial sub-shrub (Editorial Board of Flora Repubilicae Popularis Sinicae 1998) with shoots that die over the winter and re-sprout again in spring. The plants flower in summer and set fruit in the autumn (Vonlanthen *et al*. 2010*a*). The general height of *A. sparsifolia* is ~1–1.5 m or so (Li *et al*. 2002). As phreatophytes, populations of *A. sparsifolia* expand by asexual clonal reproduction (Guo *et al*. 2008; Thomas *et al*. 2008), and *Alhagi* species grow in salinised and arid regions in the native range of North-western China, Central Asia, India, Middle and Near East and as an invader in North America (Kurban *et al*. 1998).

Experimental layout and treatments

An enclosure exceeding 200 ha in the Cele Oasis–desert ecotone near to the Cele Research Station of the Chinese Academy of Sciences, has been set up as a long-term ecological experimental and observational area since 1983. Various experiments have been conducted in different parts of this enclosure, and different disturbance treatments applied. In the present study, these were three typical human activities common in the *A. sparsifolia*-dominant zone around the oasis: (1) CS (cutting in spring) represented a type of human disturbance on *A. sparsifolia* associated with the increasing trend of ploughing up the *A. sparsifolia* land for growing crops in the oasis–desert ecotone; (2) CF (cutting in autumn) represented a typical and traditional harvest use pattern of *A. sparsifolia* by local communities; and (3) BS (burning in spring) representing another type of disturbance on *A. sparsifolia* preceding cultivation. A fourth plot was selected as an untreated control. These four treatments were applied in an area where the species composition had been more or less homogeneous (i.e. *A. sparsifolia* was clearly the dominant species) since the enclosure was established. The CS and BS treatments were completed in early April (spring) when some of the tillers of *A. sparsifolia* had already sprouted; CF was completed in October (autumn) before the leaves had withered. All of the shoots of *A. sparsifolia* shrubs were cut at ground level with a hoe (a traditional method of the local people) in the experimental plots of CS and CF. Plots of BS were burned with controlled fire until no aboveground biomass survived. A cigarette lighter was used as the source of fire. The dead shoots from the previous year remain on the plants of *A. sparsifolia* and they catch fire easily. The depth of burning into the soil was within 5 cm of the ground surface. All of these three treatments were conducted once per year in the disturbed area, and their season of application was comparatively stable. However, nothing yet was known about the full potential effect of these disturbances. Therefore, observations on the regeneration characteristics of *A. sparsifolia* in response to these disturbances were carried out in 2010 and 2011.

In April 2009, three fenced treatment plots (20 × 20 m) located in the CS, CF and the BS areas, were established, and a same size plot in the undisturbed area with a similar representation of *A. sparsifolia* in the enclosure was selected as a control plot (CK) for the observations in 2010 without replicates. The distance between each treatment plot and the CK was 300 m. In 2011, in order to further clarify the differences between the three treatments and the control, three replicate plots of the treatments and the control were established respectively, and the distance between each replicate plot was 200 m.

Sampling and measurements

In both years, growth features and aboveground biomass of *A. sparsifolia* were measured in the experimental plots at the end of August.

Growth features

Alhagi sparsifolia shrubs in each plot were randomly selected to determine height. The longest horizontal extent and the longest perpendicular extent of each shrub were surveyed with a tape measure for the calculation of shrub crown volume. The number of shrubs selected for survey was 20 in 2010 and 40 in 2011.

Sample shrubs of *A. sparsifolia*, similar in average size to the shrubs in each plot were harvested at ground level with a hoe (traditional method used by local farmers) for further laboratory measurements and the aboveground biomass estimation following surveys of height and shrub crown volume. Three shrubs per plot were harvested in 2010 and 10 shrubs per plot were harvested in 2011, respectively.

