Characteristics of the clonal propagation of *Alhagi sparsifolia* Shap. (Fabaceae) under different groundwater depths in Xinjiang, China

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Abstract. Clonal reproduction of plants commonly occurs in arid areas because seedling establishment is rare in such severe environments. The features of clonal architecture differ not only among plant species but also within the same species growing in different environments. The characteristics of clonal propagation of *Alhagi sparsifolia* Shap. (Fabaceae), growing on the margins of Cele Oasis on the southern rim of the Taklamakan Desert, were investigated in September 2010. The study was conducted on three sites with different groundwater depths (2.5, 4.5, and 11.0 m). The results showed that the root suckering depth and the ability to expand and the biomass of coarse lateral roots of *A. sparsifolia* significantly increased when the groundwater depth increased. Moreover, the vegetative regeneration capacity of *A. sparsifolia* significantly declined with increasing groundwater depth, and the canopy cover at the site with a groundwater depth of 2.5 m was significantly greater than at the other two sites. There was no difference in aboveground biomass at the three sites. In such hyper-arid environments with a scarcity of soil nutrients, it was demonstrated that groundwater depth plays an important role in the clonal growth and propagation traits of *A. sparsifolia*. Increases in the groundwater depth as a result of over-use of oasis water for irrigation could lead to reduced populations of this important species in the interfaces between oases and the surrounding desert.

Additional keywords: hyper-arid, oases, root suckering, shrubs, vegetative reproduction.

Introduction

Clonal propagation is widespread throughout the plant kingdom, and both productive and infertile habitats may be dominated by clonal species. Clonal growth is characterised by the ability of plants to produce offspring that are genetically identical to the parent and are potentially independent (Price and Marshall 1999). The complexities of clonal architectures differ not only among plant species but also within the same species growing in different environments (Stuefer 1996; Ikegami *et al*. 2007). Under heterogeneous growing conditions, clonal plants develop a variety of architectural forms, and may respond to variation in environmental factors by plastic adjustment of their morphology (Stuefer 1996; Huber-Sannwald *et al*. 1997, 1998), such as changing the root architecture to enhance acquisition of essential resources (Dong 1993; Dong *et al*. 1996). Although there has been an increased interest in the biology of clonal plants over the last few decades (Jackson *et al*. 1985; Dong 1993; Dong *et al*.

1996; Stuefer 1996; Wiehle *et al*. 2009), less attention has been paid to clonal shrubs than to herbaceous species or trees, especially for shrubs distributed in arid or extremely arid areas. In arid areas, sufficient rainfall for seed germination, seedling recruitment, and survival to reproductive age is a rare event. Therefore, clonality (asexual reproduction) is a very common occurrence (Yang *et al*. 2009).

Alhagi sparsifolia Shap. is a spiny, perennial, deep-rooting subshrub in the family Fabaceae, and is a typical clonal species in arid areas. It is typically found in the transition zone between an oasis and the open desert, for example at oases on the southern fringe of the Taklamakan Desert in Xinjiang, Northwestern China. This desert is the second largest in the world and is characterised by a hyper-arid climate with an average annual precipitation <50 mm. As phreatophytes in this hyper-arid environment, plants of *A. sparsifolia* are completely dependent on water uptake from the groundwater reservoir, or

its capillary fringe (Zeng *et al.* 2002; Siebert *et al.* 2004; Gries *et al.* 2005; Thomas *et al.* 2008). The groundwater table under mature stands of *A. sparsifolia* may be up to 17.5 m below the soil surface, or up to 24 m for plants on the tops of sand dunes (Vonlanthen *et al.* 2011). Seedlings can only appear and survive after flooding and are now rarely seen because flooding hardly ever occurs, due to the expansion in human population in oases and increasing water use for developing agricultural systems (Gui *et al.* 2011). Regeneration of *A. sparsifolia* mainly occurs by vegetative propagation through root suckers, which develop from the extensive system of lateral roots. The root architecture, particularly the extensive lateral root system from which root suckers are developed, needs further investigation under natural conditions with different groundwater depths because root suckering is so important for propagation in such harsh environments. Characteristics such as the depth, angle, biomass, topology, and structure are important because these traits directly affect water and nutrient acquisition and also influence suckering ability and ramet survival.

