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Effect of acidic deposition on productivity of forest ecosystem and estimation of its economic losses in southern suburbs of Chongqing, China

Wu Gang

Department of Systems Ecology, Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China

Abstract—In accordance with principles and methods of ecology, the effects of acidic deposition on productivity and volume increment of masson pine and *Cinnamomum campora* forest which are widely distributed in southern suburbs of Chongqing, China were studied. Based on the field data and measurements, a multivariable stepwise regression model was established to analyze the effects of multiple environmental factors on the productivity of the forest ecosystems. This model was used to assess the volume and economic losses of these two forest ecosystems caused by acidic deposition. The result showed that, among the environmental factors, pH value of precipitation, soil depth, soil organic contents and slope are the dominant ones influencing the growth of masson pine forest. It was also shown that the acidic deposition has no clear relation to the growth of *C. Campora* forest, so development of such broad-leaved forest is suitable in the area.

Keywords: acidic deposition; productivity; volume increment; economic loss.

1 Introduction

Following some developed industrial areas in Europe, acidic deposition occurred in success in the southwest and south China (Ulrich, 1989; Smith, 1989; Feng, 1986; Shan, 1988), which caused the decline of forest trees growth and annual productivity of forest ecosystem and even the decay of forests (Shu, 1993). By the investigation and study of forest declining, we know that acidic deposition is the main factor of the decline. Occurring frequency of acidic deposition is 100% in Chongqing each year. In 1992, pH value of precipitation was 3.01—5.57, and average pH value was 3.96. It caused death of masson pine forest and decline of the forest ecosystem. Masson pine is the main forest tree species in this area. The area of masson pine forest is 66% of the total forest area, and the wood volume is 41.1% of the total. *C. Campora* is the main tree species of evergreen broad-leaved forest in this area. The area of the forest community where *C. campora* is the dominant species as 23% of the total forest area, and the wood volume is 29.4% of the total. So masson pine forest and *C. campora* forest were selected as object of study to probe the effects of acidic deposition on forest ecosystem in this area, assess the economic loss caused by the impacts, and offer ecological decision foundation and substance model on controlling acidic deposition and restoring the declined forest ecosystem in this area.

Chongqing is the largest industrial city in the southwest of China. The main energy resource is coal. Its combustion has accounted for more than 75% of regional energy needs in recent year. The

local low grade coal contain 3%—5% sulphur, 25% ash and approximately 30% volatile combustibles. High level consumption of this type of coal has caused rapid changes in the atmospheric environment of Chongqing, and has become a major reason for the increase in acidity of precipitation and acid rain frequency in recent years. The climate of the area belongs to the subtropical type. Annual mean precipitation is 1143 mm, the soil are acid purple soil.

2 Study method

2.1 Selecting the experimental sites

This study selected masson pine (*Pinus massoniana*) and *C. Campora* as objects because the former is sensitive to acidic deposition and the distribution area of latter is large (Feng, 1988). Table 1 is the natural conditions of the experimental sites (All of the soil are mountain yellow soil).

Table 1 Natural conditions of the experimental sites

Community	Site No.	Average tree height, m	Average D.B.H., cm	Age, a	Tree number, hm^2	Slope, °
P. massoniana	1	12.4	17.8	35	1390	36
	2	13.1	21.4	36	1245	24
	3	14.2	25.1	36	1249	13
	4	14.0	24.1	38	1253	23
	5	14.3	25.4	37	1245	9
	6	14.6	28.9	35	1210	6
C. campora	1	14.7	28.6	23	1322	17
	2	14.5	26.9	20	1256	28
	3	15.6	30.8	30	1254	10
	4	16.3	36.6	30	1289	6

2.2 Water samples

The open bulk and through fall samples were collected by the water samplers with polyethylene funnels and 10 glass bottles every two weeks. The stemflow samples of *chamaecyparis obtusa* and *quercus serrata* were taken into 20 polyethylene bottes through rolled vinyl tubes, 28 mm in diameter. The soil solution samples were collected from the depth of 10, 20, 30 and 50 cm with soil solution samplers using porous ceramic cups under 85—90 kpa suction connected with vacuum glass bottles. pH values were measured by a PHL—20 pH meter.

