Effects of pit plantings on tree growth in semi-arid environments

Hyun-Kil Jo* and Hye-Mi Park

*Department of Ecological Landscape Architecture Design, Kangwon National University, Chuncheon 200-701, Republic of Korea; bDepartment of Landscape Architecture, Graduate School, Kangwon National University, Chuncheon 200-701, Republic of Korea

ABSTRACT
This study developed a pit planting technique in which only planting spots were dug to reduce earthwork costs and to enhance tree growth. This technique, in which pits of different depths were dug, was actually applied to a semi-arid experiment site to analyze its effects on soil moisture and tree growth. The soil moisture content in the pit planting 30 cm in depth (30 cm pit planting) and 50 cm in depth (50 cm pit planting) was 6.5 ± 0.1% and 6.7 ± 0.1%, respectively, which was at least 1.3 times higher (P < 0.01) than that of the control plot (surface planting). The stem diameter growth and the new shoot length were maximally 1.5 times better in the pit planting than in the control plot. The pit planting technique developed will be widely useful to promote the rooting and growth of trees in planting areas with problems of strong winds and dryness.

Introduction
Desertification of arid and semi-arid regions is one of the key environmental issues drawing global attention. Desertification not only causes air pollution, respiratory diseases, and damage to crops by the generation of yellow dust (KEI 2003; KFRI 2004), but it also has adverse effects on the natural ecosystem and on the socioeconomic system, as it results in decreases in biodiversity and in the movement of populations due to decreased productivity (Barrow 2009; UNCCD 2012; Reynolds 2013). The area of desertified regions worldwide is about 6.1 billion ha, which is about 41% of the Earth’s land surface, and about 6 million ha are desertified each year (Scoging 1991; UNDDD 2010; UNCCD 2012). The desertified area in Asia comprises about one-third of the entire desertification area in the world, and desertification in Asia usually takes place in China and Mongolia. Afforestation is necessary to prevent desertification in arid and semi-arid regions. It can also contribute to ecological soundness by conserving soil, absorbing carbon, and improving biodiversity.

As an effort to prevent desertification in Asia, China established a desertification prevention act in 2000, and has since implemented afforestation projects in Inner Mongolia and Tianjin (Bai 2006). In addition, the country will implement afforestation plans in arid regions, encompassing about 53 million ha, with fast-growing native species until 2050 (Wang et al. 2013). Mongolia, where 90% of the territory is under threat of desertification (KEI 2003; Tsogtbaatar 2004), has implemented afforestation projects in about 3000 ha since 2007 through the Korea–Mongolia Greenbelt Project (KMGP) (KFS 2016b). However, the survival rate of the trees planted in these arid and semi-arid regions is significantly low due to the strong winds and the dry and barren soil (Li et al. 2006). Thus, the objectives of afforestation projects, such as desertification prevention and wind breaking, are difficult to accomplish.

Many studies have been conducted on the planting techniques used to increase the survival rate of the planted trees (Pecay and Cullis 1986; Sharma et al. 1986; Carmona and Velasco 1988; Joffre and Rambal 1988; Carlowitz and Wolf 1991; Gupta 1994, 1995; Ojasvi et al. 1999; Li et al. 2006, 2008), and most of these studies have focused on increasing moisture use efficiency. Carmona and Velasco (1988) reported that the application of a microcatchment water-harvesting system increased the survival rate of planted trees by increasing the rainwater that could be used by the trees. Gupta (1995) reported that when trees were planted in furrow and ground surface, the furrow planting was more effective in securing the soil moisture, and that trees retained at least 3.8 times more biomass when compared with surface planting. Li et al. (2008) reported that the furrow planting to which gravel mulching was applied showed higher soil moisture and a two times higher tree growth rate when compared to surface planting. KFS (2016b) reported that tree growth was better in c. 80 cm furrow planting than in surface planting. According to Joffre and Rambal (1988, 1993), the shade produced by trees reduced the evaporation caused by solar radiation to secure a maximum of 110 mm of soil moisture. Furrow planting may also reduce the evaporation of soil moisture by providing shade in one or two directions, depending on the planting orientations.

