THE INFLUENCE OF SITE FACTORS ON THE GROWTH OF PINUS TABULAEFORMIS

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INTRODUCTION

Pinus tabulaeformis is one of the most important native coniferus trees in the mountainous areas of North China. It has been widely used in afforestation since the establishment of the People's Republic of China. Western Hills, where our research work was carried out, are located to the west of Beijing city and characteristic, in terms of their natural conditions, of the typical low-elevation mountainous areas of North China. Climate of this region is mild and relatively dry with mean annual temperature of atmosphere 11.8^{o}C and annual precipitation of 630 mm. Relatively shallow and rocky soils, mainly eluvial brown soil according to their genesis, are developed on the mountain slopes with base rock composed of sandstone and shale. Layer of deposited loess as parent material can be found only in a limited area mostly at the foot of northern slopes. Western Hills had long been deforested and soil erosion occurred there frequently in the past. A project of afforestation in the whole area of Western Hills was completed in the fifties. More than 20 tree species have been tested, among them Pinus tabulaeformis was planted widely on about 1/3 of the total cultivated area. The growth of this coniferous tree species varies significantly with the various combination of site factors. The influence of those significant site factors on the growth of Pinus tabulaeformis was studied in order to determine the suitable site for pine plantation.

METHODS

Of 119 temporary plots established in even-aged pine plantation in Western Hills 72 are in pure stands and 47 in mixed stands. The area of every plot was so designed that there were more than one hundred pine trees in each plot. The total height of trees, the height increment of the last 5 years, the diameter at breast height (1.3 meters), and the length and width of tree crown were measured for every tree (or for 20% of total number) in the plot. The age of pine stands was

in the range of 22-25 years. The average height of 8-10 dominant trees in each plot was taken as its top height. The top height of pine at the age of 25 for every plot was determined by revising its initial top height in accordance with the height increment in late years.

A soil pit was dug at the center of every plot. Site factors, such as elevation, aspect (exposure) of slope, position on slope, degree of inclination of slope, total soil depth, soil texture, condition of humus horizon, and condition of parent material were taken into consideration for each plot. Observation showed that soils of all plots were similar in texture and belonged to the texture class loam. Therefore, no further study on the influence of this factor has been done. In the process of investigation we encountered the difficulties in

Table 1: Site factors in relation to the growth of pine plantation

Variable	Symbol	Explanation
Elevation	El	Elevation in meters above sea level, 200=1, 201-400=2, 401-600=3, > 601=4
Aspect (exposure) of slope	As	The 8 aspects are divided into 3 groups according to the humidity gradient: S(SW,S,W) = 1 E(SE,E) = 2 N(NW,N,NE)= 3
Degree of inclination of slope	Is	$<10^{o}$=1, 11^{o}-20^{o}=2, 21^{o}-30^{o}=3, $>31^{o}$=4
Position on slope	Ps	upper part of slope = 1, middle part of slope = 2, lower part of slope = 3
Total soil depth	Sd	Total soil depth in centimeters excluding the soil horizon with gravel content more than 70%
Grade of soil fertility	Sf	Expressed in effective soil depth in centimeters: 1 grade=90, 2 grade=65, 3 grade=40, 4 grade=15

*Detail about the classification in grades of soil fertility can be found in the textbook "Silviculture" (in Chinese) published in 1961 by the senior author.

determining the condition of humus horizon quantitatively on spot. We only devided it into two grades: the soil with normally developed humus horizon and the soil with deteriorated humus horizon, that means the humus horizon is thinner than 10 cm and the content of humus in it is less than 2 per cent. In such case the factor of condition of humus horizon can hardly be used independently. In previous research work on site classification we have used the concept of grade of soil fertility which is determined in this mountainous areas mainly according to the total soil depth with the revision according to the condition of humus horizon and parent material. The four-grade system of soil fertility, suggested by us, has been proved to be a successful indicator of productivity of the stand *) So we adapted the four-grade system in this research as a complex factor.

The site factors that were investigated in relation to the growth of pine plantation are listed in Table 1.

All data of measurement collected from the plots were analysed with the application of various statistical methods including multiple regression method. In this paper only the data from pure stands have been analysed. Among all the growth parameters the top-height growth of stand has been chosen for calculation as it is the most sensitive parameter to the variation of site factors.

ANALYSIS AND RESULTS

The simple correlation coefficients between site variables and the top-height of pine plantation are presented as following:

Elevation to Ht	0.1475
Aspect of slope to Ht	0.3740
Degree of inclination to Ht	0.2577
Position on slope to Ht	0.1015
Total soil depth to Ht	0.6789
Grade of soil fertility to Ht	0.8123

The most significant single site factor that effects the growth of pine plantation is the total soil depth, which varies from 12 to 110 cm in all plots with an average of 60.8 cm. So it is because on the eroded slopes with relatively shallow soil depth the importance of the volume of soil in supplying the trees with water and nutrient mineral elements is ecologically evident. The complex factor of soil fertility which is shown by grades 1-4 and determined on the base of soil depth with supplementary information of the conditions of humus horizon and parent material shows more significant effect on the growth of pine plantation (0.8123) than soil depth alone

