Changing Forestry Policy by Integrating Water Aspects into Forest/Vegetation Restoration in Dryland Areas in China

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Abstract Restoration forestry (forest rehabilitation) or re-vegetation is one effective measure to solve environmental problems, notably soil erosion. It may be further stimulated by the Clean Development Mechanism for carbon sequestration. However, there is an intensive and on-going debate about the adverse effects arising from afforestation in dryland areas, such as soil drying up which may cause further damage to the success of forest restoration, and the water yield reduction from watershed which may harm the regional development. On other hand, some preliminary studies showed a possibility that these adverse effects may be diminished more or less by properly designing the system structure and spatial distribution of forest/vegetation in a watershed. However, it is urgent to develop an evidence-based and sustainable new forestry policy for harmonizing forest-water interrelation. As a leading country in afforestation, China is beginning to develop a more trans-disciplinary and cross-sectoral forestry policy for harmonizing forestry development with water management. The main points of the changing new forestry policy should include: (1) Establishing a regional development strategy focusing on harmonized forest-water relations; (2) Taking forest-water interactions as an important part of evaluation; (3) Reducing the 'eco-water' quota of forests through technical advancement; (4) Developing and extending water-adaptive forest management practices; (5) Strengthening forest ecohydrological research and decision support ability.

Keywords forest restoration, dryland areas, water resources, integrated management, forestry policy, China

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1. Introduction

Dryland is the total terrestrial regions falling within arid, semi-arid, and dry sub-humid zones (excluding the extreme arid area), which in total area accounts for 37.7% in the world and 34.6% in China (http://earthtrends.wri.org/), and supports the livelihood of more than 2 billion people worldwide and about 170 million people in China. However, there are many urgent environment problems in drylands such as water scarcity and soil erosion. They all need to be resolved by integrated approaches. Restoration forestry/re-vegetation is widely accepted as one effective measure, and big efforts have been made in China. The Clean Development Mechanism for carbon sequestration may be a further stimulus for reforestation/re-vegetation in these dryland areas.

With accelerating competition for the limited water resources, there is an intensive, on-going debate about the water yield reduction arising from afforestation. Thus, the policy of promoting forest restoration is increasingly being questioned (Farley *et al*., 2005; Zomer *et al*., 2006). However, forests supply numerous services and forest restoration cannot be negated only because of water consumption. The right way and more urgent task is to develop an evidence-based and sustainable new forestry policy, for harmonizing forestry development with water management and minimizing its side effects, particularly the water yield reduction in dryland areas. China as a leading country in afforestation, its experience and lessons learned may be of relevance for other countries.

2. Restoration of forest/vegetation is a long-term task

The fragile dryland in China faces many environmental problems. First is the serious soil erosion, *e.g.* the average is around 10,000 t km^{-2} a^{-1} in the Loess Plateau and as high as 20,000 – 30,000 t km^{-2} a^{-1} in some places (Liu, 2003). Second is the increasing occurrence of sandstorms, which cause huge damage and cost in life (Bian and Zhang, 2003) and sometimes these sandstorms extend into neighbouring countries (Liu and Diamond, 2005). Third is the water related disasters, including frequent droughts, flash floods and sometimes even disastrous floods. An integrated and protective environment management strategy is now more urgent than anytime before.

After many years of afforestation on all slopes, only the trees planted at shady slopes with relative high soil moisture can survive.

Many studies have revealed that forests can protect soil from erosion. A litter layer thicker than 2~3 cm and a soil surface cover more than 70% are required (Wang, 1986; Sun and Zhu, 1995). Increasing vegetation with respect to both density and structure is thus considered to be helpful for improving the overall environmental conditions. Such factors significantly promoted the current campaigns of forest/vegetation restoration. Several large-scale forestry projects were started in 1999, such as those for protecting natural forest (Zhang *et al*., 2000), converting slope cropland to forests, shelterbelt development, and wind erosion control (Li, 2004).

