African Journal of Biotechnology Vol. 8 (20), pp. 5415-5421, 19 October, 2009
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB09.607
ISSN 1684–5315 © 2009 Academic Journals

Full Length Research Paper

Growth process and diameter structure of *Pinus tabulaeformis* forest for soil and water conservation in the hilly loess region of China

J. B. Xia[1], G. C. Zhang[3]*, S. Y. Zhang[5] and H. B. Shao[2,4,6]*

[1]Shandong Provincial Key Laboratory of Eco-Environmental Science for Yellow River Delta, Binzhou University, Binzhou 256603, China.
[2]State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation, Chinese Academy of Sciences, Yangling 712100, China.
[3]Key Laboratory of Agricultural Ecology and Environment, Forestry College, Shandong Agricultural University, Taian 271018, China.
[4]Yantai Institute of Costal Zone Research, Chinese Academy of Sciences, Yantai 264003, China.
[5]Resources and Environmental Sciences College, Northeast Agricultural University, Harbin 150030, China.
[6]Institute of Life Sciences, Qingdao University of Science and Technology, Qingdao 266042, China.

Accepted 7 July, 2009

Using stem analysis method, the biomass, growing process and diameter structure of 21-year shady and sunny slope *Pinus tabulaeformis* forest were investigated in hilly loess-gully region. Results showed that there were distinct difference in the indexes, tree height, diameter at breast height (DBH) and timber volume between shady and sunny slope forest. The biomass, growth status and its diameter structure of shady slope forest were greater than those in sunny slope forest. The fast-growing period of tree was from 9 to 13 years. After 13 years, the annual increment of shady slope forest was greater than that of the sunny slope forest (the annual increment of shady slope forest reached 0.26 m•a^{-1}, while it was about 0.1 m•a^{-1} in sunny slope forest in the 21st year).The DBH growth increment of 2 forests were reduced greatly after 13 years, but the declining degree of shady slope forest was less than the sunny slope forest. The current annual increment of shady slope forest was greater than the sunny slope forest after 17 years. There was little difference in the increment of 2 timber production before 13 years. But the increment of shady forest was greater than the sunny forest after 13 years (in the 21st year, the annual increment was 0.0023 m^3 in shady slope, but in sunny slope it was only 0.0015 m^3). The summit of DBH distribution curve was both partial to left, while the skewness (SK was 0.75) of shady forest was lower than that of the sunny forest (SK was 1.03) and kurtosis (K was 1.05) of shady forest was higher than that of sunny forest (K was 0.94). The results indicated the density structure of sunny slope forest was greater than shady slope forest.

Key words: Hilly loess region, *Pinus tabulaeformis* forest, forest increment, diameter structure.

INTRODUCTION

Forest increment and growing process is the reflection of tree growth, which is the most important component of forest ecosystem. As the basis for the tree selection of revegetation and achieving a rational vegetation structure, 2 indexes are used not only to judge the site adaptability of tree growth, but also have a great important value in judging of forest growth and ecological effect. Higher biomass and increment forest has superior community structure and function (Onda and Yamamoto, 1998; Wei and Wu, 2006; Pan et al., 2003; Xiao et al., 2004). In the Loess plateau the natural forests were destroyed severely by human activities and climate,

*Corresponding authors. E-mail: shaohongbochu@126.com (Hong-Bo) and zhgc@sdau.edu.cn (Guang-Can); Tel.: 86-532-84023984.