Zeng *et al.* (2009, 2012) described the root architecture and suckering ability of *A. sparsifolia* seedlings (Fig. 1) in the horizontal zone under different irrigation regimes. They pointed out that there was significant variation among irrigation regimes, and that the suckering ability or suckers (ramets) decreased along a gradient of decreasing soil water availability. Under natural conditions, however, soil water availability is mainly controlled by groundwater depth, and water uptake from depth and hydraulic redistribution are probably important processes in shrublands. Root systems of woody plants which span soil layers of different water potential can act as conduits that transfer soil water from layers of wet soil to dry soil (Burgess *et al.* 2001; Bleby *et al.* 2010). This mechanism may also be important in survival and suckering of *A. sparsifolia*. There is a need to understand the effects of groundwater depth on the ground cover, aboveground biomass, and root suckering of *A. sparsifolia*.

Alhagi sparsifolia is important not only because it is a deep-rooting species typical of hyper-arid zones but also because of the part it plays in the agricultural systems of oases. It serves as an important source of fuel, firewood, and construction material, and is also grazed and browsed by sheep, goats, and camels (Zeng *et al.* 2002; Siebert *et al.* 2004; Li *et al.* 2012). Perhaps more importantly, it is a dominant species and, together with other perennial indigenous species such as *Tamarix ramosissima*

Ledeb. (Tamaricaceae) and *Karelinia caspica* (Pall.), provides shelter for oases against the strong winds from the north-west and decreases soil erosion and sand drift (Thomas *et al.* 2008; Gui *et al.* 2011; Vonlanthen *et al.* 2011). By trapping loose soil and sand, this peripheral vegetation belt performs an essential function promoting oasis sustainability. Understanding the characteristics of clonal propagation of *A. sparsifolia* under different groundwater depths will help to protect this species and help to maintain oasis ecological integrity.

The objective of this study was to describe and understand the clonal propagation and growth traits of *A. sparsifolia* along a gradient of increasing groundwater depth. It is possible that the vegetative regeneration capacity of *A. sparsifolia* would decline along such a gradient. As the root suckering arises from the extensive lateral roots near the soil surface (suckering layer), the following hypotheses were tested: (*1*) that the suckering depth and the angle between the genet lateral root and sucker lateral root would increase, and the biomass and expanding ability of these lateral roots would decrease, because the soil moisture content is decreased dramatically on the surface soil; and (*2*) that the growth characteristics above ground, such as the height, cover, and biomass, would decrease along a gradient of increasing groundwater depth. To test these hypotheses, *A. sparsifolia* plants growing in sites with different groundwater depths were dug up and the growth traits above ground and the lateral root system, from which the suckering arose, were investigated and analysed.

Materials and methods

Study area

The Cele Oasis (35°17′55″–39°30′00″N, 80°03′24″E–82°10′34″E) is in the central part of the southern rim of the Taklamakan Desert and the northern piedmont of the Kunlun Mountains and has comparatively comprehensive oasis–desert ecotone characteristics. The groundwater depth ranges from 2.5 to 15.0 m and *A. sparsifolia* is distributed across this area. The Cele Oasis is characterised by a hyper-arid climate with <50 mm annual precipitation, a mean annual evaporation rate of 2595 mm, and mean annual temperature of 11.9°C. It is perennially windy, and the prevailing winds are from the north-west (Gui *et al.* 2010). In the ecotone, the soils are homogeneous with silt contents
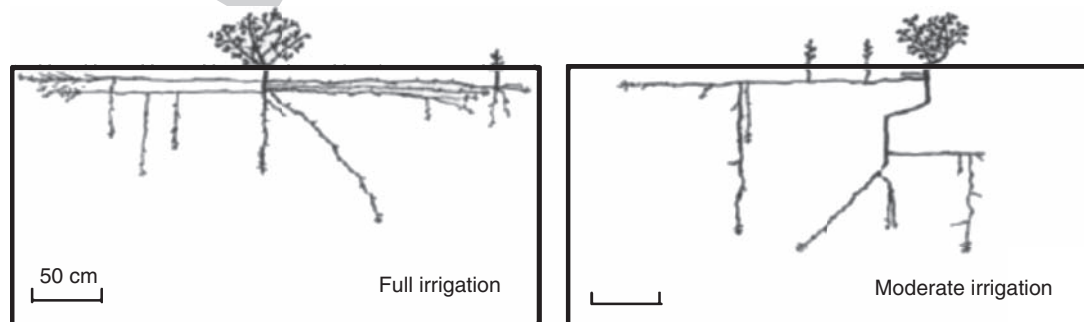
Fig. 1. Root morphological characteristics of *Alhagi sparsifolia* seedlings at the Cele Oasis, Xinjiang, China. *Alhagi sparsifolia* seedlings were excavated intact, and their root distribution was recorded. The whole plants were then placed horizontally on the ground and a side view of the root system drawn by hand on coordinate paper (Zeng *et al.* 2012).

usually >88% and with maximum sand content of ~8% (Thomas *et al.* 2000).