The forest coverage 4,000 years ago was over 60% for the whole of China and around 30% for its northwest half with a dry climate (Fan and Dong, 2001). However, Chinese forest cover decreased to 12.5% in 1949, and then fluctuated around this figure for several decades (Lei, 2005). Since the 1980s and especially in the 1990s, the forest area has begun to increase as more plantations have been established, e.g. 13.0% in 1988, 13.9% in 1993, 16.6% in 1998, and 18.2% in 2003. According to the Chinese State Forestry Administration, the forest coverage in China will be increased to 23.5% in 2020, 25.5% in 2030, and 28.4% in 2050; correspondingly in the dry northern China, from 10.4% in 2000 to 14.8% in 2050.

3. Principal ecohydrological findings and new requirements for forest restoration

3.1 Drying up of soil after afforestation

Originally the previous afforestation campaign in dryland areas was mainly for controlling soil erosion. At that time the limitation of low soil moisture for forest restoration was neglected. It is only since the 1980s, that the phenomenon of so-called "dried soil layer" was frequently observed after forest/vegetation restoration (Li, 1983; He *et al*., 2003). The term "dried soil layer" signifies a long-term permanent and critical soil water deficit in the root zone; it emerges when in the long-run plants consume more water than is supplied naturally. Taking the typical soil in northwest China of loess, the dried soil layer is defined as the soil with moisture from wilting point to 60% of field capacity, *i.e.*, the soil water content (in weight) from 8% to 14%.

"Dried soil layers" are reported mainly for sites with deep soils, *e.g.* in dune areas and in the Loess Plateau, but such layers exist in all climate zones of dryland areas (Yang, 1996). In arid zones, a dried soil layer develops directly after planting of shrubs. In the semi-arid zone, the soil dries out underneath young stands of only a few years of age. In the semi-humid zone, dried soil layers occur both underneath forest plantations and secondary natural forests. According to the study of Hou *et al*. (1999), the dryness and depth of dried soil layer varies following the gradient of annual precipitation across the Loess Plateau: in the semi-humid zone, the dried soil layer begins normally 2m below soil surface; while the corresponding depth in semiarid zone is about 1 to 1.5m. Severe soil drying has mostly been observed with artificial forests/vegetation. The unsuitable design of plant communities with non-site adapted foreign species and/or in higher densities is thought to be the main causes of dried soil layer. Such afforestations are characterised by higher water consumption compared to native vegetation.

The soil desiccation includes not only the phenomena of dried soil layer on sites with deep soil, but also the general decrease of soil water content on sites with thin soil. Soil desiccation is difficult to recover because of the inherently low precipitation being offset by enhanced evapotranspiration (ET). Based on our research (Wang *et al*., 2006) on the soil water budget (Figure 1) and the ET composition (Figure 2) of main vegetation forms in

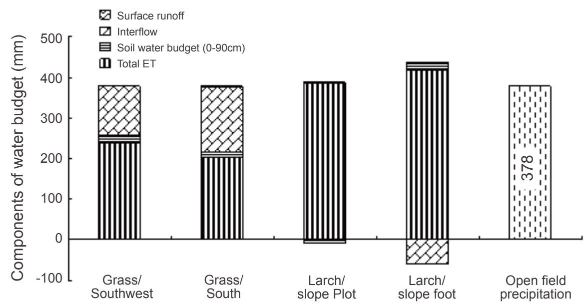

Figure 1 The components of water budget for soil layer 0–90 cm in plots of natural grassland and 20-yrs Larch plantation as typical vegetation forms in Diediegou (Liupan Mountains, NW China) with semiarid climate during growing season (Jun–Sep) in 2004. (Surface runoff and interflow measured in runoff plots (10 m × 20 m) or calculated by calibrated hydrological models of BROOK90 (Federer, 1995; 2002); soil moisture measured by TRIME and soil auger; the calculation of ET given in Figure 2)