which resulted in the very fragile ecological environment. To improve the forest ecological function and ecosystem productivity, the measure of converting arable land to forestry (pasture) was carried out in this region. However, the recessionary growth, depressed ecological effects and degenerated landscape features appeared in artificial vegetation due to irrational planting technology and extensive management (Cheng and Wan, 2002; Li and Shao, 2004). The high density of seedlings in the initial planting surpassed the forestland carrying capacity, especially water capacity (Wang et al., 2002). Therefore, a reasonable adjustment and controll-ing density structure have turned into pivotal technology to ensure forests growth stabilization and ecological function. *Pinus tabulaeformis*, the main species of tree for forestation, had important ecological benefits to water and soil conservation in the Loess plateau (Chen et al., 2002; Cheng and Wan, 2002), but many forests of *P. tabulaeformis* apparently had recessionary growth and had significant effect on soil degradation, due to high density of seedlings and extensive management. Presently, studies on *P. tabulaeformis* mostly focused on water physiological character (Feng et al., 2005; Zhang et al., 2008; Li et al., 2008), forest for protection against erosion (Zhao et al., 2003; Hou et al., 2008) and eco-hydrological effects (Pan and Shangguan, 2005; Sang et al., 2008). The relationship between site condition, forest structure and forest growth is still not well understood. Therefore, to study the site adaptability and suitable density of *P. tabulaeformis* for soil and water conservation is of great ecological significance in Hilly Loess-Gully region.

MATERIALS AND METHODS

Study area

The study area was located at the Gezhener channel drainage area (110°58′41″ - 111°01′55″E and 37°09′51″ - 37°11′58″N), Zhongyang city, Shanxi province. The annual mean precipitation is 518.6 mm and mainly occurs from July to September. The dryness coefficient is 1.44 and relative humidity is 50 - 60%. The annual mean air temperature is 6 - 10℃ and the accumulative temperature above 10℃ is up to 3000℃. The frost-free period is 120 - 200 days. The main soil belongs to grey-cinnamon soil and it is very poor. At the same time, soil erosion is very serious. Vegetation species take on a distinct changing trend and have transitional characteristics between forest and grassland.

The site of forest in the present study is located at the soil and water conservation forest area in Hilly Loess-Gully region. Forest vegetation was 21-year-old artificial *P. tabulaeformis*. The elevation is 1250 – 1300 m and the slope is about 18°. The forest canopy density of sunny slope (the slope is about 20° trending south to east) forests, mean tree diameter at breast height, mean tree height, mean crown diameter and height below branch are 0.7, 8.5 cm and 5.1, 2.9 and 1.1 m, respectively. In the shady slope (the slope is about 15° trending north to west) forests, the forest canopy density, mean tree diameter at breast height, mean tree height, mean crown diameter and mean height below branch are 0.8, 9.5 cm, 6.1, 3.6, and 1.3 m, respectively. The mean coverage of floor vegetation is about 0.4. The predominant vegetation principally includes *Lespedeza dahuricus*, *Artemisia sacrorum*, *Heteropaspus altacicus* and *Poa sphondylodes*.

Tree growth process

Plot and trunk analysis of the sample trees were used to evaluate the tree growing process. 3 sample plots of 600 m^2, located at the middle of the slope, were respectively selected in representative forest area with shady and sunny slope forests. Every tree in the sample plots was investigated and main indices included tree height (H), tree diameter at breast height (D), crown diameter and height below branch. According to the average value of these indices, the sample trees were selected. After sample trees cutting down, the fresh and dry weight of trunk, brunch, leaves and fruit were measured. Total growth increment, mean annual increment, current annual increment of tree height (H), tree diameter at breast height (D), single timber volume (V) and stumpage accumulation per hectare were measured using trunk analysis. Each index value was the mean value of three trees in this study. The fitting equation of the growing processes of tree height, tree diameter at breast height, single timber volume and stumpage accumulation were made using quadratic equations. Then, the rules of growth trend of the 2 slope forests were analyzed.

Tree diameter distribution

Based on every tree surveyed in the sample plots, taking the tree diameter at breast (D) as a stochastic variable (ξ), the coefficients of skewness and kurtosis of the tree diameter distribution and the histogram of the number of trees (Figure 2) were deduced using SPSS (Sun, 2000). The diameter distribution characteristics of trees and the reasonable extent of density structure of the 2 forests in shady and sunny slope were analyzed (Sun, 1990).