Experimental design

Root excavation is difficult below ~15.0 m, either using an excavator or by manual methods, and deeper excavations will destroy much natural vegetation. Therefore, 11.0 m was selected for the deepest excavation. Three sites were selected for studying the clonal propagation of *A. sparsifolia* with groundwater depths of 2.5 m (1339 m a.s.l.), 4.5 m (1346 m a.s.l.), and 11.0 m (1353 m a.s.l.). *Alhagi sparsifolia* was distributed across each site and no other species of plants were present.

In September 2010, a sampling plot of ~8 m by 8 m was selected at each site, and four genets of *A. sparsifolia* were randomly selected to study the growth characteristics above ground and the lateral root formation below ground. Plant height, basal diameter, number of shoot branches, and crown diameter of the four selected plants were first measured using a ruler or tape. The percentage of each sampling plot covered by the canopies of the *A. sparsifolia* plants was also estimated. To obtain a better estimate, cover of *A. sparsifolia* of two areas (each 8 m by 8 m) adjacent to each plot was also estimated.

Root excavation was used to investigate the root suckering traits, and the lateral root formations from which the suckering developed. An excavator was used to dig a trench along one edge of the plot, and then soil was removed manually across the plot to track the exposed *A. sparsifolia* root systems. Soil was removed down to near the groundwater table. During the excavation process, the root-spread area was maintained as much as possible. The depth of suckering for each *A. sparsifolia* was measured by ruler, and the lateral root angles between genets and suckers by protractor in degrees from the vertical. The numbers of ramets that arose from each genet were also recorded. Locations, coordinate labelling, and coordinate paper were used on-site to map the spatial distribution (in vertical view) of the suckering layer at a scale of 1 : 20. After excavation, the selected four genets on each plot were removed separately. Their lateral roots were first rinsed and then divided into two classes based on root diameter (≥ 5 mm and <5 mm; Steele *et al.* 1997). The root diameters were measured by vernier caliper. Finally, the suckering layer roots of the sampled plants together with the shoots were dried in an oven at 85°C until a stable weight was reached. The dry weight was weighed to $\pm 0.1\%$.

Soil samples were collected at each site using an augur at depth increments of 0.2 m (site with groundwater depth 2.5 m) or ~0.4 m (sites with groundwater depths 4.5 and 11.0 m), and the soil moisture and nutrient contents were measured. The soil moisture content (gravimetric) previously measured in September 2007 and 2009 at the 2.5 m and 4.5 m sites were also used. Three soil samples were taken at each depth, and each was oven-dried (105°C) to constant weight. The gravimetric soil water content was measured in the laboratory, as well as the contents of soil organic matter, total nitrogen (N), total phosphorus (P), and total potassium (K). Soil organic matter content was determined by the oil bath–K_2CrO_7 titration method. Total N content was determined by the semi-micro Kjeldahl method, total P content colourimetrically after wet digestion with $H_2SO_4 + HClO_4$, and total K content by the flame photometer method.

Data analyses

One-way analyses of variance (ANOVAs) procedures, using plants at the experimental unit, were performed to assess the influences of different groundwater depths on variables above ground (height, cover, crown diameter, shoots branches, and biomass) and below ground (biomass). If the differences were significant (i.e. $P < 0.05$), the univariate least significant difference (l.s.d.) test was used for a post-hoc separation of means. In addition, a *t*-test (at $P = 0.05$) was used to analyse the differences in biomass between above and below ground at each site.

