沙漠研究 22-1, 13 -16 (2012)
Journal of Arid Land Studies

"ICAL 1 / DT X"
－Refereed Paper－

Root System Development of *Prosopis* Seedlings under Different Soil Moisture Conditions

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Abstract: *Prosopis juliflora* (Swartz) DC is one of the most economically and/or ecologically important legumes in arid and semi-arid regions of the world. *Prosopis* was introduced into Sudan in early 20th century, and succeeded in controlling the expansion of desert in northern Sudan. Recently, however, this species distributes widely and rapidly in eastern Sudan, and induces many problems in human subsistence. To clarify the mechanism of rapid invasion of *Prosopis*, we investigated the response of seedling roots to different soil moisture conditions. *Prosopis* seedlings were cultivated twice (seven weeks each) in Desertification Mechanism Analysis System of Arid Land Research Center, Tottori University. Seedlings were cultivated in columns with sandy soils and dripping irrigation once per day. Second experiment was done in columns with four drip irrigations (top, top and middle, middle and bottom, or bottom of columns). Seedlings were carefully harvested, and dry weight and root structure were analyzed. Results were (1) seedlings developed two root systems, one was horizontal root just below the soil surface, and the other was tap root penetrated beyond 1m depth, (2) water supply on the surface increased dry weight and total root length of seedling, (3) seedling developed lateral roots vigorously at higher soil moisture areas. These results suggest that seedling responds sensitively to the increase of soil moisture after the rain, and develops root system flexibly against patches of soil moisture. These properties may enable *Prosopis* to invade easily into new habitats and distribute widely and rapidly in eastern Sudan.

Key Words: *Prosopis juliflora*, Root, Soil moisture, Sudan

1. Introduction

Prosopis juliflora (Swartz) DC is an evergreen legume native to South to Central America and the Caribbean, and one of the most economically and/or ecologically important trees in arid and semi-arid regions of the world. This species was introduced into North-east Africa in early 20th century (Pasiecznik *et al.*, 2001) to arrest the desertification and improve agricultural schemes. In northern Sudan, the expansion of desert has been successfully controlled by preparing the shelterbelt of *Prosopis* (Laxén, 2007). Recently, however, this species distributes widely and rapidly in eastern Sudan, and induces many problems for human subsistence in this country as follows; it crowds out native and edible plants, blocks drains and irrigation canals, and is a major menace for farmers; its thorns are harmful both to farm workers and their machinery; it consumes underground water; its pods bring about some animal diseases (Mwangi and Swallow, 2005; UNEP, 2007).

Some properties relating the invasion of *Prosopis* are as follows: 1. Tree has low branching and highly coppicing abilities (Bosu *et al*., 2009), 2. Trees flower at 3-5 years of age generally, and under certain experimental condition, begin flowering at 3-4 months after germination (Pasiecznik *et al.*, 2006), 3. Trees develop two distinct root systems as surface lateral roots and deep tap roots (Jenkins *et al.* 1987, Pasiecznik *et al.*, 2001), which may have a role of hydraulic redistribution (Hultine *et al.*, 2004), and cause of survival in drier condition without obvious xeromorphic adaptations (Bristow, 1996), 4. allelopathic effects of leaves inhibit the growth of other plants (Nakano, 2010), 5. seeds are rapidly and easily dispersed by livelihoods and other animals (Berhanu and Tesfaye, 2006), and so on. All or parts of them might facilitate the invasion of *Prosopis* into eastern Sudan, and the establishment of appropriate management plans of *Prosopis* is keenly demanded.

We investigated the growth pattern of *Prosopis* seedlings in different irrigation conditions. The purpose of this study is to clarify the factor of *Prosopis* invasion, focusing on the architecture and development of roots.

2. Materials and Methods

This study was done in Desertification Mechanism Analysis System (DMAS) of Arid Land Dome, Arid Land

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Research Center, Tottori University. Environmental conditions in DMAS were set as follows: air temperature, 27˚C; air relative humidity, 40%; wind speed, 0.85 m/sec.

Twelve columns (diameter 45cm, depth 1m) of polyvinyl chloride were prepared in DMAS and filled with sandy soil. *Prosopis juliflora* seeds were disseminated on 27 April 2010, germinated and nursed in an incubator beforehand. Seedlings with four mature leaves were transplanted in the columns (one seedling per column) on 21 May 2010, and cultivated with drip irrigation (5 minutes, once per day). Seven seedlings were harvested on 7 July 2010. Sandy soils around roots of the seedlings were carefully removed under running water, and lengths of shoots were measured. To examine the distribution of roots, tap roots were rearranged vertically, divided into segments of 20cm-intervals from the soil surface downward, and the lengths of lateral roots attached to each segment were measured. All these parts were oven-dried (60˚C, 24 hours), then weighed with electric balance.

