Chinese Science Bulletin

Influence of floodwater irrigation on vegetation composition and vegetation regeneration in a Taklimakan desert oasis

GUO HaiFeng[1,2,3], ZENG FanJiang[1,3†], ARNDT S. K.[4], ZENG Jie[1,2,3], XING WenJuan[1,2,3] & LIU Bo[1,2,3]

[1] Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China;
[2] Graduate University of the Chinese Academy of Sciences, Beijing 100049, China;
[3] Qira National Field Station of Desert-Oasis Ecosystem, Qira 848300, China;
[4] Department of Forest and Ecosystem Science, The University of Melbourne, 500 Yarra Boulevard, Richmond, Vic. 3121, Australia

Naturally occurring floods in the summer months are the main source of surface water application in the foreland of Qira oasis, which is characterized by a hyperarid climate and is located at the southern fringe of the Taklimakan Desert. We investigated the impact of repeated artificial flood irrigation on seedling recruitment and growth of *Alhagi sparsifolia* and *Karelinia caspica* plant communities which are part of the dominant vegetation in Qira oasis. Flood irrigation was applied three times during the growing season and we studied the effect of irrigation on species recruitment, vegetation growth, species composition, and changes in soil water and nutrient concentrations in the soil profile. Results show that (1) repeated flood irrigation had a positive effect on seedling recruitment of the two species, with vegetative recruitment via root tillers being more important than seed recruitment for both species. (2) Irrigation promoted the germination and establishment of herbaceous weed species, which increased species diversity as well as ground coverage. (3) Irrigation also increased soil water and soil nutrient concentrations in the upper soil layer and changed the soil nutrients in the vertical profile. Available N, P, K and the total P and K increased in the soil profile. Our study demonstrates that naturally occurring flood irrigation has significant ecological benefits and plays an important role in promoting the renewal of desert vegetation and a short-term increase of soil nutrients. Our study also highlights the potential negative consequences for vegetation composition and rejuvenation if naturally occurring floods in the study area are diminished by either the effects of climate change or human management.

floodwater irrigation, *Alhagi.sparsifolia, Karelinia caspica*, species recruitment, vegetation composition, soil nutrients

The Taklimakan Desert in Western China is a hyperarid ecosystem with annual precipitation of less than 50 mm. At the south fringe of the desert seasonal rivers and groundwater are fueled by melting snow and glacier in the Kunlun Mountains in the summer months and are thought to influence the vegetation composition in river oases. The vegetation in the transition zone separated oasis from the desert are ecologically and commercially important as they protect farmlands and settlements from sandstorms[1]. Snow melt is causing floods of differing severity in the transition zone in the summer months, providing significant amounts of soil water recharge for the vegetation. The effect of these summer floods on vegetation composition and plant recruitment is yet unknown.

Earlier studies between 1998 and 2005[1−4] show that water is a key limiting factor in this ecosystem. However, results demonstrated that artificial short-term flood irri-

Received September 2, 2007; accepted March 26, 2008
doi: 10.1007/s11434-008-6018-z
†Corresponding author (email: fjzeng369@sohu.com)
Supported by National Natural Science Foundation of China (Grant No. 30670386) and Station Foundation of Chinese Academy of Sciences

gation had little effect on the vegetation in the oasis foreland.

These studies confirmed that groundwater is the only available water source for plants. The root systems of the vegetation are connected to the groundwater table but short-term irrigation usually infiltrates only the upper soil layers where the plants have no active roots. Vegetative reproduction via root suckers is a common way of reproduction in the oasis foreland. Although many plants produce significant amounts of seed, i.e. *Populus euphratica* and *Alhagi sparsifolia,* this does not lead to new seedling establishment, even after short-term flood irrigation. However, naturally occurring significant floods certainly would have played an important role in the establishment of the natural vegetations. Only significant floods are able to provide a suitable condition for successful seedling establishment in this extreme environment. Consequently, artificial flood irrigation with significant amounts of water could promote perennial plant renewal and succession.