The number of branches is an important indicator of regenerative capacity of *A. sparsifolia* shrubs (Maimaiti *et al.* 1995). Branch class number, graded from first – therefore, was counted. Maimaiti *et al.* (1995) also found that, as the proportion of spiny branches and thorns increased, its utilisation by grazing livestock in *Alhagi* rangelands decreased. Feeding rate is also negatively correlated with spine density (Gowda 1996). Consequently, in this study, the number of leaves, thorns and next class branches were also counted. Whole branches were chosen from each *A. sparsifolia* shrub sample for the measurement of branch class number and the number of the various organs on the shrub. One branch was selected per shrub in 2010 and three branches selected per shrub in 2011, respectively. The length and diameter of *A. sparsifolia* thorns were measured with a vernier calliper, and 30 samples of thorns on each branch were measured in 2010 and 2011.

Aboveground biomass

The aboveground biomass of *A. sparsifolia* under different disturbances was measured following the measurements of growth features. Withered stems and dead branches from the previous year in the CK were removed after harvest and not included in the measurement of aboveground biomass because the focus of this study was on the effects of the treatments on regeneration of *A. sparsifolia*. The biomass of leaves, thorns, stems and seeds were separately weighed after drying in an oven at 80°C for 48 h. The total aboveground dry matter of each shrub was calculated using the biomass of leaves, thorns, stems and seeds. The harvested biomass values for each treatment were also compared with estimates using the following equation (Siebert *et al.* 2004):

$$\ln(\mathrm{AGB}) = \mathrm{a} \times \ln(\text{shrub volume}) + \mathrm{b} \qquad (1)$$

where, a = 0.9753, b = –7.0649, AGB is aboveground biomass (g) and shrub volume (m^3) was calculated as an ellipsoid by using the shrub height, length and width.

Statistical analysis

Due to the lack of replication of treatments in 2010, the results were not subjected to statistical analysis. Statistical analyses were conducted only with the data of 2011. The data derived from the harvest of 10 shrubs in each plot of the three replicates were used to examine whether plots differed, and the test results [significant values (i.e. *P*-value) of CS, CF, BS and CK were 0.14, 0.35, 0.54 and 0.91, respectively], showed no significant differences between the plots of each treatment. Mean values of the three replicate plots were used to represent the treatments. The Kolmogorov–Smirnov test was used to check the normal distribution of data. Normal distribution was assumed for *P* if H1 >0.05. Homogeneity of variances was tested using the Levene median test ($P > 0.05$). Significance of differences between means was compared by one-way ANOVA. The least significance range method was used for multiple comparisons.

Results

Growth characteristics of A. sparsifolia after cutting and burning

The height of *A. sparsifoli*a shrubs in all treatments decreased compared with the CK in 2010. The height of the *A. sparsifolia* shrubs after cutting or burning decreased significantly compared with the CK in 2011 (Fig. 1; $P < 0.05$). The height of *A. sparsifolia* shrub showed significant differences between the different seasonal cutting treatments (i.e. CS and CF), but there was no significant difference between treatments CS and BS. The crown volume of *A. sparsifolia* shrubs of the *A. sparsifolia* shrubs after cutting or burning decreased significantly compared with the control. Statistically significant differences in shrub crown volume of *A. sparsifolia* were also found between treatments in a similar manner to those for height (Table 1).

Branch classes on *A. sparsifolia* shrubs from the bottom to the top did not exceed 4 in the experimental plots (Table 2). In the first branch class, leaf numbers of *A. sparsifolia* shrubs in CF plots were significantly higher than in the other treatment plots. Thorn numbers in CS plots were higher than in other experimental plots in the same branch class of the *A. sparsifolia* shrub. Statistically significant differences of next order branch numbers on the first branch class were also found among treatments in 2011. Leaf, thorn and next order branch numbers from second branch class to the fourth branch class all showed no significant differences among treatments (Table 2).