As a second experiment to investigate the root developments in different soil moisture conditions, other polyvinyl chloride columns (diameter 15 cm, depth 1.3 m) were prepared in DMAS. Four types of irrigation conditions were set up as follows: A, top irrigation in the column; B, top and middle (depth 0.6 m) irrigations; C, middle and bottom (depth 1.2 m) irrigations; D, bottom irrigation. Three columns were prepared for each irrigation treatment (total 12 columns). Prearranged seedlings, disseminated on 4 August 2010, were transplanted in the columns on 10 September 2010, cultivated with drip irrigation (10 minutes, once per two days), harvested on 27 October 2010, and measured in the same manner to the previous experiment.

Differences of dry weight or root length among the irrigation treatments were tested by Tukey-Welsch stepwise multiple comparison.

3. Results and Discussion

3.1. Root weight and length distribution

In the first experiment, seedlings expanded 11~13 leaves in seven weeks after transplantation. Some seedlings penetrated single tap root beyond 1 m. Others formed two- or three-branched tap root, maximum total length of them reached 2.3 m. Averaged shoot length of seven seedlings was 19.0 ± 3.7 cm. Mean value of total root length of them was 184.1 ± 35.0 cm, and 9.8-times longer than that of shoot (**Table 1**). Averaged dry weight of shoots was 0.34 ± 0.092 g, whereas that of roots was 0.15 ± 0.035 g, which was a half of shoot weight. All seedlings expanded lateral roots vigorously just below the soil surface (**Fig. 1**). Some seedlings formed lateral roots also at the bottom of column, because of moistened condition of bottom sand. Lateral root growth was suppressed between 20 and 80 cm depths in the column.

Table 1. Length, weight and Root/Shoot ratio of *Prosopis* seedlings (Average ± S.D).

Length (cm)		Weight (g)		Root/Shoot ratio	
Shoot	Root	Shoot	Root	Length	Weight
19.0 ± 3.7	184.1 ± 35.0	0.34 ± 0.092	0.15 ± 0.035	9.8 ± 1.6	0.45 ± 0.10

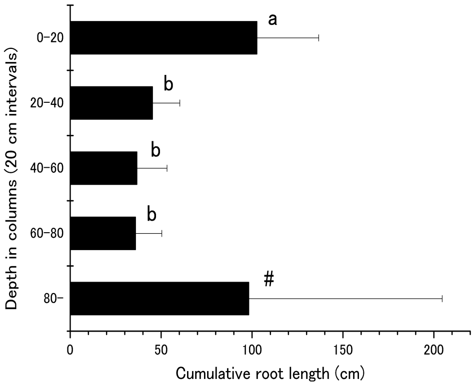

Fig. 1. Root length distributions along 20 cm-interval in thick columns. Bars with different letters indicate significant differences between data sets (n = 7, $P < 0.05$). "#" means to be no significant difference because of large variation of data values.

Prosopis is typical phreatophyte, and has distinct two root systems as tap root and lateral root (Gallaber and Merlin, 2010). We also confirmed this property in cultivated seedlings. They formed roots about ten-times longer than shoots within seven weeks after germination. In addition, roots were extremely longer than that reported by Pasiecznik *et al.* (2001), in which root length of *Prosopis* seedling reached 40 cm in eight weeks after germination. Vigorous root elongation observed in our study ensure that *Prosopis* seedling responds to soil wetting just after the rain, and penetrates tap root rapidly, which would make possible to survive in the following dry seasons.

Glendening and Paulsen (1955) reported that nine-month-old seedling of velvet mesquite in the field had root/shoot ratio in dry weight as 1.99/1, whereas the ratio of ten-month-old seedling under cultivation was 0.87/1. In our study, two-month-old seedlings showed root/shoot ratio as 0.45/1, and suggested that the root development under cultivation should be suppressed. Further improvement of experimental conditions might reveal some potential growth ability of *Prosopis* root system.