Furthermore, the availability of soil nutrients is also an important factor restricting plant growth. A number of factors lead to low nitrogen and phosphorous concentrations in the soil with low soil moisture levels[5,6]. Most soil nutrients are mainly concentrated in the upper layer of soil but the dry soil conditions in the upper soil layers mean that plants cannot absorb nutrients from it. How does the vegetation obtain nutrition to meet its growth needs? Perennial plants in this ecosystem most likely get their nutrients from groundwater although[7]. The impact of long-term significant flood irrigation on soil nutrient concentrations in the foreland of Oasis is currently unknown.

This study is part of a long-term research on the relationship of vegetation growth and floodwater, which follows up the study of how short-term floodwater irrigation impacts water use of predominant plants in the foreland of oasis supported by "China-EU intergovernmental cooperation in science and technology projects (INCODC972774)". We conducted a repeated flood irrigation experiment in the desert foreland to investigate how flood irrigation makes impacts on the growth and recruitment of perennial plants and the vegetation community composition and soil nutrient concentrations.

1 Study area

The study area is located in the foreland of Qira oasis at the southern fringe of the Taklimakan Desert (37°00′N, 80°43′E). Qira County has an area of 33147 km^2 of which the oasis only accounts for 1.6%, forest coverage is 0.24%. The annual average temperature in the area is 11.9℃, the extreme maximum and minimum temperature is 41.9℃ and −23.9℃. Rainfall is highly erratic and mainly occurs between May and July, with an annual average precipitation of 35.1 mm and an evaporation of 2595.3 mm. The annual average wind speed is 1.9 m·s^{-1} and high winds frequently cause sandstorms and sand drift[8]. There are nine seasonal rivers in Qira oasis, and the water flux of the rivers is subjected to great seasonal oscillation. The water originates from rain, snow and glacier water. Groundwater level in the oasis is 16 m, that on the oasis foreland is 7 m, but groundwater table depth changes during the year depending on demand and supply. Generally, in July and August when the river flow exceeds the capacity of the water storage reservoir at Qira oasis, the surplus water was used to irrigate natural vegetation on the forefront of oasis[9].

2 Methods

2.1 Sample plot arrangement

Four experimental sample plots were established in the desert oasis transition zone which had uniform vegetation type and growth and similar soil and terrain condition Two plots were irrigated and the other two were non-irrigated controls. The plot size was 30 m×30 m. In order to make sure that sample plots were not affected by irrigation water we established six meter buffer zones between the plots.

2.2 Flood simulation

We simulated flooding by irrigating the two sample plots three times in two years: in April, June, August in 2006 and in 2007. The floodwater was sourced from the Qira reservoir. Floodwater was directed to the sample plots via 3 km surface channels. Irrigation water was allowed to infiltrate soil for about 30 min with the water table at a height of 30 cm. This resulted in an infiltration depth of about 1.5 m after 48 h. These conditions are similar to a naturally occurring flood. The irrigation plots were surrounded by 50-cm-high dams in order to make the water infiltration more effective.

2.3 Community investigation

The composition and total growth of the vegetation in all four plots was assessed at the end of the growth period in October 2006 by the traditional ecological method. We recorded plant species, plant height, canopy dimensions, number of newly recruited plants and type of recruitment.

2.4 Soil water and soil nutrient concentration

Soil moisture was determined gravimetrically across the soil profile. Three soil cores in each plot were drilled down to a depth of 3 m and soil samples were collected every 20 cm. Samples were dried to measure the net water content at 105℃. Soil organic, total and available nitrogen, phosphorus and potassium oncentrations were analyzed by Soil Analysis Laboratory of Xinjiang Institute of Ecology and Geography , CAS.

2.5 Data statistics

Recruitment rate is the ratio of newly recruited plants divided by the total number of the plants of a particular species. All data were calculated by MS Excel 2003 and SPSS 14. Data average was expressed by average± standard error. Statistically significant differences of the treatments were examined by Student's t-test.

