Energy of forest systems in the Three Gorge Reservoir area *

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Abstract—The energies of three forest ecosystems in the Three Gorge Reservoir area were analyzed. The results showed that the existing energies were 151.2438, 139.2014 and 175.1659 ($\times 10^{10}$ J/hm^2), the annual net fixed energies were 38.8924, 31.2214 and 46.8231 ($\times 10^{10}$J/hm^2), and the utilization efficiency of light energies were 1.16, 0.99 and 1.40 for the *Quercus acutissima* forest(Q.A.), the *Pinus massoniana* forest (P.M.), and the *Queresus acutissima* and *Pinus massoniana* mixed forest (Q.P.), respectively. In the Three Gorge Reservoir Area, the energy efficiency of *Quercus acutissima* and *Pinus massoniana* mixed forest is the best.

Keywords: forest ecosystem, energy, Three Gorge Reservoir area.

1 Introduction

The development of forestry has made a great productivity in the Three Gorge Reservoir area in China, and it reached much desirable biomass, productivity, structure, function, soil and water conservation, forest soil improvement, and income increment and so on. However, only the qualitative description and some economic indices are not enough for the analysis of ecosystem characteristics. Therefore, the three forest ecosystems, *Quercus acutissiama* and *Pinus massoniana* mixed ecosystem, *Quercus acutissima* ecosystem, and *Pinus massoniana* ecosystems were quantitatively analyzed for energy during 1996—1997. It not only overcame the quantitative analyzing difficulties brought out by the complexity of ecosystem and other random elements, but also opened out the most fundamental and substantial relationships in the forest ecosystems. This article will provide the scientific basis for the evaluation and application of forest ecosystems through energy analysis of the three types of forest ecosystems in the Three Gorge Reservoir area, and for comparison of them with local traditional forest ecosystems.

2 Study area and methods

2.1 The study area

This study has take the Three Gorge Reservoir area as an investigation area, and the sampling plots were set in Quxi watershed, Zigui County, Hubei Province, where the climate of the area belongs to the subtropical zone. The annual average air temperature is 18℃, the annual average precipitation is 1015 mm, the >12℃ annual accumulation temperature is 1700℃, and the >10℃ annual accumulation temperature is 5700℃. The annual absorbed radiation is 3352.15×10^{10} J/hm^2. The soil is yellow soil. In the *Quercus acutissima* and *Pinus massoniana* mixed forest ecosystems, the main plant species are *Pinus massoniana*, *Quercus acutissima*, *Cunminghamia lenceolate*, *Cupressus funebris*, *Carpinus tarczanizowii*, *Rhododendron simsi*, and the density of stands is 4500 trees per hm^2, and the age range of trees is from 6 years to 50 years, the average

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height of trees is 6.75 m, and the D.B.H. of trees is 6.70 cm. In the *Pinus massoniana* forest ecosystems, the main species are *Pinus massoniana*, *Cunminghamia lenceolata*, *Carpinus tarczanizowii*, *Rhododendron simsi*, the stand density is 3400 trees per hm^2, age ranges from 10 years to 55 years, the average height of trees is 7.50 m, and the D.B.H. of trees is 7.20 cm. In the *Quercus acutissima* forest ecosystems, the main species are *Quercus acutissima*, *Cunminhamia lenceolata*, *Cupressus funebris*, *Carpinus tarczanizowii*, *Rhododendron simsi*, the stand density is 3100 trees per hm^2, age ranges from 4 years to 30 years, the average height of trees is 8.50 m, and the D.B.H of trees is 9.60 cm.

2.2 Methods

The measuring methods of biomass, annual net production and the amount of litters referred to Feng(Feng, 1983). The trunks, branches, leaves and roots, and litters and withered root were sampled in Oct. 1997. All of these samples were dried with a constant oven in a temperature of 80℃, and the calorific values of these samples were determined using a GR-3500 thermometer afcterwards.

3 Results and analysis

3.1 Analysis of calorific values of various parts of plants

Because the components of various parts, illumination intensity, duration of sunshine time, nutrient contents, growing seasons, and soil types are very different among different plant parts, the calorific values were also different(Table 1).

Table 1 Calorific value of plants parts(10^4 J/hm^2)

Part	*Quercus acutissima*	*Pinus massoniana*	Shrub and herb
Trunk	1.74	1.72	1.63
Branch	1.80	1.76	1.69
Leaf	1.96	1.91	1.71
Root	1.64	1.61	1.54

Table 1 shows that the calorific values of plants parts of tree layer were higher than shrub and herb layers in different stands. The calorific values of *Quercus acutissima* were higher than *Pinus massoniana* and other shrub. The calorific values aboveground of part were higher than that of the underground part. The calorific values of leaves were higher than other parts.