RESULTS AND DISCUSSION

Biomass in different artificial *P. tabulaformis* stands

The total biomass and every tree body biomass of shady 3 slope forest were higher than that of sunny slope forest, such as individual tree biomass and unit stand biomass (Table 1). The unit stand biomass of shady forest was 1.times as high as that of sunny slope forest. The results in the present study were different from the trees with the similar age and density of *P. tabulaeformis* in other regions of Loess plateau (Zhang and ShangGuan, 2005). The results indicated that the site environment had a great important effect on the growth of *P. tabulaeformis* forest. The value of the biomass can reflect the using natural resource ability of tree, which not only implied the forest productivity, but also reflected the ecological benefit to some extent. The higher biomass of forest can ensure better forest structure and ecological functions.

Annual growth dynamic of artificial *P. tabulaeformis* forest

Growing process of tree height

The growing process of tree height and growth yield of the 2 slope forests are shown in Figure 1. The curve of

Table 1. Biomass on ground in different artifical *P. tabulaformis* stands.

Tree body	Individual tree (kg)				Unit stand (t·hm^{-2})			
	Fresh weight		Dry weight		Fresh weight		Dry weight	
	A	B	A	B	A	B	A	B
Trunk	23.1	20.1	10.8	7.7	51.328	44.662	23.998	17.109
Brunch	11.4	9.5	5.3	4.4	25.331	21.109	11.777	9.777
Leaves	15.2	12.4	3.3	2.7	33.774	27.553	7.333	5.999
Fruit	1.9	1.5	1.4	1.1	4.222	3.333	3.111	2.444
Total	51.6	43.5	20.8	15.9	114.655	96.657	46.219	35.329

A: Stand in shady slope; B: Stand in sunny slope.

