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SWCF of Forest in Three-Gorges of Yangtze River

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In Qinjiagou watershed of Three-Gorge of Yangtze River, 18 indices were selected from canopy layer, litter layer, soil layer and topography to evaluate the soil and water conservation capacities of four common plantation types by ideal point method. Results indicated that the broadleaf plantation of robur (*Lithocrpus glabra*) and Chinese gugertree (*Schima superba*) (*LS*) has the biggest soil and water conservation capacity. The rank of three other plantation types from big to small is the mixed broadleaf plantation *of* sweetgum (*Liguidambar formosana*), Chinese gugertree and camphor tree (*Cinnamomum camphora*) (*LSC*), the mixed broadleaf-conifer plantation of Chinese fir (*Cunninghamia lanceolata*), Masson pine (*Pinus massoniana*) and Chinese gugertree (*CPS*), and the mixed Pine plantation of Chinese fir and Masson pine (*CP*). Under the same climate and topographical condition, the broadleaf plantation has better soil and water conservation capacity than the conifer plantation. Sensitivity analysis showed that the three most sensitive indices are soil non-capillary porosity, soil aggregation, and soil initial infiltration rate. The litter amount and soil properties are the most important indicators of soil and water conservation capacity of plantations. Therefore, suitable measurements such as deep tillage should be taken to improve the properties of soil under different plantations.

Keywords: The Three-Gorge Area; Soil and Water Conservation; Function; Soil Properties; Sensitivity Analysis

Introduction

Soil erosion is one of the biggest environmental problems in the Southwest region of China. Many measurements have been taken to protect soil and water resources. Researches indicated that various types of plantations are all able to reduce surface runoff and soil erosion effectively (Woodward et al., 1995; Jiang et al., 2007), and their function was affected by human and natural disturbances (Noske et al., 2010; Uzun et al., 2011). In the upper reaches of the Yangtze River, people have replanted most of farmlands with Chinese fir (*Cunninghamia lanceolata*), Masson pine (*Pinus massoniana*), robur (*Lithocrpus glabra*), sweetgum (*Liguidambar formosan*), camphor tree (*Cinnamomum camphora*) and other tree species. Are these plantation types suitable for reforestation, and are they helpful to protect soil and water? The information is urgently needed to understand soil and water conservation capacity of different plantation types.

Methods and Materials

Study Area

Simian Mountain, belongs to the Three Gorges Reservoir Area, is a typical case in terms of its complexity of natural environment and fragility of ecosystem in China. The soil erosion is posing a serious threat to the ecological security and regional sustainable development in upper reaches of Yangtze River. The study area, Qinjiagou watershed (28˚31′N - 28˚46′N, 106˚17′E - 106˚30′E), is situated in the middle part of Simian Mountain, Southwest of China. The forest land of Qinjiagou watershed belongs to the upstream of Yangtze River. The altitude is from 900 m to 1,500 m. Soils are mainly yellow loam and purple soil, which is infertile, with a depth ranging from 10 to 70 cm. The representative types in Simian Mountain are mixed forest of CP, *CPS*, *LS*, *LSC*. All the four plantation types were planted in 1999, with 1 ha of *LSC*, *CP*, *CPS*, and 0.8 hm^2 of *LS*. The previous shrubs were cut off before new plantations were planted, but the litter is kept. There was no management after the plantations were planted except irrigation in spring.

Samples Collection and Treatment

Ideal Point Method

Ideal point, a popular method for multiple objective decision-making, is objective thus avoiding large deviation due to subjective opinion (Henry et al., 1989; Zhang et al., 2006; Hagemann, 2007). That method could reduce the disturbance of subjectivity in the course of assessment, and reflect the contribution of each index to regional ecological safety more objectively (Jia et al., 2006). Therefore, normalizing indices and weighting determination was dealing with the above methods.