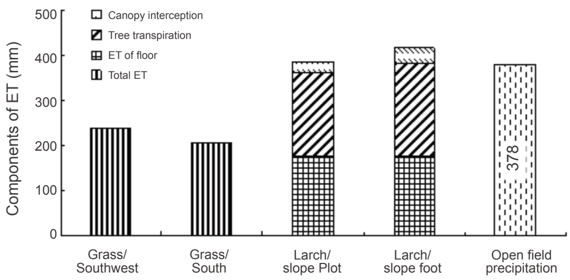

Figure 2 The ET and its components in plots of natural grassland and 20-yrs Larch plantation as typical vegetation forms in Diediegou (Liupan Mountains, NW China) with semiarid climate during growing season (Jun–Sep) in 2004. (Tree transpiration measured as sapflow by thermal dissipation probe techniques (Ecomatic Inc., Dachau, Germany); shrub transpiration by Dynagage Systems (Dynagage, Dynamax, Houston, Texas, USA); the stand transpiration by scaling-up the measured values of individual trees/plants based on LAI or sap-wood area; soil evaporation of forest floor and the total ET from grassland by weighing lysimeter)

Diediegou in Liupanshan Mountains with semiarid climate in northwest China, ET takes a very large ratio in water balance especially for forests, and forest consumes much more water than grassland. As a result of elevated canopy interception and transpiration of trees after afforestation, the soil water or even interflow will be negatively balanced, *i.e.*, runon from upper slope being absorbed by planted trees.

3.2 Success of forest restoration limited by low soil moisture

The decreased soil water leads to lower survival rate and growth of trees (Sun and Zhu, 1995). The yearly height increment of poplar (*Populus simonii* Carr.) on sites with dried soil is only 5 - 20 cm, equaling a mere 10 - 25 % of that of normal trees (Hou *et al*. 1999; Wang *et al*. 2001). Soil drying also stunts the natural regeneration of woody plants and makes planting more difficult (Hou *et al.* 1999). For example, there is nearly no young Chinese pine (*Pinus tabulaeformis* Carr.) or poplar (*Populus simonii* Carr.) on sites of severe soil drying. The survival rate of *Hippophae rhamnoides* on a semi-shadow site of sandy loess with a soil water content of 11.5% was as high as 80% one month after planting; while it was only 15% on a dried site with soil water content of 4% caused by previously planted Lucerne (*Medicago sativa*). It is widely noticed that the drought stress is an important factor provoking the outbreaks of forest disease and insect pest (Mattson and Haack, 1987; Rouault *et al*., 2006), however, no quantitative relationship was studied in China.

Elsewhere the lowering of groundwater levels due to increased irrigation demands has resulted in damage to afforested/re-vegetated areas within oasis-type ecosystems, *e.g*. the Ejina Oasis in Inner Mongolia (Liu and Zhang, 2002) and along the Tarimu River in Xinjiang (Cao *et al*., 2003). The setting aside of a certain amount of so-called “eco-water” in regional water use plans is imperative for ensuring the sustainability of forest/vegetation restoration (Tang, 1995), and calls for such measures is continuing to increase (Shen, 2001).

The long-term success of forest/vegetation restoration in dryland areas of northern China is and continues to be greatly influenced by drought stress and soil drying up. The availability of soil water is a key factor for the stability of newly established stands.

3.3 Water yield reduction after afforestation

Water yield reduction by increased afforestation is observed worldwide (Farley *et al*., 2005; Jackson *et al.*, 2005; Zomer *et al*., 2006), although the magnitude varies. Similar trends are observed when concerning the dryland areas of China, across scales from the plot (Figure 1) to the drainage basin (McVica *et al*., 2007). Using a simplified hydrological model (Sun *et al*., 2006), the potential annual water yield reduction due to afforestation was estimated to be around 50mm (50%) in the semi-arid Loess Plateau region in China. Huang *et al*. (1999) simulated the effect of increased vegetation cover on runoff based on 44 years of observation data linked with some small drainage basins in the Loess Plateau. The basin areas ranged from 0.87 – 1.15km^2 with an annual precipitation of 565mm. The respective annual runoff of 19.6, 12.3, and 6.0mm for a corresponding grassland coverage ratio of 40%, 60% and 80% was determined from the simulation. For the same percentages of forest cover, the annual runoff was 13.7, 6.6 and 3.2mm. Based on the assessment of hydrological impact of afforestation using the data of 57 basins in the Loess Plateau (Wang *et al*., 2011), it was found that in average the annual water yield will be decreased from 39mm for non-forestlands to 16mm for forestland of these basins. In absolute values, the runoff reduction after afforestation compared with grassland is not excessive; however, the relative change and its socio-economic impacts are much more considerable in dryland areas. Consequently, there is an overall growing concern about this potential water yield reduction due to afforestation in China.