3.2. Response of root system to different soil moisture conditions.

Second experiment revealed that dry weights of seedlings were clearly different among four irrigation treatments (**Fig. 2**). Treatment "B" induced seedling to grow the most vigorously, followed by treatment "A". Seedling growths in treatments

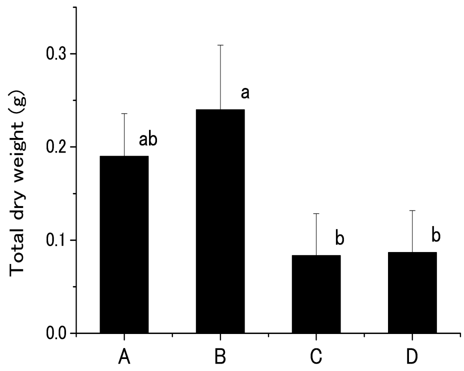

Fig. 2. Total dry weight of seedlings under four irrigation treatments. Bars with different letters indicate significant differences between data sets (n = 3 in each treatment, P < 0.05).

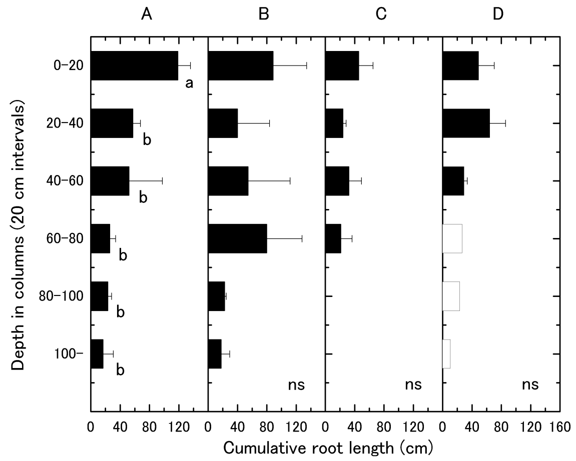

Fig. 3. Total root length distributions along 20 cm- interval in depth below the soil surface of columns under four irrigation treatments. Bars with different letters indicate significant differences between data sets (n = 3 in each treatment, P < 0.05). One sampling in "D" elongated a tap root beyond 1 m (open column).

"C" and "D" were not different significantly, and both these treatments suppressed seedling growth than the former two treatments. Two seedlings in "A" and all seedlings in "B" penetrated tap roots beyond 1m, whereas the length of tap roots in "C" did not exceed 0.8 m. Tap root length in "D" varied among three seedlings as 0.2 m, 0.6 m or over 1 m.

Root distributions in columns were also different among the four irrigation treatments (**Fig. 3**). In treatment "A", seedlings formed lateral roots vigorously just below the soil surface, and suppressed root development in the deeper area of columns below 20 cm depth. Seedlings in treatment "B" responded to the two irrigations (top and middle portions of columns) with active lateral root developments. Difference of root length was statistically not significant among depths because of various responses of three seedlings. Treatments "C" and "D" constrained root growth more than the former two treatments.

Prosopis flexuosa modified root architecture plastically according to different soil moisture conditions, and acquired water and nutrients in the soil effectively using horizontal surface roots and deep tap roots (Guevara *et al.*, 2010). *P. juliflora* in our study showed the similar response, water supply to the soil surface in treatments "A" and "B" promoted the growth of surface lateral roots, and increased dry weights of seedlings. In addition, the response of seedlings in treatment "B" suggested that *P. juliflora* has an ability to modify root architecture in heterogeneous soil water distribution, and acquire available water resources effectively in the soil.

In Sudan, there are distinct dry and wet seasons in annual, the latter continuing three months from July to September (Cabmerlin, 1997; Elagib and Mansell, 2000). Results in this study show that, during the three months of the rainy season, *Prosopis juliflora* seedling has potentials to penetrate tap roots beyond 3 m depth in the soil and to grow vigorously with expanding lateral surface roots. With acquiring these properties, *Prosopis* seedling responds to desirable water condition as rain fall immediately, and constructs root system rapidly prior to dry-up of soil in the following dry season. If the root system would reach to some water-plentiful areas in the soil as sub-aquifer during the rainy season, the seedling could secure its establishment in new habitats even within the dry season. As a result, *P. juliflora* might to survive and/or tolerate under drier environmental conditions, and invade and expands in various areas rapidly. All these properties detected in the earlier developmental stages of *P. juliflora* seedlings would be advantageous to invade into the new habitats and expand distribution rapidly in arid and semi-arid environment as Sudan.

Acknowledgements

This study was carried out under the cooperative research with Research Project "A Study of Human Subsistence Ecosystems in Arab societies: to Combat Livelihood Degradation for the Post-oil Era" (Project Leader: Hiroshi Nawata, Research Period: 2008-2013), Research Institute for Humanity and Nature (RIHN), Japan, and the Joint Research Program of Arid Land Research Center, Tottori University.

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