Thus, afforestation projects implemented in arid and semi-arid regions partially employ a furrow planting technique to enhance the survival rate of planted trees. However, furrow planting causes great changes in the soil’s topography and requires much earthwork by deeply digging long planting rows over the entire surface. Such problems related to digging and mounding require high earthwork costs, a high operation rate of heavy equipment, and much labor.

CONTACT Hye-Mi Park phm2071@gmail.com
A planting technique to improve tree rooting and growth with minimum effort and cost is needed in order to enhance afforestation effects in arid and semi-arid regions. Although more attention is being paid to afforestation projects in these regions, studies on planting techniques for improving tree growth are still insufficient.

Therefore, instead of the deep and long furrow, this study developed a pit planting technique where planting spots were dug, so as to minimize topological changes and save on digging costs. The purpose of this study was to actually apply the technique to a semi-arid experiment site, and to analyze the effects of this technique on soil moisture and tree growth. There is little information on techniques and performance associated with pit planting. This study tackles exploration of a new, practical planting method to secure desirable tree growth in arid and semi-arid regions that are characterized by problems of strong winds and dryness.

Materials and methods

Experiment site

The site where the planting technique of this study was applied was an area around the Desertification Research Center in Mongolia (Figure 1). The center belongs to a semi-arid steppe where desertification is progressing. The center was chosen as the experiment site, given that tree planting and onsite investigations were allowed to take place through research collaboration. The location of the experiment site is 47°19′N, 103°42′E in the Bulgan region.

![Figure 1](image1.png)

**Figure 1.** Location of experiment site at the Desertification Research Center, Mongolia.

Pit planting and experiment design

To monitor the effect of pit planting on soil moisture and tree growth, as dependent on pit depth, a land area of 430 m² was divided into three zones for pit planting 30 cm in depth (30 cm pit planting), pit planting 50 cm in depth (50 cm pit planting), and a control plot (surface planting) (Figure 2). The 30 cm pit planting and the 50 cm pit planting refer to pit plantings where the base of the tree trunk is located at pit depths of 30 cm and 50 cm from the ground surface, respectively. The pits were actually dug at depths of 50 cm and 70 cm, respectively, to secure an additional depth of about 20 cm so the roots could be buried. The width of the pits was 60–80 cm at the top and 30–50 cm at the bottom. The slope in the pit was about 50°–60° (Figure 3).

The planted tree species was *Populus sibirica*, as recommended by local residents and experts. This tree species, which...
is a deciduous tall-tree that natively grows throughout the entire northern part of Mongolia, has good drought resistance and wind resistance (Tungalag et al. 2012). A total of 102 *P. sibirica* trees, 34 trees for each plot, were planted in May 2014. The size of the planted trees was as follows: stem diameter at the ground of 1.0–1.3 cm × height of 1.3–1.5 m, and the planting interval was 2 × 2 m. There was no significant difference in the tree size among treatment plots (*P* > 0.05). For 1 month after the planting, trees in all three plots were equally watered twice per week, for 1 hour (about 4 L), in early morning or late afternoon using a drip irrigation system. However, considering that the research objective was to investigate the effect of pit depth, fertilization was not implemented.

**Measurement and analysis**

After applying the pit planting technique to the actual site in 2014, the soil moisture and tree growth were monitored for the three plots for a total of 2 years until 2015; these factors were monitored in late August each year when the annual tree growth ends. The soil moisture was measured using Hydrosense (Spectrum Technologies Inc., Illinois, USA) from 0900 h to 1500 h in 3 hour intervals at the root zone of all the trees planted in the three plots. This measurement was performed at three locations for each tree. The tree growth was analyzed by measuring the stem diameter at ground, height, crown width, and new shoot length. Statistical significance including ANOVA for the soil moisture and tree growth measured among the plots was then tested using SPSS 23.0 for Windows.