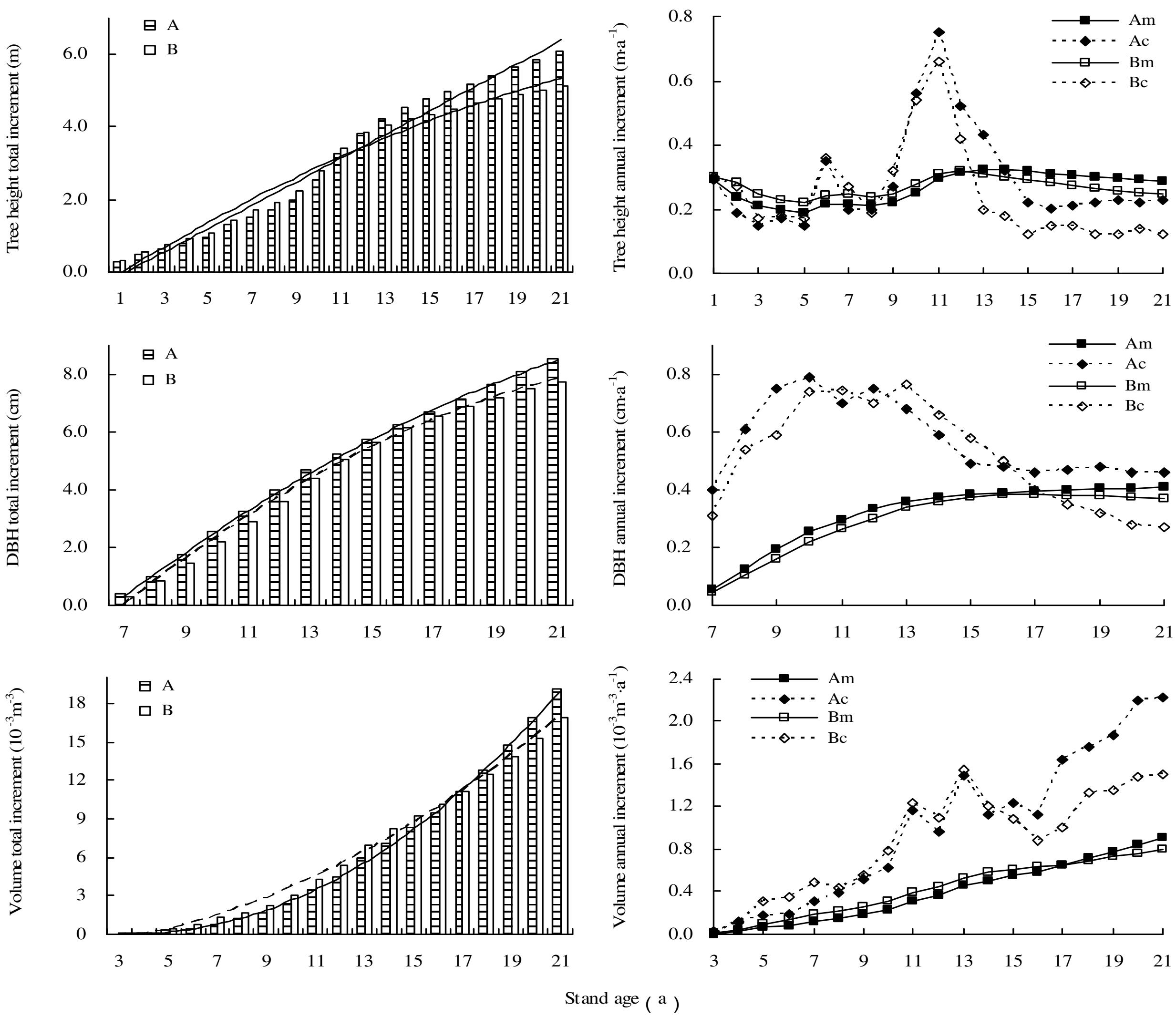

Figure 1. Total increment (cm) and annual increment (cm) of tree height, diameter at breast height (DBH) and Individual tree volume in different *P. tabulaformis* stands. A: Stand in shady slope; B: stand in sunny slope. m: mean; c: current.

the growing process of tree height was conical (Table 2). The growing rate of the tree height in the shady forest increased every year (the increase rate of annual growth yield was 0.002 m/year), while that in the sunny forest decreased every year (the decrease rate of annual growth yield was 0.011 m/year). The difference of total tree height increments of the 2 stands were not obvious before 13-year-old stand age, but the total tree height increments of the shady forest was obviously higher than that of the sunny forest after 13-year-old stand age. The difference between them increased with the time length.

According to the annual increment, the fast-growing period of tree height was in 9 - 13 years, but the annual increment of shady slope forest was larger than that of the sunny slope forest. The current annual tree height increment of two forests was less than that of the mean increment after 13 years. The tree height growing rate of 2 forests was both declining, but the tree height growing rate of sunny slope forest declined faster than that of the shady slope forest. It suggested the tree height growth status in shady slope forests was superior to that in the sunny slope forests. This situation was especially obvious after 13 yeas.

Growing process of forest diameter at breast height

The growing process and growth yield of forest diameter at breast height of the 2 slope stands are shown in Figures 1 and 2. There were obvious differences between the 2 stands. From the total diameter at breast height increment (Figure 1), it can be concluded that the growing process of the diameter at breast height fitted the quadratic curve equation. With the increase of stand age, the growth rate of the annual increment of diameter at breast height decreased and the rate of decrease in shady slope forests (0.032 cm•a^{-1}) was less than that in sunny slope forests (0.042 cm•a^{-1}). The total increment of diameter at breast height in shady slope forests was greater than that in sunny slope forests. The difference between them enhanced with the increase of stand age. The total increment of tree diameter of the former was 8.6 cm, while that for the latter was 7.8 cm. There were no obvious differences between the annual increments of the tree diameter in 2 slope stands. The maximum of the annual current increment in 2 slope forests was about 0.8 cm and the fast-growing period of tree diameter appeared in 8 - 13 years. There were obvious differences in the growing process of forest diameter in 2 slope forests after 13 years. The annual increment of tree diameter decreased quickly in sunny slope forests and the current annual increment of tree diameter was firstly less than the mean increment in the 17^{th} year. It was only about 0.27 cm in the 21^{th} year. However, the annual increment of tree diameter decreased slowly in shady slope forests, the current annual increment of tree diameter was larger than the mean increment every year. It was about 0.46 in the 21th year and was 1.7 times as high as that in the sunny slope forests. This indicated that the growing process of forest diameter at breast jn shady slope forest was superior to that in sunny slope forests.