In the first branch class, thorn length of *A. sparsifolia* in treatment CS was significantly greater than in treatments CF and CK, and treatments CS and BS showed no significant differences (Table 3). In the second branch class, thorn length of treatment BS was significantly greater than in the other treatments and in the CK. Thorn diameter in the second branch class on treatment CS was significantly greater than in treatment CF and the CK. Thorn

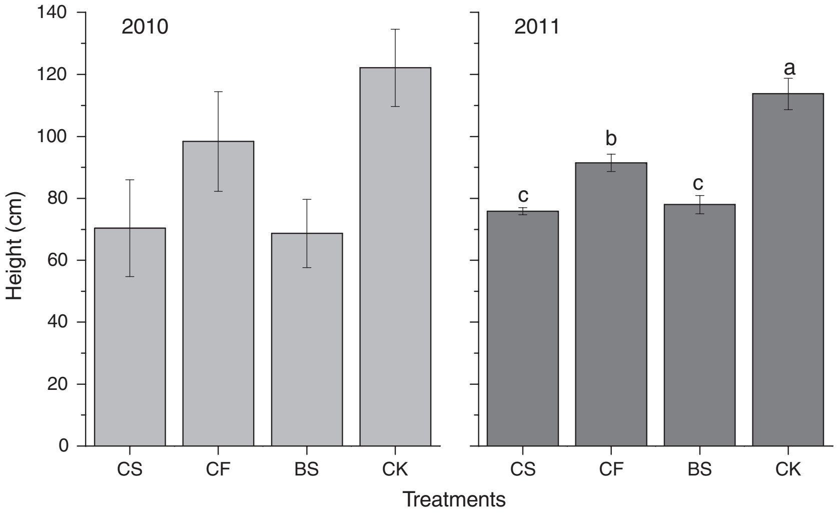

Fig. 1. Height of *Alhagi sparsifolia* shrubs under different treatments (mean ± s.d.). Note: The data were calculated with samples from one plot of each treatment ($n = 30$, no replicates of treatments in 2010; $n = 40$, 3 replicate plots of each treatment in 2011). Values with the same letter are not significantly (LSR) different among treatments ($P < 0.05$). Treatment CS: cutting in spring; treatment CF: cutting in autumn; treatment BS: burning in spring; treatment CK: control.

Table 1. Crown volume (m^3) of *Alhagi sparsifolia* shrubs under different disturbances calculated according to Siebert *et al.* (2004)

Data are reported as means ± s.d. The data were calculated with samples from one plot of each treatment ($n = 20$, no replicate plots of treatments in 2010; $n = 40$, 3 replicate plots of each treatment in 2011). The different lower case letters in each row indicate significant differences among treatments (l.s.d., $P < 0.05$). Treatment CS: cutting in spring; treatment CF: cutting in autumn; treatment BS: burning in spring; treatment CK: control

Year	Treatments			
	CS	CF	BS	CK
2010	0.6 ± 0.26	0.7 ± 0.45	0.5 ± 0.17	1.4 ± 0.86
2011	0.6 ± 0.06c	0.8 ± 0.14b	0.5 ± 0.07c	1.1 ± 0.07a

diameter in the second branch class of treatment BS was not significantly different from treatment CS or from the CK. In the third branch class, thorn length of treatment CS was significantly smaller than that of treatments CF and BS, while the thorn diameter on the same branch class in treatment CF was significantly smaller than in the other treatments and the CK.

Aboveground biomass of A. sparsifolia

The measured results of aboveground biomass of *A. sparsifolia* shrub under different disturbances were significantly different from the theoretical biomasses of *A. sparsifolia* that were calculated using Eqn 1 (Fig. 2). The mean aboveground biomass of *A. sparsifolia* shrubs in treatment CF was significantly higher than in the CS, BS and CK treatments (Fig. 2*a*), but the calculated results of aboveground biomass in treatment CF were significantly lower than in treatment CK (Fig. 2*b*). The aboveground biomass in treatment CS showed no significant difference from treatment BS in both the measured and estimated values (Fig. 2). The aboveground biomass of *A. sparsifolia* shrubs in the CK showed no significant difference between measurements and the theoretical calculation using the empirical formula, but this was not the case with the other treatments. Weight ratios of various shoot organs (leaves : stems : thorns : seeds) in treatment CS were 1.0 : 5.4 : 1.5 : 0.9. In the other treatment, the ratios were 1.0 : 4.5 : 1.1 : 0.4 in treatment CF; 1.0 : 2.9 : 0.9 : 0.3 in treatment BS; and 1.0 : 2.9 : 1.0 : 0.2 in the CK.