In addition, this study measured the meteorological conditions relevant to tree growth, and analyzed the physicochemical properties of the soil environment. The meteorological conditions including wind direction, wind speed, air temperature, and humidity were measured at 1 hour intervals each day, all year round, by installing an automated meteorological instrument (Onset Computer Corporation, Massachusetts, USA). Soil samples were taken at a depth of about 20 cm in the root zone of the pits with five repeats for each plot and about 500 g for each repeat, immediately after planting and at the end of the growing period; the samples that were taken were then dried in the shade. The physicochemical properties of the soil samples were analyzed using the soil analysis methods of the Korean Institute of Agricultural Science and Technology (KIAST 2000).

**Results and discussion**

**Growth environments**

The plant growing period at the experiment site is relatively short, spanning from late May to early September (FAO 2006), and the yearly mean air temperature over the course of 2 years, from 2014–2015, was 1.7 °C (Table 1). At the experiment site, cold weather below 0 °C continues from November to March. The winter’s lowest temperature was –35.2 °C, while the summer’s highest temperature was 35.6 °C, showing a significant seasonal difference in air temperature. The main wind directions were from the north and west, and a strong wind in the range of 16.6–20.9 m/s frequently blew during the growing period. The strong wind resulted in yellow dust and the falling of planted trees (KFS 2016a). The evaporation of the Bulgan region, where the experiment site is located, is greater than the annual precipitation of 220 mm, and it increases by 2 mm each year (MOE 2008; KFS 2015). Throughout the monitoring times in late August in 2014 and 2015, the air temperature and humidity were in the ranges of 20.5 °C to 33.9 °C and 13.0% to 50.3%, respectively.

The soil at the experiment site was sandy, with a pH of 7.3, organic matter (OM) of 0.6%, total nitrogen (TN) of 0.03%, Ca²⁺ of 1.0 cmol+ kg⁻¹, and a cation exchange capacity (CEC) of 2.7 cmol+ kg⁻¹ at the time of the planting in May 2014 (Table 2). In late August 2015, after a 2 year growing period following the planting, the OM, Ca²⁺, and CEC of the soil increased by at least 1.3 times (*P* < 0.05), largely due to the litterfall. The conditions of the soil in Mongolia including grassland, desert, and forest were pH 8.6, OM 3.2%, and CEC 8.4 cmol+ kg⁻¹ (Kim et al. 2010). The forest soil of South Korea featured OM 4.5%, TN 0.19%, and CEC 12.5 cmol+ kg⁻¹ (Jeong et al. 2002). Compared with these data, the OM, TN, and CEC of the soil at the experiment site were significantly lower. Although fertilization was not implemented in this study to compare the effects of pit depth on tree growth, it is desirable to prepare a soil environment that enhances tree growth through composting.

**Changes in soil moisture**

The soil moisture content measured for each *P. sibirica* planting plot was highest in the 50 cm pit planting (6.7 ± 0.1%), followed by the 30 cm pit planting (6.5 ± 0.1%) and the control plot (5.1 ± 0.1%) (Table 3). Thus, the soil moisture content of the 30 cm and 50 cm pit planting plots was at least 1.3 times higher than that of the control plot (*P* < 0.01) (Table 4).