In order to understand the ability of lateral roots to expand under different groundwater depths, the fractal method was used to study lateral root structure. Fractal geometry can be used to describe complex natural objects using a parameter-fractal dimension (*D*) generated by an algorithm. Root systems with higher *D* values are considered to have more highly branching structures (Tatsumi *et al.* 1989). In this study, the box dimensions on lateral roots (*D*) of each sampled plant, including its ramets, were calculated. The analysis was as follows. In the sectional view of the root suckering layer, divided into squares with side *r*, the number $N(r)$ of squares that intersected the roots was counted, and *D* was calculated using the following equation:

$$\log N(r) = -D\log r + \log k \qquad (1)$$

where *k* is a constant, $\log N(r)$ was plotted against $\log r$, and *D* is the fitting slope of the logarithmic curves. Values for *D* can vary between 1 and 2 (Tatsumi *et al.* 1989). In this study, *r* was assigned values of 0.4, 0.8, and 1.6 cm (Nielsen *et al.* 1997). Based on the sectional view of the suckering layer, the number of squares intersected by roots, $N(r)$, was recorded for each level of *r*. Equation 1 was applied to groups of $N(r)$ and *r*, and $\log N(r)$ *v.* $\log r$ plotted to obtain *D* values from the resulting slope of the straight line. The variations of *D* values among different sites were analysed using ANOVA, and l.s.d. was used to determine if the differences were significant at $P = 0.05$

Statistical analyses used the SPSS 16.0 software (SPSS Inc., Chicago, IL) with three replicates, and Photoshop 7.5 (Adobe Systems Inc., San Jose, CA) was used to generate the root distribution maps.

Results

Root characteristics

Depth

The average suckering depth was 0.22 m below the soil surface at the site with groundwater depth 2.5 m, compared with suckering depth >0.5 m at the sites with groundwater depths 4.5 and 11.0 m, showing that suckering depth increased under deeper groundwater conditions to some degree. However, suckering depth never exceeded 1 m in any of the groundwater depth conditions. As the lateral roots from which suckers arose expanded horizontally, they produced many vertical roots. At the site with groundwater depth 2.5 m, many of the vertical roots of these suckers or ramets grew down to the groundwater table,
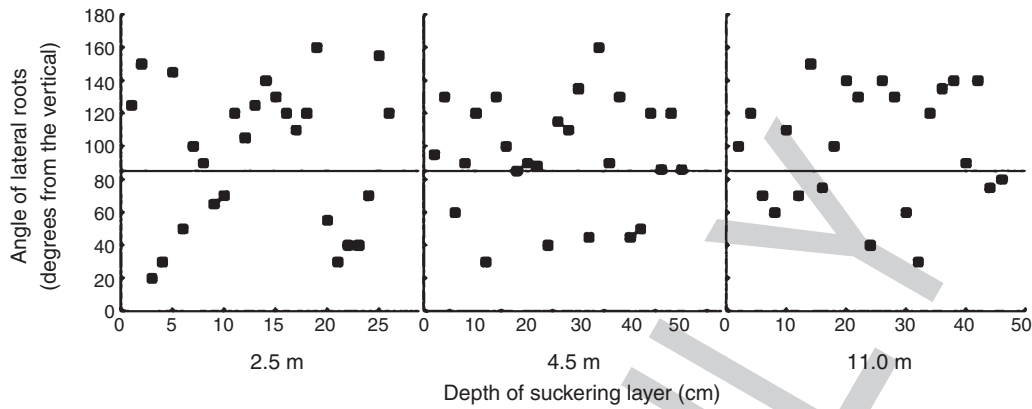
Fig. 2. Variations in lateral roots angles (degrees from the vertical) of *Alhagi sparsifolia* under different groundwater depth conditions (2.5, 4.5, 11.0 m) at the Cele Oasis, Xinjiang, China, in September 2010. The sampling plot was 8 m by 8 m on each selected site, and in each sampling plot, four genets of *A. sparsifolia* were randomly selected to survey the lateral root angles.

but few vertical roots of suckers grew into the groundwater table with 4.5 and 11.0 m groundwater depths. However, the vertical roots of all genets reached the groundwater table at each site.

Angle

There were no obvious differences in the angles of lateral roots of plants growing above different groundwater depths (Fig. 2). The lateral roots irregularly expanded in different directions and ~60% of the angles exceeded 90° under every groundwater depth condition. The angles were mainly concentrated in the range between 90° and 100°. No statistical analyses were performed on the data.

Biomass

The fine root biomass (<5 mm) showed significant decreases as the groundwater depth increased (Fig. 3). However, the coarse root biomass significantly increased as the groundwater depth increased, and the proportion of total root biomass comprising coarse roots also increased with increasing groundwater depth, being 33%, 90%, and 98% of the biomass of the roots, respectively.