As described above, the forest-water conflict has sharpened in recent times, so that it has quickly become a focus for both scientists and the public as well as decision makers (Shen and Wang, 2000). New requirements for forest/vegetation restoration in dryland areas are being considered to ensure its stability, sustainability and contributions towards regional development especially through a safe water supply. The key issues are how to design, establish, and manage forests/vegetation from a holistic viewpoint, so that they will be compatible with water carrying capacity of sites, and with minimal water yield reduction. These are the new challenges, both in the theoretical and practical aspects.

3.4 Preliminary attempts of water-adaptive forest management

Keeping soil water balance at relatively high levels over extended periods of time becomes a prerequisite for restoration success. This goal can be achieved by designing and managing forest/vegetation communities based on soil water carrying capacity. Guo and Shao (2006) defined soil water carrying capacity as the density of trees/plants under which soil water consumption is not excessive and the water consumed can be recharged by infiltrated precipitation.

However, the soil water carrying capacity is dynamic if plant density is used as an indicator, simply because of the growth of perennial plants notably in the case of trees. Based on a 5-year study of water balance in the southern part of the Loess Plateau, Yu and Chen (1996) concluded that the soil water can support a normal growth of the first 10 – 16 years of the black locust (*Robinia pseudo-acacia* Linn.) plantation and 5 – 8 years for the Chinese pine (*Pinus tabulaeformis* Carr.) plantation. In contrast, shrubs can be supported throughout their life cycle. To improve the soil moisture condition for individual trees planted, Wang *et al*. (2002) have tried to develop a rainwater harvesting system for afforestation in the Loess Plateau. It was successful in increasing soil moisture and improving the tree growth when the trees were young. However, the soil water deficit re-appeared as trees grew up. Therefore, the rainwater harvest system can not ensure the water supply to the afforested trees for their whole life cycle. And more critical is that this rainwater harvest system goes against the principle of keeping a water yield function of watershed in dryland areas. Thus it can not be widely applied to solve the increasing forest-water conflict in dryland areas.

Keeping the forest area ratio within an allowable range limited by water carrying capacity across scales from landscape up to a regional level, selecting water-saving species and designing optimal stand structure for adapting site water condition, all of these considerations appear to be implemental approaches of forest management in dryland areas. Liu and Liao (1999) suggested the water-adaptive and proper forest area ratio for Chifeng of Inner Mongolia to be 33.1%, much lower than the earlier ratio of 42.4% which was determined mainly based on land-use. In order to mitigate the water deficit problem in dune-fixation forests, Cui (1998) suggested to lower forest density and use native instead of foreign species. Taking the example of a 16-years-old shrub community of *Caragana Korshinskii* Kom., planted on loess site with semiarid climate (annual precipitation of 414mm), Guo and Shao (2006) calculated the equitable density of 8,115 clumps per hectare as the soil water carrying capacity after determining the empirical relations of soil water supply and soil water consumption with plant density.

Decreasing density looks to be an effective measure to reduce the water demand of dense plantations. To quantify