The average biomass of stems in treatment CF was significantly greater than in the other treatments and the CK; there was no significant difference in the biomass of stems between treatments CS and CK (Fig. 3). A statistically significant difference was found in the biomass of leaf between treatments CF and BS, but there was no significant difference in the biomass of leaf between treatments CF and CK or between treatments BS and CK. Moreover, the biomass of thorns in treatment CF was significantly larger than in treatment BS. The biomass of seeds of treatments CS and CF were larger than in treatments BS and CK, and treatment BS showed no significant difference from the control treatment.

Discussion

Alhagi sparsifolia exhibited significant changes in height and crown volume after cutting and burning in this study. Brockway *et al.* (2002) concluded that burning shortgrass prairies during the growing season appears to place the plant community at greater risk of decline or stagnation. A previous study by Asaeda *et al.* (2006) found that cutting in June reduced the rhizome resource storage more than cutting in July. The earlier cutting was a better control option because it reduced the vigour of the stand. Cutting and burning in spring destroyed the stems and buds of *A. sparsifolia* shrubs and stunting of *A. sparsifolia* growth was also observed in the burned plots. After burning in spring, the height of *A. sparsifolia* was 31% lower than that in the CK in 2011.

Table 2. Numbers of leaves and thorns on each succeeding order of branches, as well as the numbers of the next orders of *Alhagi sparsifolia* under different treatments

Data are reported as means ± s.d. The data were calculated with samples from each branch class of *A. sparsifolia* on plots of each treatment (no replicate plots of treatments in 2010; 3 replicate plots of each treatment were used in 2011). The different lower case letters in each row indicates significant differences of thorn length among treatments (l.s.d., $P < 0.05$). Treatment CS: cutting in spring; treatment CF: cutting in autumn; treatment BS: burning in spring; treatment CK: control. A fourth class branch was only formed on the plants of treatment CF in 2010 and of treatment CS in 2011, and, therefore, no data on the thorn characteristics can be given for the fourth class branch of the other treatments

Year	Branch class	Item	Treatments			
			CS	CF	BS	CK
2010	1st (*n* = 3)	Leaf	9 ± 1.7	24 ± 7.4	14 ± 2.3	9 ± 5.0
		Thorn	23 ± 4.5	23 ± 11.9	23 ± 1.7	27 ± 4.7
		Next order branch	41 ± 6.8	56 ± 3.2	36 ± 3.1	21 ± 6.8
	2nd (*n* = 9)	Leaf	26 ± 2.4	35 ± 8.6	23 ± 5.4	14 ± 3.0
		Thorn	41 ± 3.2	38 ± 7.8	33 ± 3.6	37 ± 9.2
		Next order branch	28 ± 12.7	27 ± 7.6	8 ± 3.1	21 ± 8.7
	3rd (*n* = 27)	Leaf	14 ± 6.8	14 ± 8.8	6 ± 2.2	7 ± 9.1
		Thorn	13 ± 11.6	16 ± 6.4	1 ± 1.4	12 ± 10.8
		Next order branch	–	1 ± 2.3	–	–
	4th (*n* = 9)	Leaf	–	16 ± 9.4	–	–
		Thorn	–	13 ± 7.7	–	–
		Next order branch	–	–	–	–
2011	1st (*n* = 30)	Leaf	14 ± 4.2b	48 ± 6.6a	13 ± 1.4b	13 ± 3.4b
		Thorn	78 ± 4.4a	67 ± 4.0b	50 ± 1.2c	31 ± 0.4d
		Next order branch	56 ± 6.1a	55 ± 3.2a	44 ± 1.5b	23 ± 0.5c
	2nd (*n* = 30)	Leaf	33 ± 3.6	36 ± 2.1	35 ± 3.6	34 ± 4.3
		Thorn	22 ± 3.0b	31 ± 3.3a	26 ± 1.8ab	26 ± 3.5ab
		Next order branch	22 ± 2.1a	23 ± 4.6a	11 ± 1.3b	19 ± 2.0a
	3rd (*n* = 30)	Leaf	11 ± 1.0	15 ± 8.7	14 ± 2.3	12 ± 1.1
		Thorn	14 ± 1.1	15 ± 10.0	18 ± 1.3	9 ± 1.5
		Next order branch	2 ± 0.2	–	–	–
	4th (*n* = 30)	Leaf	12 ± 0.8	–	–	–
		Thorn	12 ± 0.6	–	–	–
		Next order branch	–	–	–	–

