Sensitivity of Forest Growth Rate to Temperature and Precipitation Change in Taihang Mountains

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Abstract

An attempt was made to assess the effect of increase in mean annual temperature and precipitation on forest growth rate. By analyzing data from 77 meteorological stations and 721 forest sample plots in different faces of Taihang Mountain, it was approved, through regression, that there was a good relationship between temperature and forest growing stock in the whole Taihang Mountain. And furthermore, the effect of temperature on forest growing stock in different faces represented by Shanxi Province in the northwest slope of the whole Taihang Mountain, which run from southwest to northeast, and Hebei Province in the southeast face was analyzed. The result suggested that, in Shanxi Province, 1°C of temperature increase could result in 3.8 m^3 decrease in forest growing stock. But in Hebei Province, 1°C of temperature increase could result in 6.88 to 8.68 m^3/ha of decrease in forest growing stock for 23 year's old forest averagely. The relationship between precipitation and forest growing stock was not very certain since the unevenly distribution of rainfall in this region.

Key Words Temperature, Precipitation, Forest Growing Stock, Taihang Mountain.

1. Introduction

Temperature is one of the most important components for forest. The variation of Taihang Mountain, which span an area of 6° in north latitude and about 2500 m in elevation, creates a big difference in temperature. According to the meteorological records from 77 meteorological stations in Taihang Mountain, temperature varies from -4.1 °C in Wutai of Shanxi Province to 14.9 °C in Jiaozuo of Henan Province. This could result in a big difference in forest growth rate. But throughout 50's study after the establishment of the People's Republic of China, hardly has any study been done on this aspect. In forest, change in elevation was considered as an important factor for site classification but not temperature directly[2]. The temperature difference created by latitude change was ignored. Actually, according to site classification in 1989, Taihang mountain was treated as four different regions for afforestation such as mountains in Hebei, Mountains in Shanxi, Mountains in North part of Taihang Mountains, which refers to area with elevation more than 1500m, and Mountains in South part, which refers to area in Henan Province. These regions were mainly distinguished by administrative territory and change in elevation. Inside of each type, although temperature changes about 5°C from south to north, and temperature decreases about 3 to 4°C, sites were classified by face of slope, soil thickness, microtopography, and elevation. No temperature factor was considered.
Throughout the world, the relationship between temperature and biomass was widely discussed. A world recognized map[1] describes the generally relationship between temperature and

precipitation and vegetation type change. John Grace(1988)[3] studied the effect of temperature on plant productivity and pointed out that temperature is a very critical factor for the productivity of plants in England where temperature was a limited factor for the growth of plants. It was concluded that when temperature increase 1°C, the productivity could increase by 10%. Yang(1997) demonstrated a 1.5 to 1.9 times increase in biomass after transfer plant cores down to 800 m which result in a temperature difference of 5°C in north in England. The condition in Taihang Mountain is quiet different in climatic factors to the con dition in England. It is well known that the vegetation type in Taihang Mountain is mainly limited by the low precipitation and drought condition. Therefore, it is no doubt the increase in temperature will raise the evapotranspiration and results in a more serious drought condition which will act on the growth rate of trees. As Taihang Mountain already located at the transition zone of sparse forest, shrub, and grassland in terms of the generally relationship between temperature, precipitation and vegetation distribution in that map[1]. Therefore it is interesting to find out how big the effect of temperature increase on forest growth rate will be? This can also reflect the trend of forest under global warming.

2. Variation of Temperature and Rainfall in Taihang Mountain

The relationship between temperature and elevation has been well recognized. Generally, when elevation raise 100 meter, temperature will decrease 0.4-0.7°C. But the relationship between temperature and elevation has been hardly studied. In Taihang Mountain, the relationship between precipitation and elevation has been noticed that when elevation increase precipitation will increase, when elevation reach a certain level, precipitation will start to drop. An attempt was made to testify the correlation between these two climatic factors with latitude and elevation by collecting data from 77 meteorological stations all over the Taihang Mountain from 34°42′ to 39°59′ north latitude. The correlation between latitude and elevation and temperature was expressed by the following equation:

$$T=15.4-0.62\times(L-34.7)-0.52\times(H/100) \quad r^2=0.91 \quad n=74 \qquad (1)$$

Where, T=average annual temperature, L=degree of north latitude, H=elevation in meter.
The correlation of precipitation with latitude and elevation did not show any significant relationship. Therefore, it was hard to predict any precipitation change by means of elevation change.

3. Variation of forest growth rate and in relation to temperature and precipitation change.

In order to develop the relationship between temperature, precipitation and forest growth rate. Data from 721 sample plots from Shanxi Province, Hebei Province and Beijing was analyzed.