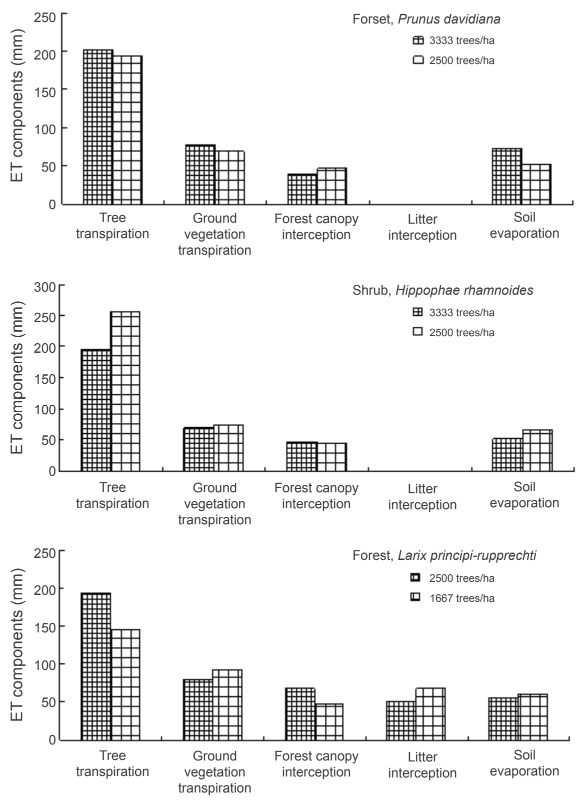

Figure 3 The effect of density on ET rate and its components in growing season (May-Oct, 2002) for main vegetation forms in Diediegou (Liupan Mountains, NW China). (The precipitation during research period amounted to 404 mm. The measuring methods of ET components see the captions of Figure 1 and Figure 2)

Larch plantation in the Liupan Mountains of northwestern China.

the effect of reduced density of plant communities on water consumption, two densities (Figure 3) were created by thinning in the spring of 2002 for three main vegetation forms in Diediegou of Liupan Mountains. Then the amount and composition of ET of these communities were measured in the growing season (May – Oct.) of the same year of 2002 (Wang *et al*., 2006). It showed a reduction of transpiration after thinning for stands of *Larix* and *Prunus*, but the reduction ratio was much lower than the thinning ratio since the transpiration of individual tree was increased after thinning. In contrast, the transpiration of the thinned shrub community of *Hippophae* was increased, probably because of the promoted growth of individual plant of *Hippophae* by thinning/cutting.

The different transpiration response of the shrub of *Hippophae* to thinning compared with tress may be explained by its different growth response to thinning/cutting. According to an experiment of growth behavior of *Hippophae* after cutting (Li *et al*., 2000), the biomass of two communities, which have been cut 4 and 9 years ago, reached 6.84 and 4.30 times of that of controlled community without cutting. Another experiment (Zhou, *et al*., 1998) showed that both the height and the ground diameter of *Hippophae* 2 years after cutting reached 2.2 times of that before the cutting. It is also the fast recovery of canopy of shrubs making the canopy interception of *Hippophae* was only slightly reduced after thinning; whereas interception loss from forest was obviously reduced. The ground vegetation transpiration and soil evaporation after thinning for all species did increase. As an integrated effect, the total ET after thinning differed among vegetation forms as follows: slightly reduced (-8%) for the forest stand of *Larix principi-rupprecht*; very slightly reduced (only -2%) for the forest stand of *Prunus davidiana*, a small arbor species; and conversely an increase (+21%) for the shrub community of *Hippophae rhamnoides*. The above work showed that reducing density of forest/shrub community will be not as effective as presupposed in alleviating the water yield reduction after afforestation in dryland areas. Moreover, instead of density as suggested by Guo and Shao (2006), the LAI may be a more suitable indicator for soil water carrying capacity (Wang *et al*., 2006).

The decision making process for forest restoration based on water carrying capacity is very complex in the dryland areas, since many factors and feedbacks should be considered. The most important factor to be considered is the hydrological effect of water yield reduction. McVicar *et al*. (2007) have newly developed a decision support tool called Re-Vegetation Impacts on Hydrology (ReVegIH) based on a simplified and regional steady state model for the region of the Loess Plateau. It is useful to select the priority area of afforestation and suitable species in a spatial resolution of 100 m, and to simulate the related hydrological impact on an average annual basis in the level of catchment or county. However, it is still unable to guide the site specific planning and practice of afforestation, since the detailed site conditions and temporal variation of soil moisture are often critical in determining the success of re-vegetation in the dryland areas. A decision support tool based on eco-hydrological processes and considering the temporal variation and spatial heterogeneity more detailed is required.