Table 3. Length and diameters of the thorns of *Alhagi sparsifolia* shrubs under different treatments

Data are reported as means ± s.d. The data were calculated with samples from each branch class of *A. sparsifolia* one plot of each treatment ($n = 30$, no replicates of treatments in 2010; 3 replicate plots of each treatment were used in 2011). The different lower case letters in each row indicates significant difference of thorn length among treatment (LSR, $P < 0.05$), capital letters indicate significant difference of thorn diameter. Treatment CS: cutting in spring; treatment CF: cutting in autumn; treatment BS: burning in spring; treatment CK: control. A fourth class branch was only formed in the plants of treatment CF in 2010 and of treatment CS in 2011, and, therefore, no data on the thorn attributes can be given for the fourth class branches of the other treatments

Year	Branch class	Treatments							
		CS		CF		BS		CK	
		Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)	Length (mm)	Diameter (mm)
2010	1st	29.2 ± 6.10	1.5 ± 0.42	21.3 ± 5.05	1.1 ± 0.35	24.0 ± 7.46	1.3 ± 0.38	23.2 ± 5.70	1.2 ± 0.22
	2nd	26.3 ± 5.99	1.3 ± 0.32	23.9 ± 5.76	1.0 ± 0.21	24.6 ± 8.68	1.0 ± 0.41	21.0 ± 5.52	0.8 ± 0.18
	3rd	22.6 ± 6.46	0.9 ± 0.24	22.9 ± 4.55	0.8 ± 0.10	21.9 ± 7.28	0.8 ± 0.21	20.1 ± 7.95	0.7 ± 0.16
	4th	–	–	17.6 ± 3.58	0.6 ± 0.11	–	–	–	–
2011	1st	31.3 ± 0.22a	1.9 ± 0.07A	23.8 ± 3.06b	1.2 ± 0.05B	29.7 ± 1.61a	1.7 ± 0.34A	22.6 ± 3.75b	1.2 ± 0.14B
	2nd	23.7 ± 0.53b	1.3 ± 0.07A	25.5 ± 2.47b	0.8 ± 0.08C	29.6 ± 2.10a	1.2 ± 0.10AB	22.8 ± 1.55b	1.17 ± 0.10B
	3rd	20.8 ± 0.68b	0.9 ± 0.07A	25.3 ± 3.55a	0.6 ± 0.06B	25.2 ± 1.61a	0.9 ± 0.02A	20.8 ± 2.10b	0.8 ± 0.13A
	4th	20.1 ± 1.96	0.7 ± 0.02	–	–	–	–	–	–

Vonlanthen *et al*. (2010*a*) indicated that the main reproduction mode of *A. sparsifolia* is clonal spread with belowground tillers. Shrubs of *A. sparsifolia* in non-disturbed plots with well preserved dead branches from the previous year could shade the base of the plants, reducing solar radiation resulting in the postponement of tiller germination compared with disturbed plots (Maimaiti *et al*. 1995). Hence, removal of these branches by cutting or burning will influence this interaction. In addition,