3 Results

3.1 Recruitment of perennial plants

Our irrigation treatment clearly demonstrated that repeated floodwater irrigation can promote recruitment of new seedlings in case of *Alhagi.sparsifolia* and *Karelinia caspica*. In non-irrigation control plots only 6 *Alhagi.sparsifolia* and 2 *Karelinia caspica* seedlings were found. However, in the irrigated plots 98 *Alhagi.sparsifolia* and 25 *Karelinia caspica* seedlings were found. Analysis of recruitment type in these two perennial species showed that all newly recruited seedlings in the control plots were tiller seedlings from root systems. In case of *Alhagi.sparsifolia* the tiller branches were found 75 to 100 cm belowground whereas for *Karelinia caspica* they were located 14 to 25 cm belowground. Most seedlings in the two irrigation plots were also tillers from the root systems. 9 *Alhagi.sparsifolia* plants and 6 *Karelinia caspica* plants were randomly selected in the irrigation plots, and only 2 *Alhagi.sparsifolia* and 1 *Karelinia caspica* seedling that originated from seeds were found. In the irrigated plots *Alhagi.sparsifolia* seedling tiller branched at a depth of 20—40 cm, while the *Karelinia caspica* tillers branched at a depth of 10—20 cm.

3.2 Growth change of two plants

Repeated floodwater irrigation during the growing season had an effect in promoting *Alhagi sparsifolia* and *Karelinia caspica* growth. In the irrigated plots *Alhagi sparsifolia* grew better with deeper color and also a greater density compared to non-irrigated treatment. Plant height in the irrigated plots were significantly greater than in the control plots (t=1.99, P=0.022, df=78), and canopy diameters were also significantly greater in the irrigated plots (t=–4.58, P=0.000, df=78). Similarly, *Karelinia caspica* also grew better in irrigated plots. Both height and canopy of plants in irrigated plots were significantly greater compared to control plots (t=–2.79, P=0.000, df=28; t=–4.05, P=0.000, df=28 (Table 1)).

3.3 Species composition and coverage

The repeated floodwater irrigation also provided good growing conditions for the seeds of annual herbs which notably increased the species number, plant density and coverage. The number of species increased from 2 to 14 after irrigation (Figure 1). These newly recruited species are *Corispermum heptapotamicum* Iljin., *Echinochloa crusgalli* (L.) Beauv., *Bassia dasyphylla* (Fisch. et C. A. Mey.) O. Kuntze, *Parthenocisus tricuspidata*, *Salsola collina* Pall., *Halogeton glomeratus*、*Agriophyllum squarrosum* (L.) Moq., *Scorzonera divaricata* Turcz., *Phragmites communis* Trirn., *Cenchrus echinatus* Linn., *Setaria viridis* (L.) Beauv. and *Solanum nigrum* Linn. The control plots had a plant density of 0.2 plants per square meter and a coverage is 30%, while irrigated plots had a plant density of 0.7 plants per square meter and a coverage of 95%.

Table 1 Plant height and canopy dimension of *Alhagi sparsifolia* and *Karelinia caspica* in irrigated and non-irrigated sampling plots[a)]

Types	*Alhagi spasifolia*		*Karelinia caspica*	
	Height (cm)	Canopy (m^2)	Height (cm)	Canopy (m^2)
Contrast	86.4±2.0a	0.97±0.07A	77.9±5.8A	1.20±0.16A
Treatments	93.6±2.9b	1.55±0.11B	100.2±5.5B	2.85±0.37B

a) The different letters indicate significant differences in different treatments (t test, A and B indicate P<0.01; a, b indicate P<0.05); the number of *Alhagi spasifolia* is 40, the number of *Karelinia caspica* is 30; average±se.