From the discussion above it can be concluded that the current progresses of ecohydrological studies are still limiting the development of water-adaptive forestry. The water-adaptive forestry should include a set of integrated measures, rather than one or several individual techniques such as density regulation. More specific researches should be implemented in future for improving the ability of comprehensive decision making with an optimal trade-off among the multiple goals of management (erosion control, water protection, flood alleviation, water yielding, biodiversity protection, carbon sequestration, bio-products supply, *etc*.). The water adaptive forestry requires the region/site specific and integrated decisions of forest area ratio, spatial distribution, plant species composition, community structure (density, LAI, ground coverage, *etc*.) based on the dynamic soil water carrying capacity in different scales (site, slope, draining basin, region) for multifunctional management. The current forest policy mainly for timber production and/or soil protection without enough consideration of water aspects should be adjusted as soon as possible.

4. The changing forestry policy for harmonized forest-water relations

The Chinese government is paying increasing attention to accelerating forestry development, mainly for exerting its ecological benefits. To ensure the success of the large-scale forest/vegetation restoration, it is inevitable and urgent to integrate water aspects into forest management across different scales, notably in dryland areas. Therefore, China is beginning to develop a more trans-disciplinary and cross-sectoral forestry policy for harmonizing forestry development with water management. The main points of the changing new forestry policy are described below.

4.1 The establishment of a regional development strategy concerning harmonized forest-water interrelation

Within the framework of complex natural environment and associated socio-economic interactions, a regional specific and long-term development strategy is the best means for promoting close cross-sectoral cooperation. The interrelations between forest/vegetation restoration, water protection, soil conservation, water resources allocation, land-use and poverty alleviation is an integral part of this development strategy. Balanced water allocation and water carrying capacity should be especially emphasised as two new features of forest-land-water policy. The 'eco-water' for forest/vegetation restoration should be allocated in water use plans and ensured by compensating water-saving policy and actions elsewhere. On the other hand, the forestry development should be based on the water carrying capacity at both regional and site scales. Therefore, long-term and water-harmonized forestry development plans should be set up for different regions. A "close-to-nature" forestry practice should be encouraged based on a more comprehensive understanding of its hydrological impacts.

4.2 Taking forest-water interactions as an important part of evaluation methods

The evaluation system separately developed mainly for timber-production or water management is now no more suitable for ecological forestry, watershed management and regional development, especially in dryland areas. It is essential to develop a new evaluation system that includes quantified forest-water interactions, and to determine the corresponding indicators and criteria. This is also the basis for developing a more economic compensating mechanism to ensure the hydrological benefits and water yield function of forested watersheds.

4.3 Reducing the 'eco-water' quota of forest through technical advancement

With increasing competition for water use and the elevated uncertainty in climate change, it is essential to take some effective measures for reducing the amount of 'eco-water' per unit forest area without loss of its other functions. Firstly, forest should be planted with the most optimal stand structure and spatial distribution, which is adaptive to the water carrying capacity of the local soils and groundwater conditions. Secondly, the use of water-saving tree species and shrubs should be encouraged. Thirdly, some engineering measures, such as soil preparation and soil protection, should be applied.

4.4 Developing and extending water-adaptive forest management practices

The existing successful forest practices for soil protection and timber production need to be further developed for their adaptation to the water management and water carrying capacity. Concrete measures that need to be taken include tree species selection, stand structure

The small watershed of Diediegou in Liupan Mountains for studying the hydrological impact of afforestation.

design, optimal spatial distribution, and multifunctional management. The latter is a continual, iterative process of systematically summarizing, updating, newly developing, and extending the water-adaptive forest practices to progressively achieve optimal targets of sustainability.

4.5 Strengthening forest ecohydrological research and decision support ability

As an accompanying measure, a long-term research network with representative sites along the aridity gradient should be established. The interdisciplinary, multi-scaled, multi-processes based eco-hydrological research should be strengthened. The foci of the current key research are the quantification of eco-water demand in different scales, understanding of ecohydrological processes, the stability of forest/vegetation in dryland areas, the development of distributed ecohydrological watershed models, and the trans-scaled decision support tools. With help of new technology, a comprehensive and optimal decision for integrated management of forest and water will be operable.