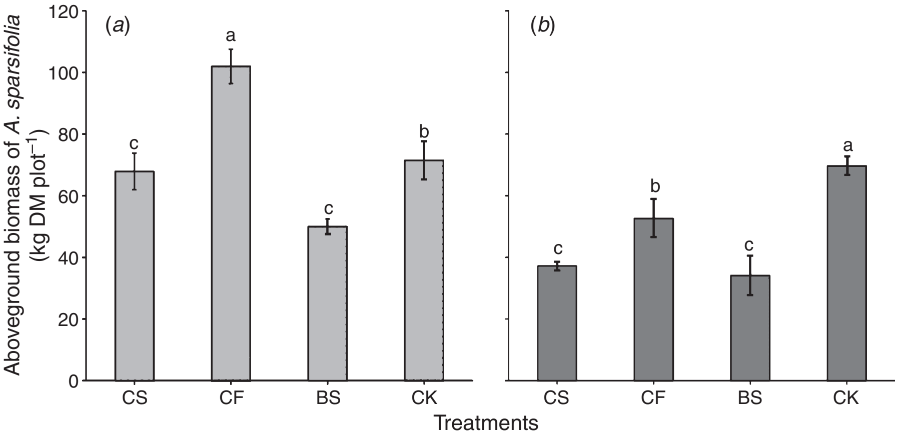

Fig. 2. The aboveground biomass of *Alhagi sparsifolia* under different treatments. Note: The data were calculated with samples from plots of different treatments in 2011. (*a*) The measured results of aboveground biomass of *A. sparsifolia* ($n = 3$); (*b*) the theoretical biomass of *A. sparsifolia* calculated with shrub volume according to Eqn 1 ($n = 3$). The different lower case letters indicate significant difference among treatments (LSR, $P < 0.05$). Treatment CS: cut in spring; treatment CF: cut in autumn; treatment BS: burning in spring; treatment CK: control.