2.3 Study method

Six patches of masson pine forest and 4 patches of *C. campora* forest in the study area were selected as experimental sites. According to forest investigation rules and measurement of forest productivity, the area of experimental site was 0.1 hm^2. Annual productivity of masson pine and *C. campora* forest in each experimental site was investigated from October, 1992 to October, 1993. Stem analysis was used to calculate the annual volume increment in the sites. The natural

ecological conditions of each site were investigated respectively and pH value of precipitation in each site was determined. A multivariable stepwise regression model was established to analyze the relationship of pH value of precipitation and other natural ecological factors on the average annual productivity and volume increment of masson pine and *C. campora* forest.

Assess the loss of volume: according to the forest resources data of Chongqing Forest Bureau, the age distribution of masson pine in Chongqing was analyzed and the standard volume table of masson pine forest was made. According to different site classes and age classes, the annual volume loss (V) of coniferous masson pine forest with different acidic deposition was calculated with superposition method.

$$V = \sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{k=1}^{p} X_{aijk} \cdot X_{bijk} \cdot X_{cijk}. \quad (1)$$

In this equation, X_a means the area of coniferous masson pine forest with a certain acidic deposition, X_b means annual volume increment of control (coming from standard table), X_c means the annual volume loss of coniferous masson pine forest caused by a certain acidic deposition (calculated by relationship of the real annual productivity of stand volume and X_b), i means acidic deposition class, j means age class of stand, k means site class.

3 Result and discussion

3.1 Investigation and measurement of ecological factors in the experimental sites

In 1993, pH value of precipitation and other natural factors of each site were measured (Table 2).

Table 2 Ecological factors in the experimental sites

Community	Site No.	Mean pH of precipitation	Annual precipitation, mm	Relative humidity, %	≥10℃ accumulated temperature, ℃	Soil depth, cm	pH of soil	Soil organic contents, %
P. massoniana	1	4.05	1145	78	5940	20	3.77	0.84
	2	4.37	1245	76	5840	31	4.06	1.69
	3	4.62	1341	76	5760	55	4.38	2.61
	4	4.51	1309	76	5940	44	4.84	2.38
	5	4.84	1310	76	5940	62	4.91	2.94
	6	5.03	1309	76	5940	69	4.99	3.63
C. campora	1	4.24	1268	79	5840	32	4.98	5.32
	2	4.67	1354	79	5840	20	4.36	4.89
	3	4.12	1378	78	5870	46	4.85	5.03
	4	4.26	1169	79	5760	54	4.86	5.91

3.2 Annual productivity and volume increment

According to the investigation result of mean trees with difference diameter in sample plot, the

power function equations of tree biomass with diameter and height were established by method of least squares (Table 3).

Table 3 Regression equations of biomass and tree diameters

Species	Organ of trees	Sample No.	Regression equation	Correlation coefficient
P. massoniana	Trunk	16	$W=0.0864D^{2.3250}$	0.9643**
	Branch	16	$W=0.00120D^{3.3460}$	0.7540**
	Leaf	16	$W=0.0055D^{2.4557}$	0.6871**
	Root	16	$W=0.1062D^{1.9814}$	0.8461**
	Total	16	$W=0.2191D^{2.0052}$	0.9121**
C. campora	Trunk	16	$W=0.0694(D^2\cdot H)^{0.8490}$	0.9450*
	Branch	16	$W=0.0420(D^2\cdot H)^{0.8010}$	0.8620*
	Leaf	16	$W=0.0067(D^2\cdot H)^{1.1204}$	0.9360*
	Root	16	$W=0.0604(D^2\cdot H)^{0.8550}$	0.8250*
	Total	16	$W=0.02634(D^2\cdot H)^{0.9237}$	0.9827*

W: dry weight of organ, kg; D: diameter at breast height, cm; H: height, m.

* $p<0.05$; ** $p<0.01$

Annual productivity and wood volume increment in the experimental site were calculated by the foregoing regression equation and the investigation results of each tree (Table 4).