5. Conclusion

Forest/vegetation restoration in dryland areas is a costly, time-consuming and, thus, difficult task. To guarantee a sustained success, a sound understanding of factors and processes controlling the dynamics of water availability is indispensable. Nevertheless, the forest-water interaction and its rational regulation are very complex. The current knowledge is very limited for guiding large-scale forest/vegetation restoration. Therefore, the optimization of water-adaptive forestry policy is a long-term and iterative process of "learning by doing". Many further actions are required, such as the need to further integrate forestry development into national planning, further harmonizing all forest-related policies and actions, creating new financial support from different donors for implementing the new forestry policy based on economic compensation mechanisms which also have to incorporate forest hydrological benefits. Finally, a basic requirement to meet these goals of a new forestry policy is to strengthen the scientific/technological basis. Therefore, the development and application of transdisciplinary, multi-scaled, process-based, distributed ecohydrological models as powerful decision-making support tools should be encouraged.

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References

Bian, X.C., Zhang, Z.L., 2003. The research on the cause and harm of the dust storm and its countermeasures. *Territory and Natural Resources Study*: 2, 60–61 (in Chinese, with English abstract).

Cao, T.L., Hu, J.H., Sun P.H., 2003. Issues of water resources and harnessing measures for the mainstream of Tarim river. *Northwest Water Resources and Water Engineering*: 14(1), 51–53 (in Chinese, with English abstract).

Cui, G.F., 1998. Water balance of dune fixation forest and suitability of artificial vegetation. *Journal of Beijing Forestry University*: 20(6), 89–94 (in Chinese, with English abstract).

Fan, B.M., Dong, Y., 2001. Percentage of forest cover in different historic periods of China. *Journal of Beijing Forestry University*: 23(4), 60–65 (in Chinese, with English abstract).

Farley, K.A., Jobbágy, E.G., Jackson, R.B., 2005. Effects of afforestation on water yield: a global synthesis with implications for policy. *Global Change Biology*: 11, 1565–1576.

Federer, C.A., 1995. BROOK90 - A simulation model for evaporation, soil water, and streamflow. Version 3.24. *Computer freeware and documentation*, USDA, Forest Service, Durham, USA.

Federer, C.A., 2002. BROOK90 - A simulation model for evaporation, soil water, and streamflow. Documentation for Version 4 and 3.2/3/4. http://users.rcn.com/compassbrook/brook90.htm.

Guo, Z.S., Shao, M.A., 2006. Preliminary study of vegetation carrying capacity of soil water (VCCSW). *Science and Technology Review* 24(2):56-59 (in Chinese, with English abstract).

He, F.H., Huang, M.B., Dang, T.H., 2003. Distribution characteristic of dried soil layer in Wangdonggou watershed in gully region of the Loess Plateau. *Journal of Natural Resources*: 18(1), 33-36 (in Chinese, with English abstract).

Hou, Q.C., Han, X.L., Han, S.F., 1999. A primary study on the soil drying in the forest and grass land in the Loess Plateau. *Soil and Water Conservation in China*: 5, 11–14 (in Chinese).

Huang, M.B., Kang, S.Z., Li, Y.S., 1999. A comparison of hydrological behaviours of forest and grassland watersheds in gully region of the Loess Plateau. *Journal of Natural Resources*: 14(3), 226–231 (in Chinese, with English abstract).

Jackson, R.B., Jobbágy, *et al.,* 2005. Trading water for carbon with biological carbon sequestration. *Science*: 310, 1944–1947.

Lei, J.F. (2005). *Forest Resources of China*. Beijing: China Forestry Publishing House (in Chinese).

Li, G.Q., Tang, R.D., Zhao, Y.Q., 2000. The ability of germination and re-growth of Hippophae after cutting in the Maowusu Desert of China. *Hippophae* 13(4):9–12. (in Chinese)

Li, W.H., 2004. Degradation and restoration of forest ecosystems in China. *Forest Ecology and Management*: 201, 33–41.

Li, Y.S. (1983). The properties of water cycle in soil and their effect on water cycle for land in the loess region. *Acta Ecologica Sinica* 3(2):91–101 (in Chinese, with English abstract).

Liu, J.G., Diamond, J., 2005. China's environment in a globalizing world - How China and the rest of the world affect each other. *Nature*: 435, 1179–1186.