3.1 Relationship between temperature, precipitation and forest growing stock in Taihang Mountain.

Firstly, data of forest investigation including 721 sample plots from Shanxi Province, Hebei Province, and Beijing was collected and collated. Base on the location and elevation of sample plots, temperature in different sample plots was calculated according to equation 1 and meteorological data from nearby meteorological station. Since there was not any relationship between elevation and precipitation, precipitation from nearby meteorological stations was recognized as the precipitation of the sample plots. Next, straightforward linear regression between temperature and growing stock was established to estimate the effect of temperature on growing stock. But just as what was concluded by Leith(1972)[5] in trying to regress the relationship of productivity and temperature, accurate field measurements of net primary productivity were notoriously difficult to achieve because sampling problems. The R squared was only 0.23 which suggested exactly no correlation between temperature and growing stock. This was very reasonable since many factors such as face of slopes, location such as valley, slope, soil thickness, precipitation, age of new planted forest, could result in big or small influence on growing stock. In order to decrease the influence of different factors on growing stock of different sample plots, data with different temperature was divided into different groups to achieve an average result to compromise the variation caused by different factors. Since the sample plots in different groups were not evenly distributed, sampling data listed in Table 1 were grouped by every 2°C of temperature change.

Table 1. Forest investigation data grouped by different temperature intervals.

temperature interval °C	growing stock (m^3)	average height of tree(m)	average WHD (cm)	precipi-tation (mm)	age (a)	direction of slope*	soil thickness (cm)	sampling number
0-1.9	80.25	8.63	11.08	436	23.3	5.79	48	61
2-3.9	67.12	7.73	9.44	527	18.8	5.56	49	32
4-5.9	96.2	7.89	12.38	586	23.6	4.59	60	38
6-7.9	48.6	5.97	9.43	618	24.4	4.30	60	133
8-9.9	44.48	6.78	9.08	588	22.1	4.30	51	244
10-11.9	39.67	6.27	8.86	582	24.3	4.63	48	167
12-13.9	34.02	6.59	7.06	534	15.5	2.32	50	18

*In this investigation, direction of slopes was divided by 8. 1 direction means southeast(SE), 2 means south and other direction follow that way, 8 means NE. So the average of 8 directions is 4.5. If the number of average direction is lower than 4.5, there will be more sample plots in south direction otherwise there will be more sample plots in north face.

On basis of table 1, the correlation between temperature, precipitation, direction of slopes and forest growing stock was established. The best correlation lineal was expressed in the following way:

$$V=104.02+P\times0.066-T\times6.62-D\times7.88 \quad r^2=0.72 \qquad (1)$$

Where, V=growing stock, P=precipitation, T=temperature, D=direction of slopes.

The above equation suggested that for every 1°C of change in mean annual temperature, forest growing stock would decrease 6.62 m^3, if precipitation raise 100mm, forest growing stock would increase 6.6 m^3. This model illustrated the relationship between temperature, precipitation and forest growing stock in the special region with an annual precipitation varying from 500 to 600 and mean air temperature spanning from 0 to 13°C. However, the coefficient of precipitation may not be the truth, as 500mm of precipitation is right the transition area of sparse forest to shrub and grassland, even little change in precipitation may caused a big difference in vegetation type.

Generally speaking, there is a significant difference between the condition of Shanxi, which represents the northwest slope of the whole Taihang mountain, which run from southwest to northeast, and the condition of Hebei, Henan and Beijing, which located in the southeast slope of the whole Taihang Mountain. In Shanxi, slope is generally in northwest direction and gentle, and soil thickness is generally evenly distributed. In Hebei, slope is generally in southwest direction and steep, and the soil thickness is very variable. Therefore, it is necessary to look at the relationship between two climatic factors, temperature and precipitation, and forest growing stock in different condition.

3.2 The relationship between temperature, precipitation and forest growing stock in southeast slope of Taihang Mountain.

The data of 273 sample plots from Hebei Province and Beijing, which are very near each other and represent the southeast slope of Taihang Mountain, was collected and collated by means of the same analysis method as in 3.1. Compared to the whole Taihang mountain, temperature in the east slope change only from 6°C to 13°C. By dividing temperate data into different groups, table 2 is obtained.