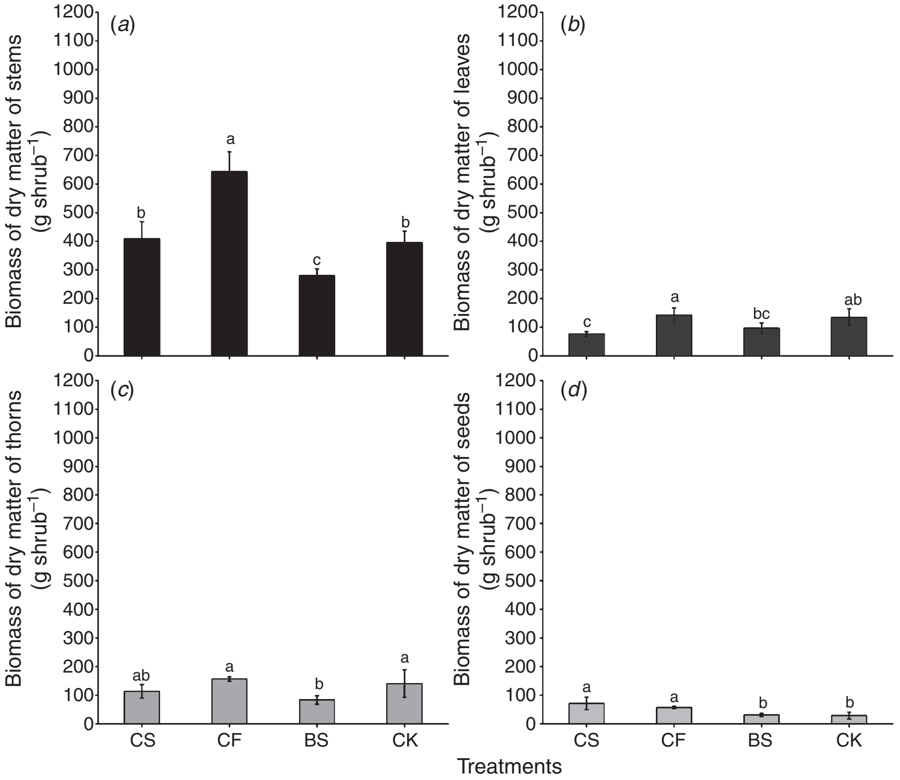

Fig. 3. Biomass of dry matter of shoot organs on *Alhagi sparsifolia* shrubs under different treatments. Note: The data were calculated with samples from plots of different treatments in 2011 ($n = 10$, 3 replicate plots of each treatment). (*a*) Biomass of dry matter of stems; (*b*) biomass of dry matter of leaves; (*c*) biomass of dry matter of thorns; (*d*) biomass of dry matter of seeds; the different lower case letters indicate significant differences among treatments (LSR, $P < 0.05$). Treatment CS: cut in spring; treatment CF: cut in autumn; treatment BS: burning in spring; treatment CK: control.

the vegetative growth stage of non-disturbed *A. sparsifolia* shrubs was longer than that in the disturbed plots (Xia *et al*. 1995) and so the plants of *A. sparsifolia* were significantly taller. It would also explain why the patterns of differences in biomass of *A. sparsifolia* shrubs between disturbed and undisturbed plots were not the same as those for plant height.

Plants injured early in ontogeny were able to compensate for loss of biomass and fecundity, whereas plants injured later were less successful in regeneration and compensation (Latzel *et al*. 2011). In this study, autumn treatments were implemented in October in each previous year and spring treatments were implemented in April in any given year. The *A. sparsifolia* vegetation disturbed in spring had only 4 months to recover from disturbance compared with nine months for the autumn treatments.

As a legume, *A. sparsifolia* can utilise atmospheric nitrogen (N) (Zeng *et al*. 2002*b*). Arndt *et al*. (2004) reported that the N concentration of *A. sparsifolia* was greatest in April and declined consistently towards the end of the growing season in October. The energy-demanding process of biological N fixation in *A. sparsifolia* (Thomas *et al*. 2006), which can contribute more than 80% of the total N concentration of the photosynthetically active organs in these stands (Arndt *et al*. 2004), might have resulted in a decrease in the growth characteristics of *A. sparsifolia* after cutting in the spring compared with the autumn. The results of this study agree with the conclusion of Latzel *et al*. (2011) that the later the disturbance, the worse the regenerative success and regrowth of woody shrubs.

Gowda and Raffaele (2004) reported that the number of spines showed a significant increase for plants growing in the burned treatment compared with unburned plants, and they concluded that the increments in spine density should be considered an induced response triggered by fire. It would explain why there were considerably higher thorn numbers of *A. sparsifolia* sub-shrubs after spring burning than in the undisturbed plants. After cutting, a similar increase was found in the amounts of leaves and thorns. Increases in leaf and stem biomass can improve the photosynthetic potential of plants, and increase the allocation of photosynthetic products to the shoots (Holland and Detling 1990).

Plants defend themselves using various physical structures, including spines and thorns (Yamazaki and Takakura 2011) and the production of spines is a common type of physical protection against vertebrate herbivores in species of the Fabaceae (Ronel *et al*. 2010). As the potential herbivory pressure in the oasis forelands is very intense because of the large numbers of camels, donkeys, sheep, and goats raised in the oases (Zeng 2004), the significantly higher thorn number on the first branch class of *A. sparsifolia* sub-shrubs after spring cutting compared with the other treatments, might be an induced defence of the plants against the potential herbivores because the basal spines may protect them against grazing (Gowda 1996). Additionally, Gowda (1996) documented that increased spine length may result in better protection of the foliage, which probably explains the increases in thorn length of *A. sparsifolia* after spring cutting and burning.

According to Siebert *et al*. (2004), aboveground biomass of naturally growing *A. sparsifolia* shrubs can be estimated non-destructively. However, assuming the aboveground parts to be ellipsoid in shape gave estimates of shrub volumes that were not suitable for estimates of the aboveground biomass of disturbed *A. sparsifolia* shrubs, because the results of the calculations were significantly lower than the actual measurements except for the CK.