This may have been due to the fact that pit planting increased the soil moisture content by approaching the

| Season | Air temperature (°C) | Wind speed (m/s) |
|--------|----------------------|------------------|
| Spring | 3.9 – 26.6 | 31.8 | 2.8 | 23.7 |
| Summer | 17.4 | 0.4 | 35.6 | 1.9 | 20.1 |
| Autumn | 6.6 | –15.3 | 31.6 | 2.0 | 16.6 |
| Winter | –14.3 | –35.2 | 16.0 | 1.4 | 18.4 |
| Mean   | 1.7 | –15.8 | 21.1 | 2.0 | 16.0 |

Notes: Spring: March–May; summer: June–August; autumn: September–October; winter: November–February.

| Sampling | Soil texture | pH | OM (%) | TN (%) | ava. P (mg/kg) | Ca²⁺ (cmol+ kg⁻¹) | Mg²⁺ (cmol+ kg⁻¹) | CEC (cmol+ kg⁻¹) | EC (cmol+ cm⁻²) |
|----------|--------------|----|--------|--------|----------------|------------------|------------------|-----------------|----------------|
| May, 2014 | Sandy | 7.3 | 0.6 | 0.03 | 19.4 | 0.4 | 1.0 | 0.7 | 2.7 |
| August, 2015 | Sandy | 7.0 | 0.9 | 0.03 | 18.4 | 0.3 | 1.9 | 0.6 | 3.6 |

Notes: OM = organic matter (%); TN = total nitrogen (%); Ava. P = available P₂O₅ (mg/kg); EC = exchangeable cation (cmol+ /kg); CEC = cation exchange capacity (cmol+ /kg); (standard error).

| Season | Air temperature (°C) | Wind speed (m/s) |
|--------|----------------------|------------------|
| Spring | 3.9 – 26.6 | 31.8 | 2.8 | 23.7 |
| Summer | 17.4 | 0.4 | 35.6 | 1.9 | 20.1 |
| Autumn | 6.6 | –15.3 | 31.6 | 2.0 | 16.6 |
| Winter | –14.3 | –35.2 | 16.0 | 1.4 | 18.4 |
| Mean   | 1.7 | –15.8 | 21.1 | 2.0 | 16.0 |

Notes: Spring: March–May; summer: June–August; autumn: September–October; winter: November–February.

| Sampling | Soil texture | pH | OM | TN | Ava. P | Ca²⁺ | Mg²⁺ | CEC | EC |
|----------|--------------|----|-----|----|--------|------|------|-----|----|
| May, 2014 | Sandy | 7.3 | 0.6 | 0.03 | 19.4 | 0.4 | 1.0 | 0.7 | 2.7 |
| August, 2015 | Sandy | 7.0 | 0.9 | 0.03 | 18.4 | 0.3 | 1.9 | 0.6 | 3.6 |

Notes: OM = organic matter (%); TN = total nitrogen (%); Ava. P = available P₂O₅ (mg/kg); EC = exchangeable cation (cmol+ /kg); CEC = cation exchange capacity (cmol+ /kg); (standard error).

**Changes and ANOVA of soil moisture content by treatment plot of *Papulus sibirica* plantings.**

| Control plot | 30 cm pit planting | 50 cm pit planting | n | F | P |
|--------------|---------------------|---------------------|---|---|---|
| 5.1 ± 0.1    | 6.5 ± 0.1           | 6.7 ± 0.1           | 102 | 54.941 | 0.000 |

Table 1. Changes in air temperature and wind speed for study years from 2014 to 2015.

Table 2. Physicochemical properties of soils at experiment site.

Table 3. Changes and ANOVA of soil moisture content by treatment plot of *Papulus sibirica* plantings.
The survival rate of trees over 2 years after the planting was 91.2% in the control plot and there were no dead trees in the pit planting plots. Table 5 shows the growth rate of the Populus sibirica crown width and stem diameter at the ground, as well as the new shoot length measurements in each planting plot. At 2 years after the planting, the crown growth rate of Populus sibirica was 889.4 ± 58.5% in the 50 cm pit planting, 733.5 ± 43.3% in the 30 cm pit planting, and 526.1 ± 38.5% in the control plot. The results for both the stem diameter growth rate and the new shoot length showed a similar pattern: 147.9 ± 4.7% and 17.6 ± 0.7 cm in the 50 cm pit planting, 128.2 ± 2.9% and 14.7 ± 0.4 cm in the 30 cm pit planting, and 111.3 ± 1.2% and 12.0 ± 0.5 cm in the control plot, respectively.