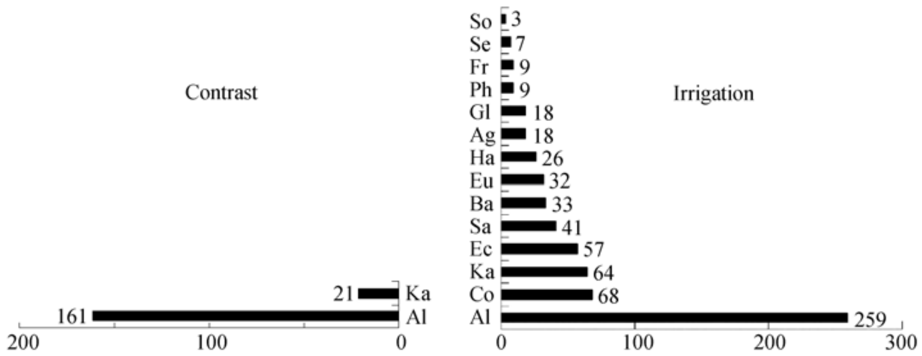

Figure 1 Total number of individuals of different plant species in irrigated and control plots. Al (*Alhagi sparsifolia* SHAP.), Co (*Corispermum heptapotamicum*), Ka (*Karelinia caspica*), Ec (*Echinochloa crusgalli* (L.)Beauv.), Sa (*Salsola Collina* Pall.), Ba (*Bassia dasyphylla* (Fisch.et Mey.) O.Kuntze), Eu (*Euphorbia heyneana*), Ha (*Halogeton glomeratus* (Bieb.) C. A. Mey.), Ag (*Agriophyllum squarrosum* (L.) Moq.), Gl (*Glossogyne tenuifolia* Cass.), Ph (*Phragmites communis* Trirn.), Fr (*Fructus Tribuli*), Se (*Setaria viridis*), So (*Solanum nigrum* L.).

3.4 Soil water and nutrients

Soil water content increased significantly in the irrigation plots throughout the soil profile down to 3 m. The average soil water content of the soil profile was 5.89%, significantly greater than 1.04% in non-irrigation sample plots (t=1.69, P=0.000, df=31, Figure 2(a)). In irrigated plots, soil water content was relatively stable between a depth of 40 cm and 150 cm and reached the maximum of 10.2% at a depth of 160—180 cm. In control plots soil water was stable until a depth of 160—180 cm and reached the maximum value of 1.847% at a depth of 180—200 cm. Concentrations of available N, P, K and total P and K showed some changes throughout the soil profile. Soil organic C and total N showed no marked changes. In contrast, available N, P, K had the greatest concentrations at a depth of 50 cm (Figure 2(b)—(h)). The average concentration of soil organic C was 0.231% and total N was 0.015% in irrigated plots compared to 0.213% for soil organic C and 0.014% of total N in non-irrigated control plots and this was not statistically significant. The average concentration of total P was significantly greater with 0.510% in irrigated plots compared to 0.497% in control plots (t=2.15, P = 0.024, df= 15). The average concentration of total K was also significantly greater with 2.137% in irrigated plots compared to 2.086% in control plots (t=2.21, P = 0.021, df = 15). The concentration of available N was significantly greater (15.817 mg/kg) in irrigated plots compared to 8.762 mg/kg in the control plots (t=2.23, P= 0.021, df = 15). The same was true for plant available P with 2.094 mg/kg in irrigated plots compared to 1.642 mg/kg in control plots (t = 2.29, P = 0.018, df = 15). Available K also had significantly greater concentrations (286.791 mg/kg) after irrigation compared to control plots (100.873 mg/kg, t = 5.10, P = 0.000, df = 15).

4 Discussion

Our results clearly demonstrate that flood irrigation plays an important role in promoting *Alhagi.sparsifolia* and *Karelinia caspica* recruitment and growth. Floodwater also provides good conditions for the growth of annual herbaceous species, which enriches the composition of plant communities and makes the community structure more complex and increased coverage. Flood irrigation effectively increased the soil moisture and nutrient concentrations in the upper soil layers.

4.1 Influence of floodwater irrigation on vegetation recruitment and growth

Vegetation restoration depends on effective recruitment of new seedlings. This usually happens in two different ways: One is via sexual reproduction by seed and the other is asexual vegetative reproduction by, e.g. root suckers or tillers. An earlier investigation in this region by Thomas et al.[2] showed that only *Tamarix ramosissma* Ledeb. expands population by sexual reproduction, whereas *Populus euphratica*, *Calligonum caput-medusae* and *Alhagi.sparsifoli* all expand populations by asexual clone reproduction. According to the survey on the recruitment of the two main plant species (Figure 3), 6 *Alhagi sparsifolia* seedlings and 2 *Karelinia caspica* seedlings are all formed by root tiller. Seed derived recruitment only accounted for 22% of *Alhagi sparsifolia,* and 17% of *Karelinia caspica*. Consequently, vegetative reproductions seems to be the major pathway of reproduction in these two species. Floodwater irrigation has only a minor stimulating effect on seed reproduction. However, repetitive irrigation had a