3.2 The annual net fixed energy, existing energy and luminous energy transformation rate of the forest ecosystems

The annual net fixed energy is the energy fixed by photosynthesis deducted by energy consumed by respiration and animals in a unit time(a year) and a unit area(1 hm^2). The existing energy is the total energy accumulated by all parts of the ecosystems in a certain time. Luminous energy transformation rate is the proportion of annual net fixed energy to the annual solar radiant energy (Table 2).

Table 2 Analysis of energy in different forest systems

Ecosystem	Annual net fixed energy, $\times 10^{10}$ J/($hm^2 \cdot a$)	Existing energy, $\times 10^{10}$ J/hm^2	Light energy use efficiency, %
Quercus acutissima forest	38.8924	151.2438	1.16
Pinus massoniana forest	31.2214	139.2014	0.99
Quercus acutissima and *Pinus massoniana* mixed forest	46.8231	175.1659	1.40

Table 2 shows that use efficiencies of the existing energy, annual net fixed energy and light energy use efficiency of the *Quercus acutissima* and *Pinus massoniana* mixed forest are higher than the *Quercus acutissima* forest and the *Pinus massoniana* forest,

3.3 Distribution of existing energy in three forest ecosystems

3.3.1 Distribution of existing energy in different layers

Fig. 1 shows that the trees layer makes up 86%—88%, shrubs layer makes up 11%—12%, and herb layer makes up 0.8%—1.3%, of the existing energy in the studied forests. It is clear that the existing energy is mainly fixed by trees in the studied forest ecosystems in this area.

3.3.2 Distribution of existing energy in different plant parts

Fig.2 shows that the existing energy of trunk makes up 74%—75%, branches 10%—11%, leaves 7.0% 9.0%, and roots 6.0%—8.5%, of the total in the forests. It is clear that the existing energy is mainly fixed by trunks in the studied forest ecosystems in this area.

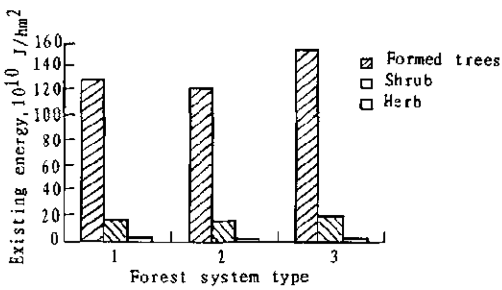

Fig.1 Distribution of existing energy in different levels of forest systems
1. *Quercus acutissima* forest; 2. *Pinus massoniana* forest; 3. *Quercus acutissima* and *Pinus massoniana* mixed forest

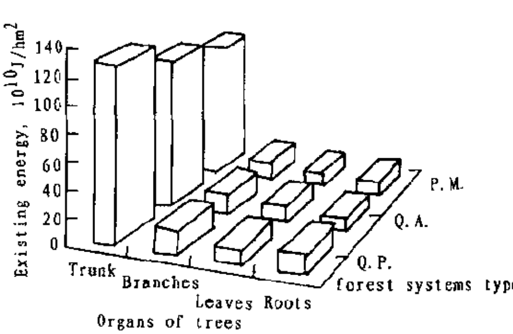

Fig.2 Distribution of existing energy in different organs of trees

3.4 Energy efficiency analysis

3.4.1 The energy conversion efficiency

The energy sources of forest can be divided into natural energy(mainly solar energy) and auxiliary energy. The auxiliary energy includes biological energy (renewable resource energy as straw litters, human and animal power). The efficiency of three types of forests is analyzed in this paper(Table 3).

Table 3 Energy conversion efficiency of different forests ($\times 10^{10}$ J/hm^2)

Forest	Energy input				Energy accumulation				Energy efficiency			
	A	B	C	D	E	F	G	H	I	J	K	L
Q.A.	3353.82	3352.15	0.96	0.71	151.24	130.20	112.38	18.24	0.0116	0.0388	0.0335	1.16
P.M.	3355.90	3352.15	2.78	0.97	139.20	122.00	103.43	16.13	0.0093	0.0364	0.0308	0.99
Q.P.	3353.82	3352.15	0.96	0.71	175.17	153.10	130.15	21.11	0.0140	0.0456	0.0388	1.40

Notes: A. total input energy; B. solar energy; C. biological energy; D. non-biological energy; E. total accumulated energy; F. accumulated energy of formed trees; G. accumulated energy of trunks of formed trees; H. accumulated energy of shrub; I. annual net fixed-input ratio of energy; J. accumulated energy of formed trees/total inputs energy (solar energy efficiency); K. energy of trunks of formed trees/total inputs energy (economic benefits energy efficiency); L. light energy use efficiency.

Using synthetically evaluation methods, the paper evaluated the superiority of energy efficiencies for various forest ecosystems.