Sensitivity Analysis

Sensitivity analysis is necessary for evaluation (Chen, 1987; Fan et al., 2004). The analysis will determine the certainty of the rank of every two plantation types. Taking $\overline{y}_k$ as the possibly changed value of y'_{ij}, then

$$\overline{T}_i = 1 - \frac{\sum_{j=1}^{m-1} y'_{ij} V_j^* + \overline{y}_k V_k^*}{\sum_{j=1}^{m} \left(V_j^*\right)^2} \quad (1)$$

$$\Delta = \overline{y}_k - y'_{ij} = \frac{\left(T_i - \overline{T}_i\right) * \sum_{j=1}^{m} \left(V_j^*\right)^2}{V_k^*} \quad (2)$$

When $\bar{y}_k \in \left[\min_i y'_{ij}, \max_i y'_{ij}\right]$, the change of $\bar{y}_k$ will not induce the change of V_k^*. When $\bar{y}_k$ is very close to y'_{ij}, the original rank is not steady. y'_{ij} is the sensitive index. If $\bar{y}_k$ is very close to y'_i when the Δ value belongs to $[0,0.1]_j$, it means that y'_{ij} is sensitive. And the lower the value is, the more sensitivity indices are. If the numbers of sensitive indices between two plantation types are more than 3, the rank of them is uncertain.

Results and Discussion

Plant Investigation

In July 2009, three 20 × 20 m^2 plots were established at each plot of four plantation types in study area. The height of all trees was measured. The number of trees in each subplot was counted and recorded. In each 20 × 20 m^2 plot, four 5 × 5 m^2 subplots were established for investigation of shrub diversity. The number and names of the different shrubs were recorded. In each shrub plots, two 1 × 1 m^2 subplots were established for investigation of grass diversity and the names and amounts of the different grasses were recorded. Five 1 × 1 m^2 subplots were randomly chosen in each 20 × 20 m^2 plots and leaf litter fall was sampled. A total of 15 leaf litter fall samples were taken in each plot of every plantation type. The maximum water capacity of litter was measured by putting leaf litter fall in water 24 hrs.

Soil Properties

In June 2009, soil samples for physical properties measurements were collected from each location of plantation types. Five replicated soil cores for bulk soil density, total porosity and non-capillary porosity were taken in each 20 × 20 m^2 plot along a diagonal transect. Analyses of physical soil properties were conducted. Three composite surface soil samples were collected from the plots of each plantation. The soil samples were sieved to pass a 2 mm mesh and the percent of soil particles bigger than 2 mm equals the percent of gravel in the soil. The infiltration rate (IR) of the soils was measured by using a double-ring infiltrometer with a 22 cm outer diameter, a 10.5 cm inner diameter and a height of 25 cm (Song et al., 2007). Organic matter of the soil was determined by an oil bath-$K_2Cr_2O_7$ titration method.

Implementing Ideal Point Method

Values of All the Indices

18 indices were selected for ideal point model. That is one of differences from the previous research (Truman et al., 1990; Deuchras et al., 1999). There into two indices, aspects and roots distribution, are qualitative indices obtained by the method of expert's gradation according to the studies about the relationship between indices and soil erosion. And the other 15 indices values are all obtained from field measurements.

Normalization of Indices

The evaluation system is composed of 4 programs (4 plantations) and 18 indices. Then, the original matrix of the evaluation system is

$$X = \left(x_{ij}\right)_{4\times 18},$$

$$X = \begin{bmatrix} 46 & 2.87 & 30 & 0.15 & 202.79 & 19.17 & 0.237 & 1.096 & 0.049 & 0.186 & 0.397 & 0.085 & 4.53 & 0.18 & 10.75 & 36 & 90 & 1161 \\ 70 & 2.2 & 70 & 0.03 & 191.82 & 16.82 & 0.113 & 1.033 & 0.031 & 0.313 & 0.502 & 0.112 & 5.04 & 0.37 & 17.42 & 38.5 & 50 & 1160 \\ 78 & 3.26 & 30 & 0.043 & 246.94 & 25.43 & 0.134 & 1.139 & 0.097 & 0.238 & 0.484 & 0.127 & 5.24 & 0.35 & 37.92 & 36 & 90 & 1166 \\ 55 & 3.83 & 50 & 0.26 & 64.47 & 6.04 & 0.069 & 1.236 & 0.117 & 0.203 & 0.525 & 0.126 & 5.29 & 0.30 & 10.08 & 28.8 & 70 & 1170 \end{bmatrix}$$