Gries *et al*. (2005) indicated that maximal shrub mass was reached in June and remained constant until September. Cutting in the autumn resulted in the greatest production of aboveground biomass in the following year when all treatments were compared. Considering the ongoing degradation of the foreland vegetation in the oases, cutting in the autumn might increase the chances of preserving this vegetation and its multiple functions in the future (Vonlanthen *et al*. 2011).

After cutting and burning in spring, the bare soil absorbs more solar radiation, increasing temperature and evaporation (Zhou and Earle 1997) compared with the undisturbed plots. In the desert, the temperature of the ground surface can exceed 70°C at noon; these higher temperatures causing the decline of cell vitality and limiting the growth of *A. sparsifolia* (Xue *et al*. 2011). This could be one reason that spring cutting and burning biomass was lower than that in the CK.

In arid environments where water availability is low and decomposition rates are too slow to sustain vigorous plant productivity, fire quickly reduces aboveground biomass and rapidly releases nutrients that were previously immobilised in accumulated organic matter (DeBano *et al*. 1998). *Alhagi sparsifolia* is known as an obligate phreatophyte (Bruelheide *et al*. 2010), although fire may burn withered branches of the preceding year and cause changes in the soil nutrient content, the changes are mainly concentrated in the surface layer when there is no precipitation to transport nutrients down to deeper layers where *Alhagi* roots are located. Fire cannot promote the nutrition supply processes needed for *Alhagi* regeneration. The decrease in the aboveground biomass of *A. sparsifolia* in the burnt plots supports the hypothesis that burning would reduce vegetation production and cover (Davies *et al*. 2007). Spring burning has a detrimental effect on *A. sparsifolia* in the desert–oasis ecotone. The reduction in the production of vegetation by burning may be a long-term impact, and, therefore, farmers should consider this negative effect before burning for land ploughing in this region.

The aboveground biomass allocation to compartments (i.e. weight ratios of various shoot organs) of *A. sparsifolia* shrubs was significantly different between treatments. Because the number of sharp thorns in hay used as feed will affect intake (Jiang *et al*. 2010), the proportion of stems or thorns resulting from an increase in shoot biomass would result in less leafy animal feed and so decrease utilisation efficiency (Zhang *et al*. 1995). In terms of the value of *A. sparsifolia* as forage, if the proportion of spiny branches and thorns increased, making the vegetation less preferred, the result would be lower utilisation of *Alhagi* rangeland by grazing livestock.

It has been found that the successful regeneration of *A. sparsifolia* from seed is very rare (Bruelheide and Jandt 2004), and is only possible shortly after rare flooding events (Vonlanthen *et al*. 2010*b*). Clonality assures long-term persistence in habitats where establishment from seeds is rare and most clonal plants reproduce both by sexual and vegetative means (Honnay and Bossuyt 2005). Vonlanthen *et al*. (2011) reported that *A. sparsifolia* seeds are dispersed by mammals.

Endozoochorous dispersal by livestock, such as sheep, is important in providing favourable sites for germination and seedling establishment as well as for the colonisation of new habitats in grazed ecosystems (Ramos *et al*. 2006). The significant increase in the seed biomass of *A. sparsifolia* under disturbance seems to be a propagation strategy of plants. Passage of seeds through the digestive tract of mammals (Yu *et al*. 2012) could increase the opportunities for *A. sparsifolia* to become established on river banks at a time when the surface layers down to the ground watertable are water-saturated, which is only the case at or shortly after sporadic flooding events (Vonlanthen *et al*. 2010*a*).

The conflict between socioeconomic development and protection of natural vegetation is a key problem that local people must confront. It seems clear that cutting in the autumn could improve the production of *A. sparsifolia*, sequentially affording a greater supply of fodder for livestock; moreover, *A. sparsifolia* could also be conserved as a feed with a high nutritive value, which could provide substantial economic benefits, lessen the pressure on the rangelands, and strengthen the fragile ecology of the Cele Oasis. The research also demonstrated that sustainable use of this ecologically and economically important vegetation may be possible but requires flexible and sound management.

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