3.4.2 Selection of evaluation indices

Because the total accumulated energy (X_1) can make the system going on through exchange of matter, energy, and information, and can keep the system to producing forest, and sideline products continuously, the accumulated energy is an important criterion for measuring the functions for the forest ecosystem. The energy of trees (X_2) is a key criterion for measuring the energy efficiency of the ecosystem. The energy of trunks (X_3) is a key criterion for measuring the energy utilization efficiency. The solar efficiency (X_4) is a ratio of total accumulate to solar energy, and is a key criterion for measuring the utilization of the system to the unrenewable resources. The economic benefits energy efficiency (X_5) is the ratio of the total accumulated energy of the forest systems to net fixed energy of trunk of trees, and is a main criterion for economic benefits of forest systems. The biological energy efficiency(X_6) is the ratio of total accumulated energy of plants to biological energy, and is measuring the accumulated energy of forest systems transformation efficiency. The non-biological energy efficiency (X_7) is a main criterion for measuring the non-biological energy transformation efficiency of the forest systems. The solar energy is main source of energy in ecosystems, the solar energy utilization ratio(X_8) equals is total accumulated energy divided by solar energy.

3.4.3 The standardization of data

The results of standardization of date are as follows:

$$X'_{ij} = X_{ij}/X_{j(\max)}.$$

Where, X'_{ij} is the standardized data of the index, X_{ij} is the original data, and $X_{j(\max)}$ is the maximum value of each index. The results are shown in Table 4.

Table 4 Matrix of standardized data of energy efficiency indexes

Forest	X'_{i1}	X'_{i2}	X'_{i3}	X'_{i4}	X'_{i5}	X'_{i6}	X'_{i7}	X'_{i8}	$\sum X'_{ij} \cdot A_j$
Q.P.	0.9994	0.8504	0.8635	0.8286	0.8634	0.8634	0.8641	0.8633	0.8745
Q.A.	1.0000	0.7969	0.7947	0.7071	0.7938	0.2744	0.5817	0.7942	0.7179
P.M.	0.9994	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	0.9999

3.4.4 The determination of weighted values

Suppose that the effect of every index to the forest ecosystem energy efficiency is the same, we can use the method of equality to determine the weight of each index (Wu, 1994). That is

$$A_1 = A_j = A_8 = 1/8.$$

3.4.5 Synthetical evaluation

Using Y to represent the energy synthetical efficiency of a forest as the following:

$$Y = X'_{ij} \cdot A_i \qquad \text{and,}$$

$$Y = \begin{matrix} Y_1 & 0.8745 \\ Y_2 = & 0.7179 \\ Y_3 & 0.9999 \end{matrix}$$

According to analysis above, among the three forests, the energy efficiency's order was *Quercus acutissima* and *Pinus massoniana* mixed forest > *Quercus acutissima* forest > *Pinus massoniana* forest in the Three Gorge Reservoir area.

4 Conclusion

The energy efficiency of *Quercus acutissima* and *Pinus massoniana* mixed forest is the best, *Quercus acutissima* forest is the second, and *Pinus massoniana* forest is the third in the Three Gorge Reservoir area.

The annual net fixed energy, the existing energy and the solar energy utilization ratio of the *Quercus acutissima* and *Pinus massoniana* mixed forest systems is higher than that of *Quercus acutissima* forest and *Pinus massioniana* forest.

The results of this research showed that although energy efficiency of *Quercus acutissima* and *Pinus massoniana* on mixed forest is the highest, it is necessary to develop this type of forest. Because the destinations and management measures of the three forest ecosystems are different, the development of various forests must based on the site condition, the social requirement and the economical demands while developing the forest in the Three Gorge Reservoir area.

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References

Chen Lingzhi, 1983. Journal of Plant, 25(1):67—74

Feng Zongwei, 1983. Journal of Ecology, 3(2):119—129

Feng Zongwei, 1980. Research on the biomass of manmade forest of *Cunninghamia lanceolata*, comprehensive collections of exploration reports of Taoyuan. Changsha: Hunan Publishing House of Science and Technology, 322—333

Feng Zongwei, 1982. Plant Ecology and Geobotany, 6(2):257—266

Feng Zongwei, 1985. Plant Ecology and Geobotany, 9(4):245—255

Howord A S, Nair P K R, 1987. Agroforestry; A decade of development ICRAF, Nairobi

Nanjing Institute of Soil Science, Chinese Academy of Sciences, 1978. Physicochemical analysis of soil. Shanghai: Shanghai Publishing House of Science and Technology. 21—110

Nair P K R, 1989. Agroforestry systems in tropical, Kluwer, The Netherlands: Academic Publishers

Odum H T. Systems Ecology, 1983. New York: John Wiley and Sons.

Vallentyne T R, 1960. Geochemistry of the biosphere. McGraw-Hill cyclopedia of science and technology, 2:239—245

Ye Bing, 1963. Physiochemical analysis procedure of soil. Beijing: Science Press, 19—126

Zhang Fuzhu, 1991. Huanjingkexue, 11(2):131—141

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