Timber volume growing process of single tree

There were distinct differences in the increment of timber volume and growing process of single trees in 2 slopes stands (Figure 1). From the increment of total timber volume (Figure 1), we can find that the growing process of timber volume fitted the quadratic curve equation in shady and sunny slopes stands (Table 2). The single tree timber volume growth rate and annual increment of the 2 stands increased year after year. However, the increase rate of shady slope stand (0.135 × 10^{-3} m^3•a-1) was obviously higher than that of sunny slope stand (0.07 × 10^{-3} m^3•a^{-1}). In the 21st year, the tree timber volume of the shady slope was significantly greater than that of the sunny slope. There was little difference between the annual increments of tree volume in the 2 slopes before 13 years. But the annual increment of tree volume in the shady slope stand was greater than that in sunny slope stand after 13 years. In the 21st year, the current annual

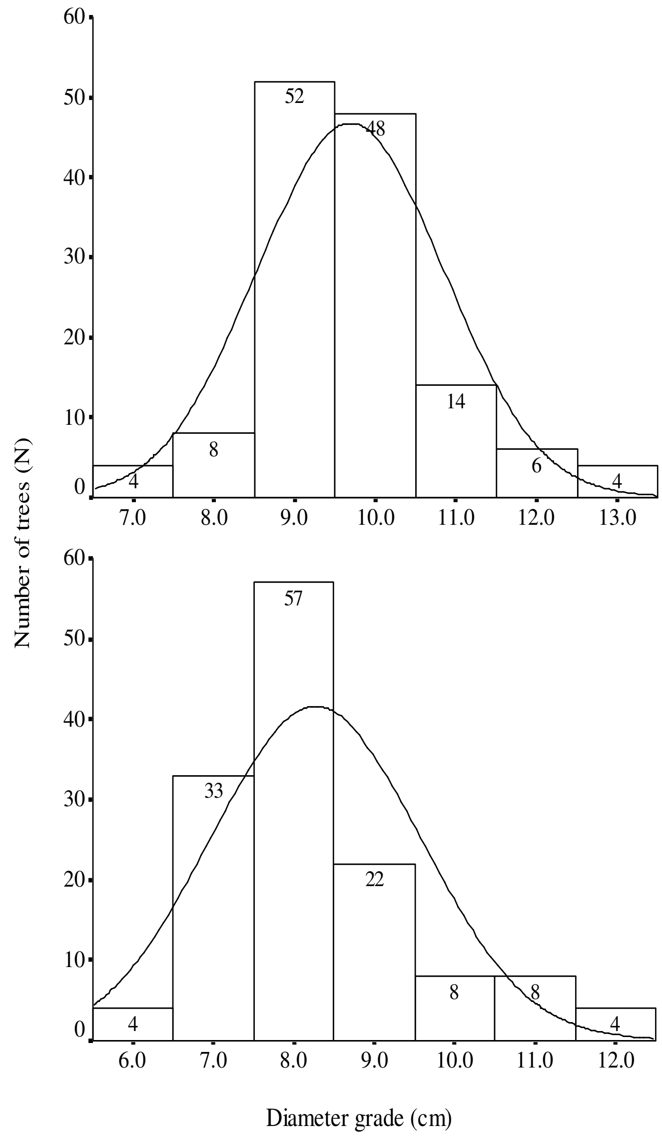

Figure 2. Diameter at height (DBH) distribution of *P. tabulaeformis* stand in shady slope (A) and in sunny slope (B).