Fractal dimension

According to the algorithm, groundwater depths of 2.5, 4.5, and 11.0 m had *D* values of 1.21 ± 0.15, 1.36 ± 0.15, and 1.74 ± 0.14, respectively. There was no significant difference between the values for groundwater depths 2.5 and 4.5 m ($P > 0.05$), but their *D* values were significantly lower than that of groundwater depth 11.0 m. These differences indicate that the roots had more expanding ability where the groundwater depth was 11.0 m.

Plant structural characteristics

Ramets

The numbers of ramets significantly decreased ($P < 0.05$) as the groundwater depth increased from 2.5 to 4.5 and 11.0 m. The maximum numbers of ramets generated by a single genet at the sites with groundwater depths 2.5, 4.5, and 11.0 m were 17, 10,
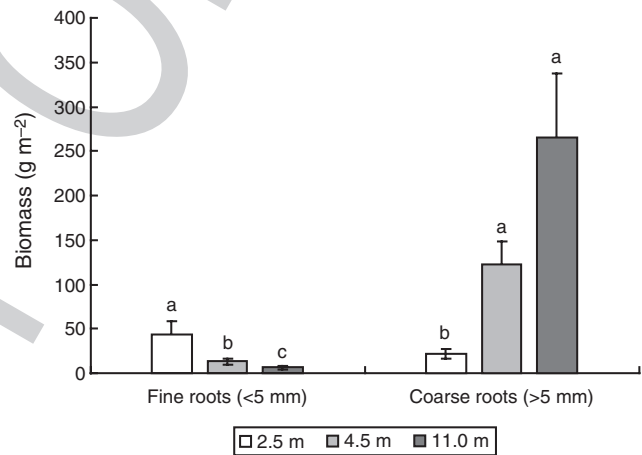

Fig. 3. Variation in lateral root biomass (mean ± s.e. of mean) of fine roots (<5 mm diameter) and coarse roots (>5 mm diameter) of *Alhagi sparsifolia* under different groundwater depth conditions (2.5, 4.5, 11.0 m) at the Cele Oasis, Xinjiang, China, in September 2010. The sampling plot was 8 m by 8 m on each selected site, and in each sampling plot, four genets of *A. sparsifolia* were randomly selected to survey the root biomass allocation. Within fine and course root categories, biomass values with different letters are significantly different ($P < 0.05$).

and 3, respectively. The mean number of ramets per genet was 7 at the site with groundwater depth 2.5 m, and significantly ($P < 0.05$) higher than at the sites with groundwater depths 4.5 and 11.0 m, which were both <1. The average distance between ramets at the site with groundwater depth 2.5 m was ~0.5 m, and significant shorter than at the sites with groundwater depths 4.5 m (2 m) and 11.0 m (2.5 m).