The tree growth rates in terms of crown width, stem diameter at the ground, and new shoot length in the 50 cm pit planting were 1.7 times, 1.3 times, and 1.5 times higher than in the control plot, respectively, and those of the 30 cm pit planting were 1.4 times, 1.2 times, and 1.2 times higher than in the control plot, respectively (P < 0.01) (Table 6). Based on KFS’s (2016b) report, the survival rate of planted trees was 9.9% higher in the furrow planting than in the control plot. Gupta (1995) and Li et al. (2006, 2008) also reported that the tree crown and height growth rates were 1.4 to 2.5 times better in the furrow planting than in the control plot. The crown width, stem diameter, and new shoot length were, respectively, 1.2 times higher in the 50 cm pit planting than in the 30 cm pit planting (P < 0.01).

Table 4. Differences and t test of mean soil moisture content (%) by treatment plot of Populus sibirica plantings.

| Treatment plots          | Control plot | 30 cm pit planting | 50 cm pit planting | n   | P   |
|--------------------------|-------------|--------------------|--------------------|-----|-----|
| Control plot             | –           | –                  | –                  |     |     |
| 30 cm pit planting       | 1.4**       | –                  | –                  |     |     |
| 50 cm pit planting       | 1.6**       | 0.2                | –                  |     |     |

Note: *P < 0.01.

Table 5. Changes and ANOVA of growth rates by treatment plot for 2 years’ growing periods after Populus sibirica plantings.

| Measurement                          | Control plot | 30 cm pit planting | 50 cm pit planting | n   | F    | p    |
|--------------------------------------|--------------|--------------------|--------------------|-----|------|------|
| Crown width (%)                      | 526.1 ± 38.5 | 733.5 ± 43.3       | 889.4 ± 58.5       | 102 | 14.692 | 0.000 |
| Stem diameter at the ground (%)      | 111.3 ± 1.2  | 128.2 ± 2.9        | 147.9 ± 4.7        |     | 31.995 | 0.000 |
| New shoot length (cm)                | 12.0 ± 0.5   | 14.7 ± 0.4         | 17.6 ± 0.7         |     | 23.402 | 0.000 |

Table 6. Differences and t test of growth rates by treatment plot 2 years’ growing periods after Populus sibirica plantings.

| Measurement                     | Control plot | 30 cm pit planting | 50 cm pit planting | P   |
|---------------------------------|--------------|--------------------|--------------------|-----|
| Crown width (%)                 | –            | 207.4**            | –                  |     |
| Stem diameter at the ground (%) | –            | 16.9**             | –                  |     |
| New shoot length (cm)           | –            | 2.7**              | –                  |     |

Notes: *P < 0.05; **P < 0.01.

Such a high tree growth rate in the pit planting could be, as mentioned previously, due to the reduction of soil evaporation by wind breaking and shading (Joffre and Rambal 1988; Carlowitz and Wolf 1991), as well as soil moisturizing through rainwater collection (Gupta 1994; Li et al. 2006). In addition, the pit planting technique not only could prevent the falling of planted trees and reduce moisture evaporation of the tree trunk at the base through wind breaking, it could also enable the root to approach the groundwater level to efficiently use underground moisture. The groundwater level of the experiment site was found to be about 120 m (KFS 2016a).