Table 2. Regression equations of growth course in different *P. tabulaformis* stands.

Stand type	Growth index	Total increments	Annual increment	Correlation coefficient
A	*H*	$H_A = 0.001a^2 + 0.307a - 0.431$	$dH_A/da = 0.002a + 0.307$	0.9739
	D	$D_A = -0.016a^2 + 0.836a - 0.518$	$dD_A/da = -0.032a + 0.836$	0.9991
	V	$V_A = 0.067a^2 - 0.297a + 0.365$	$dV_A/da = 0.135a - 0.297$	0.9996
B	*H*	$H_B = -0.005a^2 + 0.387a - 0.429$	$dH_B/da = -0.011a + 0.387$	0.9793
	D	$D_B = -0.021a^2 + 0.900a - 0.908$	$dD_B/da = -0.042a + 0.900$	0.9959
	V	$V_B = 0.035a^2 + 0.271a - 0.727$	$dV_B/da = 0.070a + 0.271$	0.9950

A: Stand in shady slope; B: Stand in sunny slope; H: Tree height (m); D: diameter at breast height (cm); V: individual tree volume ($10^{-3}\cdot m^3\cdot plant^{-1}$).

increment of tree volume in the former was about 2.3 × 10^{-3} $m^3.a^{-1}$ and was 1.5 times as high as that in the latter. This indicated that the annual increment of single tree volume in shady slope was greater than that in shady slope.

Distribution characteristics of trees diameter

There were obvious differences in the distribution characteristics curve of tree diameter between 2 slopes (Figure 2). Compared with the normal distribution, the distribution curve peak of 2 stand slope tree diameter was both deviated to the left, which predicated that the number of the little tree diameter (less than the mean tree diameter at breast height) increased and the forest density was relatively high (Sun, 1990). Using the tree diameter at breast height as an independent variable, 2 diameter distribution characteristic parameters, that is, skewness (SK) and kurtosis (K), were calculated according to statistical analysis. SK and K in shady slope stands were 0.57 and 1.15, respectively, while those in sunny slope stands were 1.03 and 0.94, respectively (Figure 2). The value of SK approaching to zero can be used as the indicator of reasonable distribution and density structure of the tree diameter (Sun, 1990). The great value of K also demonstrated the trim growing of forest (Koga and Zhang, 2004). Therefore, the tree diameter structure and density structure in shady slope forests were superior to those in sunny slope forests.

Conclusions

The growing characteristics of tree height

The results showed that the growth of tree height of the 2 slope forests was both surpressed to a certain extent. The surpressed extent of the sunny slope forests was obviously higher than that of the shady slope forests. This was not only due to the site conditions (especially the water factor), but also due to the unreasonable density structure.

Previous results (Cao et al.2005; Yang et al. 2004) showed that in normal site conditions, the growth of tree height of *P. tabulaeformis* began to increase fast at the age of 4 - 5-year-old and the fast growth period was keeping until 30 years with the average annual increment of 0.4 - 0.7 $m.a^{-1}$. Compared with our results, the initial tree height increment in 2 slope forests was near to that in normal site conditions, while, after 13 years later, the annual increment of tree height decreased obviously (less than that of the mean increment). The results indicated that the growth of tree height was surpressed to a certain degree and the limited extent of sunny slope forests was higher than that of shady slope forests. The mean tree height (or dominant tree height) was influenced by many factors and the condition of forest site was the dominating factor (Sun, 1990). The better the site conditions became, the greater the tree height grew. The growth of tree height was not influenced by forest density in good site condition. Therefore, the dominant factor of restricting growth of *P. tabulaeformis* tree height was site conditions. The less increment of tree height in sunny slope forests than that in shady slope forests was mainly owing to the greater soil water content of the former than that of the latter.