(0.6789). In our Western Hills experiment not only the growth of Pinus tabulaeformis, but also the growth of Placycaldus orientalis, Robinia pseudoacacia, and others is closely correlated with the grade of soil fertility. For instance, the single regression equation of Sf for the top-height growth of Placycaldus at the age of 25 is as following:

$$Ht = 3.2545 + 0.0316Sf \qquad R = 0.894$$

The same equation for Robinia at the age of 22 is:

$$Ht = 8.611 + 0.03702Sf \qquad R = 0.533$$

The aspect of slope also shows some important effect on the growth of pine plantation. The analysis of variance for the top-heights of pine plantation growing on slopes with different aspects but with similar grade of Sf shows a high degree of significance (variance ratio $F = 45.47$, while $E_{0.01} = 3.32$) for the effect of aspect on the growth of pine. This is mainly due to the difference in moisture content on slopes facing various aspects. In mountainous areas of North China the deficit in soil moisture is one of the serious problems causing the stagnation in growth or even failure of pine plantation. Besides the volume and structure of soil, the aspect of slope is recognized as the important site factor influencing the soil-moisture content. On the warm and dry slopes facing South and Southwest, especially on the shallow and eroded soils, the height growth of Pinus tabulaeformis is slow and its current annual height increment at the age of 25 is scarcely over 15 cm, while that of pine on the slopes facing northern aspects is about 20-30 cm.

Elevation varying from 50 m to 630 m above sea level in the investigated area shows less significant influence on the growth of pine plantation in comparison with the factors mentioned above. It seems at first contradictory to common knowledge. Ecologically speaking, elevation would have more significant influence on the growth of pine plantation. But is has not been observed in our experiment. The explanation is rather simple. Firstly, the difference of elevation in the investigated area is not large. Secondarily, the elevation as a site factor shows different influence on the slopes with different aspects. On the southern slopes with increase of elevation the pine plantation grows better due to the increase in moisture supply. But on the northern slopes with increase of elevation the growth condition of pine plantation remains practically unchanged because of the combined effect of shorter growth period and better soil-moisture supply. This can be illustrated by the data of top-height growth of pine on slopes with different elevation and aspects (see Table 2). From the data in Table 2 we come to the conclusion that elevation also has significant influence on the growth of pine plantation. But owing to the special feature of its different influence for the slopes with different aspects the correlation coefficient on the whole is relatively low.

Table 2 Top-height growth of pine plantation (A = 24) on slopes with different elevation and aspects

Aspects	Grade of Sf	Elevation (m)	No.of plots	Average top height (m)	t value test
Southern	2	below 400	6	5.08	t = 4.80
		above 400	3	6.27	$t_{0.01}$ = 3.50
Northern	1	below 400	3	6.77	t = 1.95
		above 400	3	6.37	$t_{0.05}$ = 2.45

The topographical factors, degree of inclination of slope and position on slope, have not close correlation with the growth of pine plantation. Human disturbance in the past is the main cause. In the undisturbed area the tendency of increase of soil depth and soil fertility is noted with decrease of the degree of inclination of slope and its lowering in position. However, in most part of Western Hills the mountain slopes had been wrongly utilized in the past and the moderate and lower part of slopes was often more effected and subjected to erosion.

The multiple regression of site factors with the top height of Pinus tabulaeformis is shown in Table 3. This table evidently shows that the total soil depth is the most significant site factor and was first introduced into the equation (R= 0.6789). The grade of soil fertility gives a better representation of the soil condition and serve as an efficient substitute (R= 0.8123) for the soil depth. After that the aspect of slope was introduced into equation to improve the correlation between site factors and the top-height growht of pine plantation (R= 0.8607). The introduction of degree of inclination and elevation only slightly improved the equation (R= 0.8764). And the position on slope in this experiment was proved to be insignificant to the growth of pine plantation.

Table 3 Regression coefficients for estimating top-height growth of Pinus tabulaeformis (A = 25)

Variable	Steps along gradual regression				
	1	2	3	4	5
Elevation (El)					0.114
Aspect of slope (As)			0.3295	0.3457	0.3546
Degree of inclination of slope (Is)				-0.1920	-0.2031
Position on slope (Ps)					
Total soil depth (Sd)	0.03489				
Grade of soil fertility (Sf)		0.04204	0.04038	0.03895	0.03827
Intercept a	3.5343	3.1797	2.5537	2.9926	2.8656
R	0.6789	0.8123	0.8607	0.8724	0.8764

CONCLUSION

In the region of Western Hills in Beijing several site factors have significant influence on the top-height growth of Pinus tabulaeformis. In our case the top-height of pine is not used as its site index, because the average age of pine plantation (A= 25) is too young to be taken as standard age.

From the above data the following equation was selected to estimate the top height from site factors for Pinus tabulaeformis in Western Hills:

$$Ht = 2.8656 + 0.1114El + 0.3546As - 0.2031Is + 0.03827Sf$$

multiple correlation coefficient $R = 0.8764$

partial correlation coefficient $R_{Sf-Ht} = 0.8089$

$R_{As-Ht} = 0.5334$

$R_{Is-Ht} = 0.2965$

$R_{El-Ht} = 0.1731$

Obviously, this equation can be applied efficiently in site classification and in choice of species for afforestation. These problems are of great importance in investigated region as well as in all mountainous areas of North China.