Conclusion and implications

The survival rate of the trees planted in arid and semi-arid regions is significantly low due to the strong winds and the dry soil. Afforestation projects implemented in these regions partially employ a furrow planting technique to overcome this problem. The furrow planting technique can enhance the rooting and growth of planted trees, but it leads to changes in topography and requires much earthwork. Therefore, this study developed a pit planting technique in which only planting spots were dug as a method to minimize topological change and reduce digging costs. The developed technique was applied to a semi-arid region to analyze its effects on soil moisture and tree growth. The soil moisture content was 6.5% and 6.7% in the 30 cm pit planting and in the 50 cm pit planting, respectively, which was at least 1.3 times higher than in the control plot. The crown growth rate of Populus sibirica trees for 2 years following the planting was maximally 1.7 times higher in the pit planting than in the control plot. The stem diameter growth and the new shoot length in the pit planting were maximally 1.3 times and 1.5 times better than in the control plot, respectively. The mortality of the planted trees was 8.8% in the control plot and there were no dead trees in the pit planting plots.
Thus, pit planting had a number of advantages over surface planting in terms of soil moisture and tree growth. This could be due to the fact that pit planting reduced moisture evaporation of the soil and the tree trunk at the base through wind breaking and shading, and prevented the planted trees from falling in strong wind. This method also enabled the trees to efficiently use underground moisture and to collect rainwater. The tree growth rates including crown width, stem diameter, and new shoot length were 1.2 times higher in the 50 cm pit planting than in the 30 cm pit planting, although the soil moisture content was not significantly different between the two treatment plots. The higher tree growth rates in the 50 cm pit planting could be attributed to less evaporation of the tree trunk through better wind breaking and better accessibility of the root to the groundwater level. The pit planting technique developed in this study will be more effective than the furrow planting technique, since pit planting reduces the amount of time and costs required for earthworks, and it also decreases water evaporation through wind breaking and shading effects in any direction.

Desertification prevention, carbon reduction, and biodiversity conservation are major concerns worldwide, and afforestation projects are essential to accomplish these goals. The results of this study will be practically useful in enhancing the growth of the trees planted in disadvantaged growing environments in both arid and semi-arid regions, contributing to the accomplishment of afforestation project goals. The pit planting technique is also suitable for those tree planting projects implemented in seaside or sandy soil dominant areas with other climate conditions that feature such problems as strong winds and dryness. This study did not include biomass measurement through cutting of the planted trees because of requirement of planting effects including agroforestry practices. More studies in different adverse growing environments are required to compare and verify the effects of pit planting discussed in this study.

Disclosure statement
No potential conflict of interest was reported by the authors.

Funding
This work was supported by a grant [Code # S211216I.030130] from Forest Science & Technology Projects, Forest Service, Republic of Korea.