Growing process and distribution of P. tabulaeformis forest diameter at breast height

The growth process of forest diameter at breast height was not only influenced by site environment, but also affected by forest density structure. The growth of tree diameter can reflect the reasonable extent of forest density in the same site condition (Sun, 1990). In general site situation, the tree diameter growth climax of *P.*

tabulaeformis was after the age of 15 - 20 and the fast growth period was keeping for 50 years with the annual increment of 1.0 cm or so (Cao et al., 2005; Yang et al., 2004). This was in line with the result of the shady slope forests in the present study. After 17 years, the annual increment of the sunny slope forests dropped sharply, which indicated the tree diameter growth was surpressed to a certain degree. The surpression was not only due to the site condition (absence of soil water or soil nutrient), but also due to the higher density forests.

Tree diameter distribution can reflect forest growth situation, forest competitive relationship and forest density structure (Sun, 1990). When forest density was appropriate and forests grew normally, tree diameter distribution approximated a normal distribution. The skew coefficient (*SK*) was between -0.5 - 0.5 and the kurtosis (K) was more than -0.5 (Koga and Zhang, 2004). When forest density was on the high side, tree diameter distribution kurtosis deviated to the left (SK > 0). The larger the value of SK was, the higher the forest density was. The results showed that the distribution curve peak of the 2 stand slope tree diameter was all deviated to the left (Figure 2), while there were obvious differences in the characteristic parameters of the two slope forests. The K of shady slope forests (1.15) was obviously larger than that of sunny slope forests (0.94), which indicated high tree evenness and little differentiation were in the shady slope forests and the superior tree diameter structure was in the sunny slope forests. SK (0.57) of the shady slope forests was near SK of normal forests (0.5), while the SK of the sunny slope forests (1.03) was obviously higher than 0.5. Hence, forest density was higher than the reasonable level. In artificial forests, if forest density was on the high side, the growth of individual forest and community would be limited, which in turn resulted in decrease of community production. This was confirmed by the high single timber volume increment and biomass in the sunny slope forests in the present study.

Rational forest density of P. tabulaeformis

Forest density is one of the key rules for artificial forest cultivation and management. Rational forest density is the basis of a reasonable forest structure and has great effect on forest production. It changes with tree species, forest age and field environment. Results show that there were some differences in the rational forest density of *P. tabulaeformis* in the shady and sunny slope site conditions in Hilly Loess-Gully region (the forest density of the latter was less than that of the former). In the same density forest, there were obvious differences in the tree height, tree diameter at breast height and timber volume growing process between 2 site situations. In sunny slope site, the density structure of 2222 tree hm^{-2} of 21-year-old artificial *P. tabulaeformis* forest was obviously high. Therefore, the forest had better be thinned in time at the age of 13 - 17. Although the forest density was little high in the shady slope forest, the forest growth was also limited to a certain extent and the forest had better be thinned in time at the age of 17 - 20.

The differences of the procession of forest growth and rational forest density were associated with the different carrying capacity of soil water in 2 slope forests. However, based on soil water environmental carrying capacity, little is known about the reasonable density of *P. tabulaeformis* forest in different slopes and further study should be conducted in this field in hilly loess-gully region.

ACKNOWLEDGEMENTS

The work was financially supposed by National Key Science and Technology item in “11th Five Year” period (No. 2006BAD03A1205, 2006BAD26B0601), National Natural Science Foundation of China (No. 30872003) One hundred-Talent Plan of Chinese Academy of Sciences and the CAS/SAFEA International Partnership Program for Creative Research Teams.