Shoots and roots

There were no significant differences ($P > 0.05$) for plant height, basal diameter, ground cover, number of shoots and branches, and crown areas of between plants growing at the sites with groundwater at 4.5 and 11.0 m (Fig. 4). However, all parameters were significantly different from those at the site
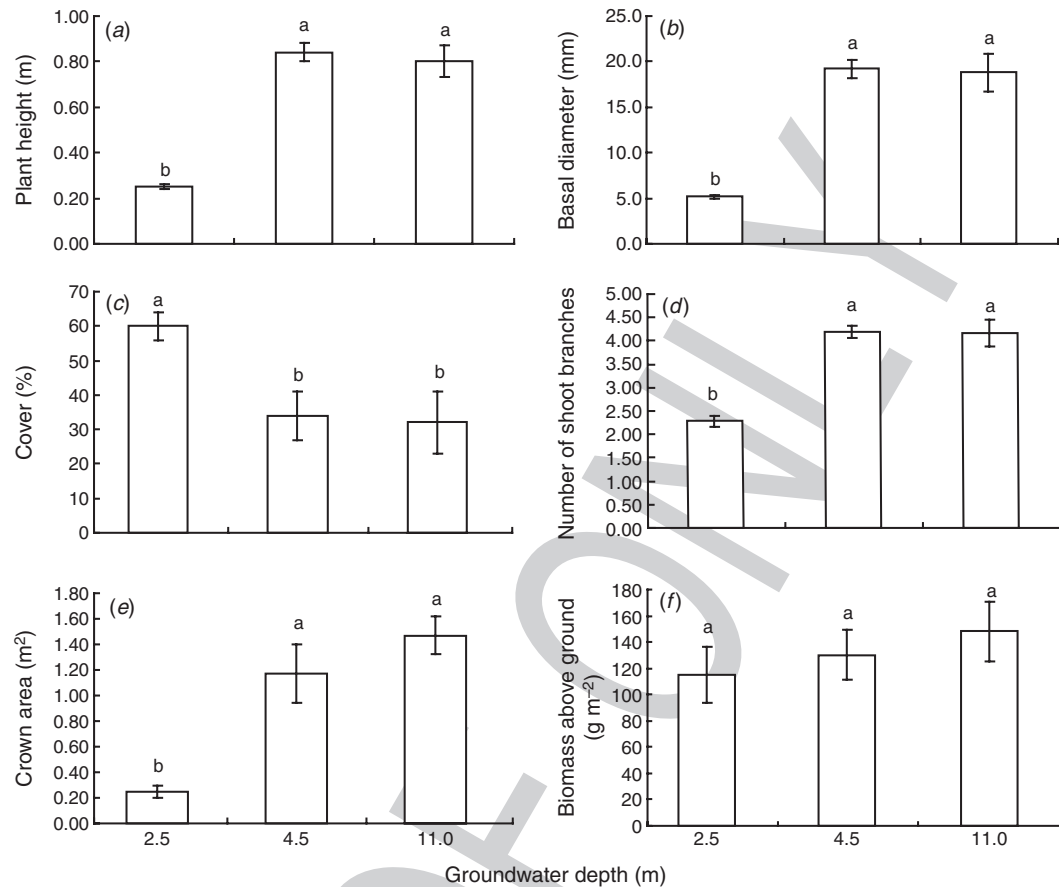
Fig. 4. Variations in above-ground growth characteristics of *Alhagi sparsifolia* at sites with different groundwater depths (2.5, 4.5, 11.0 m) at the Cele Oasis, Xinjiang, China, in September 2010. The sampling plot was 8 m by 8 m on each selected site, and in each sampling plot, four genets of *A. sparsifolia* were randomly selected to survey the above- and below-ground biomass allocation. Within each characteristic, values with different letters are significantly different ($P < 0.05$).

with groundwater at 2.5 m, with all parameters increasing with increasing depth except for ground cover, which decreased. There were no significant differences ($P > 0.05$) in the aboveground plant biomass among plants growing on the three
5 groundwater depth conditions (Fig. 4).

When the groundwater was 2.5 m deep, the aboveground biomass was significantly greater than the root biomass, but the position was reversed with the 11.0 m depth (Fig. 5). However, when the watertable was 4.5 m deep, the biomass of the root
10 system and aboveground parts was similar (no significant difference found).