Liu, W.Q. (2000). A discussion about the strategy of soil and water conservation in the Loess Plateau. *Soil and Water Conservation of China* 2000(1), 20–22 (in Chinese).

Liu, X.H., Zhang, C.X., 2002. The present situation of vegetation in Ejina Oasis and its protection. *Inner Mongolia Forestry Science and Technology*: 25(4), 34–35, 47 (in Chinese).

Liu, Z.S., Liao, Y.M., 1999. Tree species selection and the proper forest ratio in Chifeng. *Inner Mongolia Forestry Science and Technology*: 22(3,4), 75–78 (in Chinese).

Mattson, W.J., and Haack, R.A., 1987. The role of drought in outbreak of plant-eating insects. *BioScience* 37(2):110–118

McVicar, T.R. *et al*., 2007. Developing a decision support tool for China's re-vegetation program: Simulating regional impacts of afforestation on average annual streamflow in the Loess Plateau. *Forest Ecology and Management*: 251(1–2), 65–81.

Rouault, G. *et al*. 2006. Effects of drought and heat on forest insect populations in relation to the 2003 drought in Western Europe. *Annuals of Forest Science* 63, 613–624.

Shen, G.F., 2001. Ecological environment construction and protection and utilization of water resources. *Soil and Water Conservation in China*: 226, 4–8 (in Chinese, with English abstract).

Shen, G.F., Wang, L.X., 2000. *The ecological construction and the protection and utilization of water resources in China*. Beijing; Press of Chinese Water Resources and Hydropower, (in Chinese).

Sun, G. *et al*., 2006. Potential water yield reduction due to forestation across China. *Journal of Hydrology*: 328, 548-558.

Sun, L.D., Zhu, J.Z., 1995. *The research and evaluation on the multi-function of forests for soil and water conservation*. Beijing: The Publishing House of Science and Technology in China, (in Chinese).

Tang, Q.C., 1995. The development in oasis and rational use of water resources. *Journal of arid land Resources and Environment*: 9(3), 107-112 (in Chinese, with English abstract).

Wang, B.T., Tian, J.H., Zhang, F.E., 2002. Design method of rainwater harvesting system for afforestation in Loess Plateau. *Forestry Studies in China*: 4(1), 29-34.

Wang, L., Shao, M.A., Hou, Q.C., 2001. The primary research on dried soil layer in the Loess Plateau. *Journal of Northwest Sci-Tech University of Agriculture and Forestry* (Natural Sciences): 29(4), 34-38 (in Chinese, with English abstract).

Wang, Y.H., 1986. A quantitative study on the benefits of black locust (*Robinia pseudoacacia*) on water and soil conservation in the Eastern Loess Area in Gansu Province. *Journal of Beijing Forestry University*: 8(1), 35–52 (in Chinese, with English abstract).

Wang, Y.H. *et al*., 2006. A Study on the evapotranspiration of forest and vegetation in dry regions. *Science of Soil and Water Conservation*: 4(4), 19–25 (in Chinese, with English abstract).

Wang, Y.H. *et al.,* 2011. Annual runoff and evapotranspiration of forestlands and non-forestlands in selected basins of the Loess Plateau of China. *Ecohydrology* 4:227–287.

Yang, W.X., 1996. The preliminary discussion on soil desiccation of artificial vegetation in the northern regions of China. *Scientia Silvae Sinicae*: 32(1), 78–85 (in Chinese, with English abstract).

Yu, X.X., Chen, L.H., 1996. A study on water balance of protective forest ecosystem in loess area. *Acta Ecologica Sinica* 16(3): 238–245 (in Chinese, with English abstract).

Zhang, P.C.*et al*., 2000. China's forest policy for the 21st century. *Science*: 288, 2135–2136.

Zhou, Z.S., Wang, H.S., Li, L., Fu, Z. (1998). Study on the shrubbery growth and productivity. *Research of Soil and Water Conservation* 5(1):103–108. (in Chinese, with English abstract).

Zomer, R.J. *et al*., 2006. "Carbon, Land and Water: A Global Analysis of the Hydrologic Dimensions of Climate Change Mitigation through Afforestation/ Reforestation" (Res. Rep. IWMI-101, International Water Management Institue.