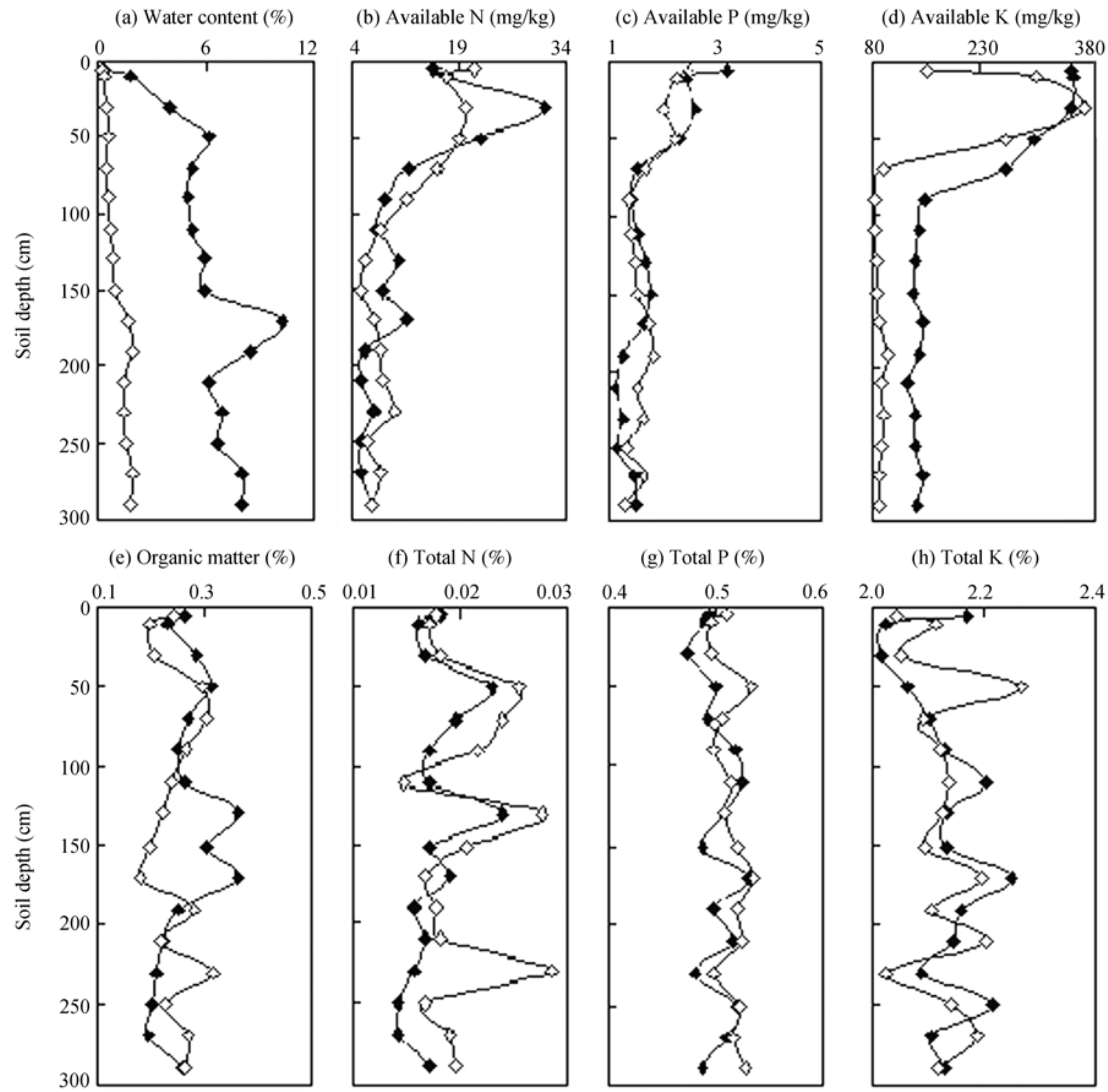

Figure 2 Soil water content and concentration of total organic C, total N, P, K and plant available N, P and K in irrigated and non-irrigated plots in the Taklimakan Desert. —◆—, Irrigation; —◇—, contrast.