Soil characteristics

Soil moisture content

The soil moisture content of the suckering layer (at 0.22 m
15 below the soil surface) was around 0.2% at the site with groundwater depth 2.5 m, compared with ~3% at the sites with groundwater depths 4.5 and 11.0 m (suckering layer at ~0.5 m below the soil surface) (Fig. 6). The soil moisture content near the watertable for all three sites was ~30% and decreased
20 rapidly to ~20% at ~1.5 m and ~10% at 2.0–2.5 m above the watertable at all sites (Fig. 6).
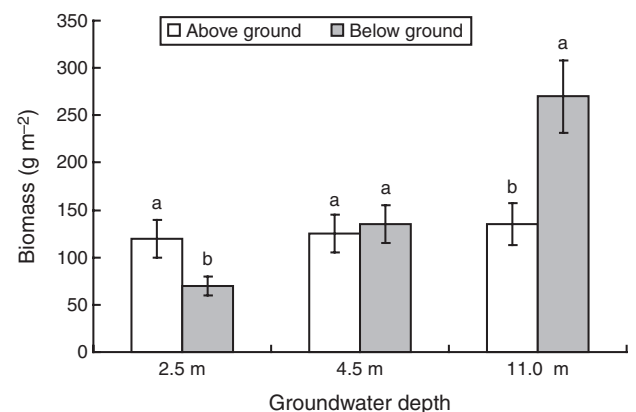
Fig. 5. Variation in above- and below- ground (lateral roots) biomass allocation (mean ± s.e. of mean) of *Alhagi sparsifolia* under different groundwater depth conditions (2.5, 4.5, 11.0 m) at the Cele Oasis, Xinjiang, China, in September 2010. The sampling plot was 8 m by 8 m on each selected site, and in each sampling plot, four genets of *A. sparsifolia* were randomly selected to survey the above- and below-ground biomass allocation. Within sites, biomass values with different letters are significantly different ($P < 0.05$).
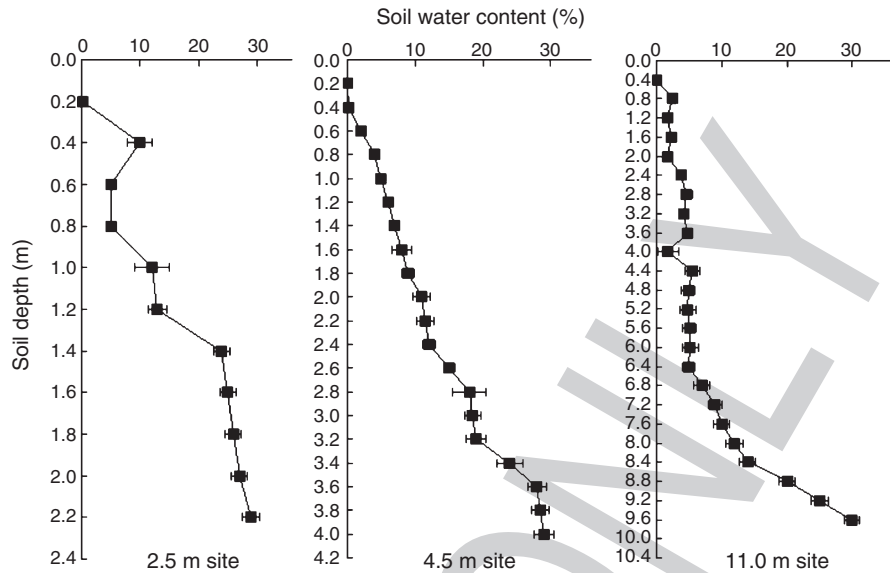
Fig. 6. Variation in soil water content at different depths at three sites with groundwater at 2.5, 4.5, and 11.0 m at the Cele Oasis, Xinjiang, China. The sampling plot was 8 m by 8 m at each selected site in September 2010, and data from surveys at the 2.5 and 4.5 m sites (mean ± s.e. of mean) in September 2007 and 2009 are also included.

Soil nutrients

The soils at all three sites were generally infertile, with contents of soil organic matter <1.5 g kg^{-1} DM, total N <0.2 g kg^{-1} DM, and total P <0.5 g kg^{-1} DM. Only total K was higher at ~20 g kg^{-1} DM. There were no significant differences among the soils at the three sites for any of the nutrients.

Discussion

Plasticity of root morphology is an important strategy to capture water and adapt to the hyper-arid environments (Zeng *et al*. 2012). During the excavation process, it was found that the vertical roots, descending from genets and some ramets, can reach and grow into the groundwater table even when it is 11.0 m deep. The lateral root architecture, which develops root suckers, also changed with different groundwater depths, as well as the growth traits above ground. Thus, in such a hyper-arid harsh environment, the depth of the groundwater as the sole water resource has an important influence on the survival and propagation of *A. sparsifolia*.

That the suckering depth would increase with increasing groundwater depth (our first hypothesis) was partly confirmed. The hypothesis that the angle of lateral roots developing suckers would increase and that the biomass and expanding ability of the lateral roots would decrease was not supported by the data (Fig. 2). In fact, the biomass and the fractal dimension values (*D*) representing the expanding capacity of the lateral roots were significantly increased at the deeper sites. The first hypothesis was based on the premise that soil moisture content of the suckering layer would dramatically change under different groundwater depth conditions. Although the soil moisture content of the suckering layer was higher at the site with groundwater depth 2.5 m, the angles of lateral roots were

similar to those at the sites with groundwater depths 4.5 and 11.0 m. The soil moisture content of the suckering layer, therefore, is not the sole factor affecting the architecture of the lateral roots. Perhaps the scarcity of soil nutrients was also important for the architecture of the lateral roots by reducing their ability to expand (Jackson and Caldwell 1989; Borch *et al*. 1999).