Table 4 Annual productivity and wood volume increment in different experimental sites

Item	Coniferous masson pine forest						Broad-leaved *C. Camphora* forest			
	1	2	3	4	5	6	1	2	3	4
Single tree biomass, kg	55.03	81.36	117.69	107.75	121.08	155.67	182.3	161.3	211.6	299.1
Annual net productivity, t/(hm^2·a)	2.19	2.89	3.97	3.65	4.07	5.42	10.48	10.13	8.84	12.85
Average of volume single tree, m^3	0.129	0.180	0.2594	0.235	0.2751	0.3521	0.251	0.223	0.322	0.425
Annual volume increment, m^3/(hm^2·a)	5.14	6.23	9.701	8.97	10.00	12.69	14.44	13.69	13.44	18.26

3.3 Multiple factors analysis of the ecological factors on annual productivity and volume increment

Multiple factors influence tree growth in forest ecosystem. Among these factors, there are interaction and antagonism, and some dominant factors which influence tree growth in a certain condition can be determined by systems analysis. Numerical analysis of the dominant factors (X_1: soil organic content, X_2: pH value of deposition, X_3: soil depth, X_4: slope, X_5: density, X_6: pH value of soil, X_7: annual precipitation, X_8: relative humidity, X_9: $\geqslant 10$℃ accumulated temperature, X_{10}: time of illumination, X_{11}: annual median temperature) on annual productivity and volume increment was done by multivariable regression. When experimental sites were selected, non-quantified factors (exposure, slope location and soil type *etc.*) and age of stand in different sites might be consistent as possible.

The results show that among all the foregoing main factors, X_1, X_3, X_2 and X_4 are most correlative with annual productivity and volume increment of masson pine. Correlative coefficient of these four factors with biomass are 0.9940, 0.9762, 0.9738 and −0.9436, and correlative coefficient of these four factors with volume increment are 0.9842, 0.9733, 0.9626 and −0.8566, respectively. X_1, X_3 and X_4 are most correlative with annual productivity and volume increment of *C. Campora*. Correlative coefficient of the factors with biomass are 0.9435, 0.9069 and −0.8566, and correlative coefficient of the factors with volume increment are 0.9894, 0.6230 and −0.5704, respectively. Regression equation of the factors with annual productivity are:

$$Y = 422.5X_1 + 269.33X_2 + 271.12X_3 - 24.28X_4 - 29.98, \text{ (masson pine)} \quad (2)$$

$$Y = 523.44X_1 + 389.67X_3 - 26.63X_4 + 27.1. \text{ (}C. campora\text{)} \quad (3)$$

In the equations, Y means annual productivity.

From the foregoing analysis, acidic deposition is the main natural factor influencing growth of masson pine, but it does not influence growth of *C. campora*. Soil organic contents, soil depth and slope are three main factors influencing growth of masson pine and *C. campora*. So accelerating the development of evergreen broad-leaved *C. campora* forest is important to restore the degenerative forest ecosystem in the area.

According to data of masson pine with different pH value of precipitation, site class and age class, annual volume loesses of masson pine with different acidic deposition were calculated (Table 5).

Table 5 Volume losses of coniferous masson pine with different acidic deposition

pH value of precipitation	4.0—5.0	4.6—4.75	4.76—5.0	>5.0	Mean losses
Annual volume losses, %	10.1—43.0	8.3—32.4	5.1—27.6	0.2—23.2	16.3

The timber losses caused by acidic deposition in southern suburbs of Changqing are: $V = 3370.206\text{m}^3$; $E = PV = 3.0332 \times 10^6$ (Yuan); E means the economic losses of coniferous masson pine forest caused by acidic deposition, and P means the price of masson pine timber.

4 Conclusion

Soil organic contents, soil depth, pH value of precipitation and slope are four main ecological factors influencing the growth of masson pine forest. Soil organic contents, soil depth and slope are three main ecological factors influencing the growth of *C. campora* forest in the area.

Growth of masson pine will be restrained if pH value of precipitation below 5.1, and if pH value is 4.0 or so, the annual volume loss of this community will be as high as 43%.

In southern suburb of Chongqing, the area of coniferous masson pine forest influenced by acidic deposition is 2320 hm^2. The annual volume loss of masson pine is about 3370.206m^3, and the direct ecomomic loss is 3.0332×10^6 RMB Yuan per year.

To restore the degenerative masson pine forest in the area where acidic deposition caused

serious harm, some tree species (such as *C. campora*) which are more resistent to acidic deposition can replace masson pine. This is an ecological technical measure to replace forest ecosystem. It can cut down and even avoid the harmful effects of acidic deposition on forest ecosystem, and also can accelerate the development of forest ecosystem to its climax-evergreen broad-leaved forest.

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