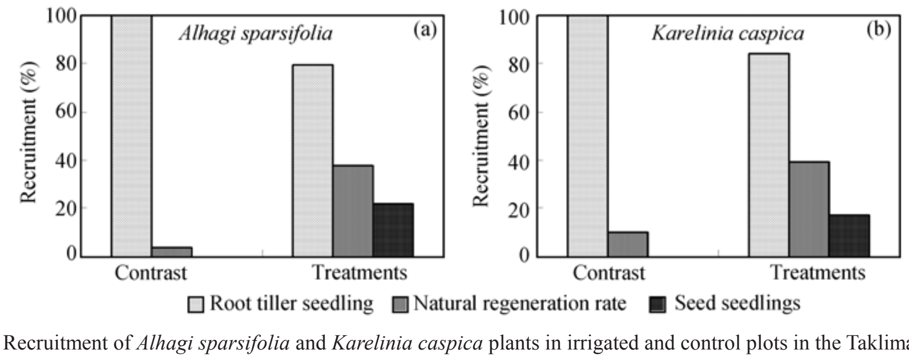

Figure 3 Recruitment of *Alhagi sparsifolia* and *Karelinia caspica* plants in irrigated and control plots in the Taklimakan Desert.

stimulating effect on the recruitment for both species. The irrigated plots had an overall recruitment rate of 38% for *Alhagi sparsifolia* which was 10 times greater compared to control plots (3.7%). Recruitment was also greater for *Karelinia caspica* in irrigated plots (39%) compared to control plots (10%).

The rate of seed derived recruitment of 22% for *Alhagi sparsifolia* in this experiment is comparable with previous results of 26.3% of Zhang et al.[10] in this region. This indicates that *Alhagi sparsifolia* may have an inherently low recruitment rate via seeds and relies on vegetative reproduction. Navratilova[11] reported that the seed capsule of *Alhagi sparsifolia* is very hardy which may the main reason why their seeds rarely germinate. Seedlings of the seed derived *Alhagi sparsifolia* plants are usually only observed in well flooded floodplains in summer, when constantly high water contents and high temperatures stimulate seed germination. There are few studies on seed renewal of *Karelinia caspica*. However, the trends are similar to *Alhagi sparsifolia*. However, the repeated flood irrigation had a strong effect on plant growth with both species exhibiting much stronger growth in irrigated plots. Li et al.[12] concluded that "a single flooding event makes no difference to improving the moisture condition of *Alhagi sparsifolia* in summer". Although short-term flooding is not ecologically significant our results confirm that repetitive irrigation can be effective in promoting the recruitment of deep-rooted perennials. In short, vegetative reproduction is an important strategy for desert plants and repetitive irrigation is an effective way of promoting the recruitment of perennial plants.

4.2 Influence of floodwater irrigation on species composition

Seed derived seedlings of *Alhagi.sparsifolia* and *Karelinia caspica* were very rare in our study and only account for 22% and 17% of all seedlings of the two species. However, the irrigation triggered an enormous increase in species diversity due to the emergence of annual herbaceous plants. Seeds of these species may either have been located in the seed bank or were introduced via the irrigation water from other regions. Of the twelve additional species most are annual herbaceous grasses except *Scorzonera divaricata* Turcz. and *Phragmites communis* Trirn. which are perennial weeds. Annual plants have to be flexible and rely on germinating when conditions are favorable and rely on a fast growing development. Annual plants are usually an important life form in arid areas as they can effectively utilize limited water resources in a short time in an arid environment[10]. *Corispermum heptapotamicum* Iljin., *Echinochloa crusgalli* (L.) Beauv., *Salsola collina* Pall., *Bassia dasyphylla* (Fisch. et C. A. Mey.) O. Kuntze and *Parthenocisus tricuspidata* had the highest plant densities of the observed species. This could mean that these species have a greater seed bank or are more effective in germination. Furthermore, the changes in species diversity and density of the plant community certainly caused change in ground coverage. The ground coverage increased from 30% to 95% after irrigation. The ecological significance and social value of the increasing ground coverage is mainly windbreak and sand-fixing and therefore plant based protection from desertification. Irrigation is therefore an effective albeit short-term way of increasing vegetation coverage in oasis foreland. Increasing vegetation coverage by floodwater irrigation was applied very early to increase windbreak and sand-fixing in arid areas in Xinjiang[13].