References
Bai J. 2006. Strategies to combat desertification in China. For Cult. 15:16–24.
Barrow CJ. 2009. Desertification. In: Kitchin R, Thrift N, editors. International encyclopedia of human geography. Oxford: Elsevier; p. 96–101.
Carlowitz PG, Wolf GV. 1991. Open-pit sunken planting: a tree establishment technique for dry environments. Agroforestry Syst. 15:17–29.
Carmona RM, Velasco MHA. 1988. Microcatchment water harvesting for raising a pistachio orchard in a semiarid climate of Mexico. In: Unger PW, Jorden WR, Sneed TV, Jensen RW, editors. Proceedings of the International Conference on Dry Land Farming Challenges in Dryland Agriculture—A Global Perspective. Texas: Texas Agricultural Experiment Station; p. 245–247.
FAO. 2006. Country pasture / forage resource profile. Rome (Italy): Food and Agriculture Organization of the United Nations.
Gupta GN. 1994. Influence of rain water harvesting and conservation practices on growth and biomass production of Azadirachta indica in the India desert. For Ecol Mgrnt. 70:329–339.
Gupta GN. 1995. Rain-water management for tree planting in the Indian desert. J Arid Environ. 31:219–235.
Jeong JH, Koo KS, Lee CH, Kim CS. 2002. Physico-chemical properties of Korean forest soil by regions. J Korean For Soc. 91:694–700.
Joffre R, Rambal S. 1993. Soil water improvement by trees in the range- lands of southern Spain. Acta Oecol. 9:405–422.
Joffre R, Rambal S. 1998. How tree cover influences the water balance of Mediterranean rangelands. Ecology. 74:570–582.
KEI. 2003. Analyzing northeast Asian dust and sandstorm damages and regional cooperation strategies I. Seoul (South Korea): Korea Envi- ronment Institute.
KFRI. 2004. Cause and mitigation of desertification in northeast Asian regions. Seoul (South Korea): Korea Forest Research Institute.
KFS. 2015. A study on combating desertification in arid and semiarid areas III. Seoul (South Korea): Korea Forest Service.
KFS. 2016a. A study on combating desertification in arid and semiarid areas IV. Seoul (South Korea): Korea Forest Service.
KFS. 2016b. Korea–Mongolia greenbelt plantation project. Seoul (South Korea): Korea Forest Service.
KIAST. 2000. Methods of analysis for soil and plants. Suwon (South Korea): Korean Institute of Agricultural Science and Technology.
Kim DR, Kim JS, Ban SJ. 2010. A study on the characteristics of soil in the Asian desert source region of Mongolia. J Korean Soc Atmos Envi- ron. 26:605–615.
Li XY, Shi PJ, Sun YL, Tang J, Yang ZP. 2006. Influence of various in situ rainwater harvesting methods on soil moisture and growth of Tam- arix ramosissima in the semiarid loess region of China. For Ecol Mgrnt. 233:143–148.
Li XY, Zhao WW, Song YX, Wang W, Zhang XY. 2008. Rainfall harvest- ing on slopes using contour furrows with plastic-covered transverse ridges for growing Caragana korshinskii in the semiarid region of China. Agric Water Mgrnt. 95:539–544.
MOE. 2008. A study on current status and mitigation measures of yel- low dust outbreak in Mongolia. Seoul (South Korea): Ministry of Environment.
Ojasvi PR, Goyal RK, Gupta JP. 1999. The micro-catchment water har- vesting techniques for the plantation of jujube (Zizyphus mauriti- ana) in an agroforestry system under arid conditions. Agric Water Mgrnt. 41:139–147.
Pacey A, Callis A. 1986. Rainwater harvesting: the collection of rainfall and runoff in rural areas. London: Intermediate Technology Publication.
Quanqi LI, Xunbo Z, Yuhai C, Songlie Y. 2012. Water consumption characteristics of winter wheat grown using different planting pat- terns and deficit irrigation regime. Agric Water Mgrnt. 105:8–12.
Reynolds JF. 2013. Desertification. In: Levin SA, editor. Encyclopedia of biodiversity. San Diego: Academic press; p. 479–494.
Scogling H. 1991. Desertification and its management. In: Bennett R, Estall R, editors. Global change and challenge geography for the 1990s. London: Routledge; p. 57–79.
Sharma KD, Pareck OP, Singh HP. 1986. Microcatchment water har- vesting techniques for raising jujube orchards in an arid climate. Trans Ameri- can Soc Agric Engin. 29:112–118.
Tsogbaatar J. 2004. Deforestation and reforestation needs in Mongolia. For Ecol Mgrnt. 201:57–63.
Tungalag R, Jamsran T, Boldgiv B, Lkhagvasuren D. 2012. A field guide to the trees and shrubs of Mongolia. Ulaanbaatar: Munkhiiin Useg. UNCCD (United Nations Convention to Combat Deserti- fication). 2010. Bonn: United Nations Decade for Deserts and the Fight Against Desertification [Internet]. Available from: http://www.un.org/en/events/desertification_decade/whynow. shtml.
Wang F, Pan X, Wang D, Lu Q. 2013. Combating desertification in China: past, present and future. Land Use Policy. 31:311–313.
Zhang JY, Sun JS, Duan AW, Wang JL, Shen XJ, Liu XF. 2007. Effects of different planting patterns on water use and yield performance of winter wheat in the Huang-Huai-Hai plain of China. Agric Water Mgrnt. 92:41–47.