The matrix after normalization is $Y = \left(y_{ij}\right)_{4\times 18}$,

$$Y = \begin{bmatrix} 0 & 0.411 & 0 & 0 & 0.758 & 0.677 & 1 & 0.690 & 0.209 & 0 & 0 & 0 & 0 & 0 & 0.024 & 0.258 & 1 & 0.9 \\ 0.75 & 0 & 1 & 0.556 & 0.698 & 0.556 & 0.262 & 1 & 0 & 1 & 0.820 & 0.643 & 0.671 & 1 & 0.263 & 0 & 0 & 1 \\ 1 & 0.650 & 0 & 1 & 1 & 1 & 0.387 & 0.478 & 0.767 & 0.409 & 0.680 & 1 & 0.934 & 0.833 & 1 & 0.258 & 1 & 0.4 \\ 0.281 & 1 & 0.5 & 0.407 & 0 & 0 & 0 & 0 & 1 & 0.134 & 1 & 0.976 & 1 & 0.833 & 0 & 1 & 0.5 & 0 \end{bmatrix}$$

According to entropy method, the weights of different indices were calculated.

Evaluation Results

After normalization and weights' determination, the final matrix Y' is as following,

$$Y' = \left(y'_{ij}\right)_{4\times 18} = Y * \omega_j \qquad (1)$$

where $Y = \left(y_{ij}\right)_{4\times 18}$ is the matrix after normalization; ω_j means weights of different indices.

$$Y' = \begin{bmatrix} 0 & 0.016 & 0 & 0 & 0.043 & 0.048 & 0.065 & 0.032 & 0.009 & 0 & 0 & 0 & 0 & 0 & 0.001 & 0.016 & 0.042 & 0.028 \\ 0.034 & 0 & 0.06 & 0.031 & 0.040 & 0.040 & 0.017 & 0.047 & 0 & 0.071 & 0.038 & 0.046 & 0.028 & 0.078 & 0.017 & 0 & 0 & 0.031 \\ 0.045 & 0.025 & 0 & 0.056 & 0.058 & 0.072 & 0.025 & 0.022 & 0.035 & 0.029 & 0.032 & 0.072 & 0.039 & 0.065 & 0.065 & 0.016 & 0.042 & 0.012 \\ 0.013 & 0.039 & 0.03 & 0.023 & 0 & 0 & 0 & 0 & 0.046 & 0.009 & 0.047 & 0.070 & 0.042 & 0.065 & 0 & 0.064 & 0.021 & 0 \end{bmatrix}$$

After normalization, the value of 18 indices all belonged to interval [0, 1]. The maximum was the best. Therefore, the ideal program I_1^* should be composed of the maximum value of each index as follows,

$$I_1^* = \left(0.045 \quad 0.039 \quad 0.06 \quad 0.056 \quad 0.058 \quad 0.072 \quad 0.065 \quad 0.047 \quad 0.046 \quad 0.071 \quad 0.047 \quad 0.072 \quad 0.039 \quad 0.078 \quad 0.065 \quad 0.064 \quad 0.042 \quad 0.031\right)$$

$$T_i = \left(0.634 \quad 0.437 \quad 0.354 \quad 0.523\right)$$

$$\alpha_i = \left(0.202 \quad 0.156 \quad 0.121 \quad 0.170\right)$$

Therefore, th*e evaluation of soil and water conservation capacity of LS* is the minimum, that of CP is the maximum. The second one is CPS, followed by LSC.

Conclusion and Suggestion

Conclusion

Soil and water conservation is one of the most important targets of eco-environment construction in Southern China. We found that under the same condition, soil and water conservation capacity of hardwood forest is better than that of mixed forest of hardwood and softwood, and much better than that of conifer forest.

According to the sensitivity analysis, it showed that hardwood *LS* has the best soil and water conservation capacity among the others. Therefore, the mixed broadleaf forest of robur and Chinese gugertree should be the first choice when we implement the "returning farmland to forest" policy in the Three Gorges area.

It also showed that the soil and water conservation capacity of *CP* is difficult to improve over a short time from now. However, the soil and water conservation capacity of *LS*, *LSC*, and *CPS* can be improved by taking proper managing practices.

Litter and soil layer under the forest play a very important role in protecting soil and water. Improving the soil properties should be taken to enhance the soil and water conservation capacity of these plantations.

That proves that ideal point method is suitable for evaluating forest soil and water conservation capacity. Using the ideal point method to evaluate the capacity of soil and water conservation of different forest types can avoid long-time processing measurement, but with more objective and precise results.

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