4.3 Influence of floodwater irrigation on soil water and nutrients

It is obvious that irrigation will increase the soil water content in soils of the oasis foreland but the consequences of the soil water content increase are not always straightforward. In this study floodwater irrigation promoted species recruitment and vegetation. The main ecological significance of seasonally occurring floods in this oasis system is probably the recharge of groundwater and thus the stability of the oasis vegetation. The main perennial species in the desert foreland are all deep-rooted perennial plants[4]. Our data also indicated that flood irrigation can lead to an increase of soil nutrients. There are two ways in which nutrients come from, floodwater deposition and increased decomposition. The floodwater itself can carry significant amounts of nutrients as clay particles, cattle and sheep dung and other organic material is carried in the floodwater which can fertilize the soil[14]. Conversely, the interaction of water and heat promotes the decomposition of organic material in the soil which would also increase soil nutrients. However, the exact amount and proportion of the two sources needs further study. Statistical analysis showed that the distribution of soil nutrients changed significantly. Available N, P, K and the total P, K all increased in the soil profile following irrigation.

4.4 Relationship between floodwater and vegetation

Water is essential for plants to thrive and regenerate in the harsh climate conditions of the southern fringe of the Taklimakan Desert[1]. Previous studies of China-EU projects showed that the vegetation of the oasis foreland relies exclusively on the groundwater for survival. However, flooding of the foreland is ecologically significant. "Floods certainly play a very important role in the existence and development of vegetation. And in a long-term perspective, occasional floods are completely necessary for the maintenance of vegetation, taking account of the completion of plant community's life cycle[1]". Flood related high water contents are essential for seed germination in an environment that has too little rainfall to provide favorable conditions. Deep infiltration of water after flood is also important to ensure that the roots of seedlings reach the deep soil layers near the groundwater table[15]. The dependence of the plant recruitment on flood irrigation is emphasized by the observation that none of the perennial plant species in the study area has departed from the modern riverbed to form a large distribution area[3]. Flood plays an important role in the asexual reproduction of *Populus euphratica* in oasis foreland. Root tillers of *Populus euphratica* have not been found in an area that has not received flooding for several successive years. Studies from Xia et al.[15] show that most *Populus euphratica* in the study area were established through root tillers during 1980 and 1982, after a great flood in 1980[16]. The investigation on the recruitment of the two perennial species *Alhagi sparsifolia* and *Karelinia caspica* also indicates that root tiller seedling formation depends on the soil water conditions and flood is a key factor to trigger tiller and sprouting in perennial plants. Effects of floodwater on the recruitment of perennial plants, changes in the plant communities, increases of soil nutrients, and the distribution of nutrients in the vertical profile all highlighted that floods have an ecological significance on vegetation survival and maintenance in this area.

By simulating naturally occurring floods we corroborated the significance of floods as a nature pulse for arid ecosystem function. However, studies show that the temperature in the study area has increased by 0.2—0.5℃ in the late two decades. Climate drought is accelerating and rainfall and annual runoff are deceasing. Together with regional economic and social development the oasis will enlarge and water use by the local population will increase which will further decrease water flow to the desert[17] and the likeliness of floods in this area. At present, a newly built reservoir upstream of the Qira River will much reduce the severity of floods and therefore also has impacts on the beneficial region of flood irrigation on species[18]. In light of the prospective shortage of water resources and the reduction of natural flood further studies are needed: (1) In water resource management, there is an urgent need to establish a groundwater monitoring network as soon as possible and study the influence of oasis water use on the groundwater level in foreland. There is also a need to calculate the maximum capacity of water resources and to determine an effective way of distributing production water and ecological water. (2) As to vegetation restoration, we should study the relationship between root growth and soil water content and develop an optimal model of irrigation which would promote the growth of roots of local plants so that they reach the groundwater as soon as possible. Then, based on the largest ecological water amount, we should choose suitable plant species for rehabilitation and reconstruction.

5 Conclusions

(1) Repetitive irrigation had a positive effect on seedling recruitment and vegetation growth of *Alhagi sparsifolia* and *Karelinia caspica*. Both species relied on vegetative reproduction via root tillers and seedling recruitment via seeds played only a minor role, also in the irrigated plots. This could provide theoretical guidance for vegetation rehabilitation and reconstruction.