Plants of arid and semi-arid environments normally produce two types of roots: fine and coarse roots (Wilcox *et al*. 2004; Guerrero-Campo *et al*. 2006). The former are more active in the absorption of water and nutrients (Wilcox *et al*. 2004; Guerrero-Campo *et al*. 2006). The coarse roots have a greater ability to penetrate hard soils and reach deep horizons, allowing better anchorage than the fine roots and also the storage of carbon and nutrients, and the uptake of water (Boot and Mensink 1990; Guerrero-Campo *et al*. 2006). In this study, these characteristics are also apparent in the biomass allocation of *A. sparsifolia* in the suckering layer at sites with different groundwater depths. That is, the proportion of coarse roots (diameter ≥5 mm) increased under deeper groundwater conditions; the depth of lateral roots also increased giving better storage of carbon, nutrients, and water; and the capacity for expansion of lateral roots also increased. In some relevant root suckering research on aspen, Schier *et al*. (1985) pointed out that the root suckering was mainly affected by the diameter of the parent roots. In the current study, the suckering also mainly developed from coarse roots, especially for sites with deeper watertables (4.5 and 11.0 m), and the increased depth of coarse roots in the lateral roots would directly result in increased suckering depth. Moreover, soil temperature may also be important for root suckering (Schier *et al*. 1985). The soil temperature will probably change with depth and, therefore, be different at the different suckering depths for sites with different groundwater depths.

These differences in temperature may contribute to the different numbers of ramets produced at the different sites. This aspect of the suckering process needs further research.

The second hypothesis was that the growth characteristics above ground, such as height, cover, and biomass, would decrease with increasing groundwater depth. Only the cover supported this hypothesis, and other attributes all increased except for plant biomass, for which there was no change.

In an experiment under artificial conditions, Zeng *et al.* (2012) found that the seedling root:shoot ratio of *A. sparsifolia* increased with declining soil moisture content as an adaptation to drought. The results of the present study are consistent with this finding, in that the root:shoot ratio changed dramatically with increasing watertable depth (Fig. 5). These changes among biomass allocations further indicated that species minimise investment in aboveground growth so as to more efficiently utilise soil resources in growth-limiting environments (Ryser 2006; Li *et al.* 2008; Vonlanthen *et al.* 2010). Thus, research using cover or crown diameter of *A. sparsifolia* to evaluate its biomass (non-destructive methods) should be viewed cautiously, especially for a large area including different groundwater depths (Siebert *et al.* 2004; Li *et al.* 2012).

Although the growth characteristics above ground and the architecture of lateral roots below ground were not as varied as initially predicted, the results still demonstrated that groundwater depth does affect the clonal propagation of *A. sparsifolia*. If the number of ramets does reflect the vegetative regeneration capacity of *A. sparsifolia*, then it would decline with increasing groundwater depth. These findings have implications for the management of *A. sparsifolia* in the transition zone between an oasis and the open desert.

Woody species with deep root systems have the capacity for hydraulic redistribution, defined as water that is transferred via root systems from wetter to drier (typically upper soil horizons) parts of the soil profile, driven by gradients of soil water potential (Burgess *et al.* 1998, 2001; Bleby *et al.* 2010). In this study, the soil water content of the suckering layer at the site with groundwater depth 11.0 m had the lowest number of ramets, but no data were collected about the hydraulic redistribution ability of *A. sparsifolia*. Zeng *et al.* (2006) assumed that the dry soil profile probably generated some potential for hydraulic redistribution of *A. sparsifolia*, but in their experiment, no hydraulic redistribution was found, and they attributed it to the relatively high resistance to water movement from deeper roots to shallow root to dry soil *v.* that from the deeper roots to the shoot. The possibility of the importance of hydraulic redistribution in the vegetative reproduction of this species is an important area for future research. Further study should concentrate on the variations in uptake ability of vertical roots for water and nutrients under different groundwater depths.

Overall, in such hyper-arid environments with a scarcity of soil nutrients, the groundwater depth influences the clonal growth and propagation trait of *A. sparsifolia*. The plants of this species adjust their survival and propagation strategy along increasing groundwater depth gradients such as by increasing the suckering depth and the biomass (especially coarse roots) of lateral roots, and by decreasing the suckering capacity and the number of ramets, and by increasing the number of shoots, height, crown diameter and biomass, and basal diameter of the ramets. These are ecologically advantageous strategies to adapt to environmental heterogeneity and differing water supply conditions. At present, due to economic and population pressures, the oases on the southern rim of the Taklamakan Desert are expanding dramatically, more groundwater is being pumped for agriculture resulting in increasing depth to the groundwater (Hyŏn and Schreurs 2007; Gui *et al.* 2010). As a multifunctional plant important for oasis ecological integrity and local livestock development, survival and propagation of *A. sparsifolia* seems assured under natural conditions. However, how the continued increase in groundwater depth will influence the clonal growth and propagation of *A. sparsifolia* needs continual observation and further research.

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