Table 2. Forest investigation data grouped by different temperature intervals in east slope of Taihang Mountain.

temperature interval °C	growing stock (m^3)	precipitation (mm)	age (a)	direction of slope	soil thickness (cm)	sampling number
6-6.9	67.98	557	22.4	4.2	73.7	23
7-7.9	50.28	542	21.8	3.9	59.5	34
8-8.9	45.41	553	23.7	4.4	49.3	26
9-9.9	44.1	572	24.8	4.1	45.1	75
10-10.9	36.52	570	22.1	4.3	47.6	58
11-11.9	32.85	595	24.3	4.2	41.4	37
12-12.9	18.39	568	23.5	4.6	38.3	19

The best correlation between temperature, precipitation and forest growing stock was expressed as the following equation:

$$V=107.5-T\times6.88 \qquad r^2=0.94 \qquad (2)$$

$$V=-74.5+P\times0.30-T\times8.68+St\times0.26 \qquad r^2=0.99 \qquad (3)$$

From this two equations, it is obvious that the correlation between temperature, precipitation and growing stock is strongly related. When temperature increase 1°C, forest growing stock decrease 6.88 to 8.68 m^3/ha, for 23 year's forest averagely, which is roughly about 10%. And for every 100mm increase in precipitation, growing stock increase 32 m^3/ha for averagely 23 year's forest, which is about 41%. These equation suggest 500 to 600mm of precipitation is very critical for forest when temperature varying from 6 to 13°C. But equation 3 may not correctly reflect the relationship between soil thickness and forest growing stock. The effect of soil thickness could be higher as in Taihang Mountain soil thickness always limited the growth of tree especially when soil thickness is less than 30cm. It is suspected that the relationship between soil thickness and forest growing stock may be offset by the strong correlation between temperature and growing stock.

3.2 The relationship between temperature, precipitation and forest growing stock in northwest slope of the whole Taihang Mountain.

Compared to the result from Hebei, the result from Shanxi province was not so ideal. The averaged data of different temperature interval was listed in table 3.

Table 3. Forest investigation data grouped by different temperature intervals in northwest slope of Taihang Mountain in Shanxi Province.

temperature interval °C	growing stock (m^3)	precipi-tation (mm)	age (a)	direction of slope	soil thicknes s (cm)	sampling number
2-2.99	67.18	534.9	18.0	5.8	53	19
3-3.99	52.21	502.3	20.1	5.6	44	12
5-5.99	95.52	551.6	22.5	3.4	55	24
6-6.99	50.96	645.0	23.9	4.4	47	49
7-7.99	46.06	630.0	23.0	4.8	49	54
8-8.99	40.23	616.3	20.4	4.6	51	87
9-9.99	50.00	589.2	22.4	4.7	53	26
10-10.99	50.91	539.5	19.9	5.0	54	28
11-11.99	58.82	566.4	19.6	5.6	53	8

From above table, two regression models were obtained:

$$V=-149.5-T\times 3.8+St\times 3.6+A\times 2.2 \qquad r^2=0.64 \qquad (4)$$

and

$$V=-170.6-P\times 0.19-T\times 2.9+St\times 5.21+A\times 5.20 \qquad r^2=0.79 \qquad (5)$$

Where, A=forest age.

From these two equations, it is clear that there is a negative relationship between temperature and forest growing stock. But the relationship between precipitation and forest growing stock is strongly against the natural law for the distribution of vegetation in this region. This could be caused by the unevenly distributed precipitation as precipitation always varies from place to place even in a small area. Also the negative relationship between precipitation and forest growing stock in equation 5 offset the negative effect of temperature on forest growing stock. In fact, the impact of temperature on forest growing stock should be higher. So, equation 4 can be a better equation to express the relationship between temperature and forest growing stocks in northwest slope of the whole Taihang Mountain.

4. Discussion

Using difference in temperature caused by elevation and latitude change to study the effect of global warming was suggested IPCC(1992) and many other scientist. Using this methodology, Yang(1997) studied the effect of global warming on the biomass in upland grassland and suggested that a 1.5 to 1.9 times of increase in biomass could happen if temperature increase $5^{0}C$ in the growing season in England. The prediction of the variation of precipitation is always a difficult problem such as the prediction of precipitation by GCMs for a certain region. Although, from geological point of view, Taihang Mountains is a relative small region, precipitation also changes a lot from area to area. So there is not any relationship between elevation and latitude. The prediction of the influence of precipitation on forest growing rate is also difficulty as different equation has different result.

Although different models have different coefficience for temperature, the trend is very obvious.

An increase in temperature increase will no doubt result in an decrease in forest growing stock though the decrease rate may change from 3.8 in Shanxi Province to 8.68 in Hebei Province. The author believe this is reasonable, as in Shanxi Province, soil condition is generally better(not very stony as in Hebei Province) and, from large geographical point of view, slopes in Shanxi province is in northwest direction and is in southeast direction in Hebei Province. Temperature may produce a lower influence on forest growing stock in north face of the mountain and in better soil condition where soil can hold more soil in reason season for the dry season[6].

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