REFERENCES

Cao Y, Yang J, Song BY (2005). Effects of artificial tending on *Pinus tabulaeformis* forest growth and. its structural characteristics. Chin. J. Appl. Ecol. 3: 397-402

Chen YM, Liang YM, Cheng JM (2002). The zonal character of vegetation construction on Loess plateau. Acta. Phytoecol. Sinica 3: 339-345

Cheng JM, Wan HE (2002). Vegetation construction and soil and water conservation in the Loess Plateau of China .Beijing: Chinese Forestry Press

Feng LG, Shi YH, Y ZF, Zee SY, Han YZ (2005). Paternal cytoplasmic transmission in Chinese pine (*Pinus tabulaeformis*). Protoplasma, 225: 5-14

Hou L, Lei RD, Zhang SX (2008). Assessment of the effect of a fully closed hillside afforestation mode on the natural *Pinus tabulaeformis* forest. Frontiers of Forestry in China. 2: 183-188

Koga S, Zhang S Y (2004). Inter-tree and intra-tree variations in ring width and wood density components in balsam fir (*Abies balsamea*). Wood Sci. Technol. 38: 149-162

Li C, Chai BF, Wang MB (2008). Population genetic structure of *Pinus tabulaeformis* in Shanxi Plateau,China. Rus. J. Ecol. 1: 34-40.

Li YY, Shao MA (2004). The change of plant diversity during natural recovery process of vegetation in Ziwuling area. Acta. Ecol. Sinica, 2: 253-260.

Onda Y, Yamamoto T (1998). The mechanism for the infiltration lowering on soils with litter coverage. J. Jpn. For. Soc. 4: 302-310.

Pan CZ, Shangguan ZP (2005). Generation mechanism of woodland runoff and sediment on Loess Plateau under hypo-rainfall - A case study of artificial *P. tabulaeformis* and secondary natural *P. dadidiana* stands. Chin. J. Appl. Ecol. 9: 1597-1602.

Pan H, Zhu W, Bao XH (2003). Study on growth characteristics of *pinus taeda* plantation grown in fujian province. Sci. Silvae Sinicae 1: 47–51

Sang WG, Chen S, Li GQ (2008). Dynamics of leaf area index and canopy openness of three forest types in a warm temperate zone. Frontiers of Forestry in China 4: 416-421

Sun JM (2000). Statistics and Analysis Tutorial of SPSS for Windows. Beijing: Electronics Industry Press, pp. 91-98.

Sun SX (1990). Silviculture. Beijing: China Forestry Press, pp. 248–258

Wang KQ, Wang BT, Wang BR (2002). Study on the growth of forests with different density in the system of afforestation by water-harvesting. Sci. Silvae Sinicae 2: 54-60.

Wei J, Wu G (2006). Hydro-ecological effects of artificial *Pinus tabulaeformis carr*. and *Hippophae rhamnoides* woods in the low mountainous upland of Western Liaoning Province, China. Acta Ecol. Sinica 7: 2087–2092.

Xiao DM, Wang M, Ji LZ (2004). Influence of water stress on growth and biomass allocation of dominant tree species in mixed forest of broad-leaved and *Korean pine* at Changbai Mountain. Chinese J. Ecol. 5: 93–97

Yang JW, Liang ZS, Hang RL (2004). Growth and water consumption characteristics of *Chinese pine* under soil drought stress. J. Northwest Sci-Tech University of Agriculture and Forestry 4: 89–92

Zhang WQ, Wang YQ, He KN, Zhou Y (2008). Factors affecting transpiration of *Pinus tabulaeformis* in a semi-arid region of the Loess Plateau, Frontiers of Forestry in China 2: 194–199

Zhang XB, ShangGuan ZP (2005). The bio-cycle patterns of nutrient elements and stand biomass in forest communities in Hilly Loess Region. Acta Ecol. Sinica 3: 527–537

Zhao HY, Wu QX, Liu GB (2003). Studies on soil and water conservation functions of litter in *Chinese pine* stand on Loess Plateau. Scientia Silvae Sinicae 1: 16–172