(2) Irrigation triggered the germination and establishment of annual weeds, which increased species diversity as well as ground coverage. The increase of ground coverage has a significant means on ecological security, at least in the short-term.

(3) Irrigation effectively increased soil water and concentrations of nutrients in the upper soil and changed the soil nutrients in the vertical profile. Available N, P, K and the total P, K increased in the soil profile following irrigation.

Our study demonstrates that flood irrigation has significant ecological benefits and plays and important role in promoting the renewal of desert vegetation and soil nutrient increase and is essential for groundwater recharge.

The authors are indebted to all colleagues in Qira National Field Station of Desert-Oasis Ecosystem for their valuable help.

1 Zhang X M, Michael R. Eco-physiology and Habitat Requirement of Perennial Plant Species in the Taklimakan Desert (in Chinese). Beijing: Science Press, 2006

2 Thomas F M, Arndt S K, Brelheide H, et al. Ecological basis for a sustainable management of the indigenous vegetation in a Central Asian desert: presentation and first results. J Appl Bot, 2000, 74: 212—219

3 Gries D, Zeng F, Foetzki A, et al. Growth and water relation of *Tamarix* ramosissima and *Populus euphratica* on Taklimakan Desert dunes in relation to depth to a permanent water table. Plant Cell Environ, 2003, 26: 725—736

4 Foetzki A . Water relations of perennial plant species of the hyper arid Taklamkan Desert. Diss Biol Fak, Univ. Göttingen, Göttingen, 2003. 256

5 Noy-Meir. Desert ecosystems, environment and producers. Ann Rev Ecol Syst, 1973, 4: 25—41

6 Gutierrez J R, Whitford W G. Chihuahuan Desert annuals: importance of water and nutrient. Ecology, 1987, 68: 409—418

7 Arndt S K, Kahmen A, Arampatsis C, et al. Importance of drought stress and nitrogen fixation in the desert legume *Alhai sparsifolia* results from ^{13}C and 15 natural abundance studies in the field. In: Proceedings of the FAO/IAEA International Symposium on Nuclear Techniques in Integrated Plant Nutrient, Water and Soil Management, 16—20 October 2000, Vienna Austria, 2002. 406—407

8 Zhang H N. Regional integrated research model on oasis in south edge of Taklimakan Desert. Arid Region Study, 1995, 12(4): 1—9

9 Zeng F J, Foetzki A, Li X Y, et al. Water physiological indicators of *Tamarix* before and after irrigation in Qira oasis (in Chinese). J Appl Ecol, 2002, 13(7): 849—853

10 Zhang L Y, Mamati Anniwaer, Xia Y. Effect of irrigation on morphological features, community ecological structure and nature renewal of *Alhagi sparsifolia* in summer. Arid Region Study, 1995, 12 (4): 34—40

11 Zhang L Y. Biological and ecological characteristics of *Alhagi spacifolia*. Plant, 2003, (1): 8—9

12 Li X Y, Zhang X M, He X Y, et al. Water characteristic of four perennial plants in Oasis-desert transition zone. Ecol J, 2004, 24(6): 1164—1171

13 Li Q. Development of floodwater irrigation (in Chinese). Chin Soil Water Conserv, 1996, (3): 36—37

14 Bruelheide H, Jandt U, Gries D, et al. Vegetation changes in a river oasis on the southern rim of the Taklamakan Desert in China between 1956 and 2000. Phytocoenologia, 2003, 33(4): 801—818

15 Xia X, Li C, Zhou X, et al. Desertification and Control of Blown Sand Disasters in Xinjiang (in Chinese). Beijing: Science Press,. 1993

16 Yu Z J. Utilize floodwater irrigates desert to combat desertification. Chin Soil Water Conserv, 1994, (4): 5—7

17 Ling Y Q .Characteristics of the climate change in Taklimakan Desert. Chin Desert, 1990, 10(2): 9—19

18 Zhou X. Features of the deserts and changes in the desert surrounding in Xinjiang. In: Xia X, Li C, Zhou X, et al, eds. Desertification and Control of Blown Sand Disasters in Xinjiang (in Chinese). Beijing: Science Press, 1993. 1—63