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Hydrological eco-service of rubber plantations in Hainan Island and its effect on local economic development

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Abstract: The impacts of economic forest on global environmental change(GEC) are one of the hot issues in environmental study. Based on the 3-year observation data and 40-year climate data, GEC and analysis of the hydrological dynamic characteristics of rubber plantations and estimate of the water balance in the rubber plantations in Hainan Island were made. The results showed that the rainfall intercepted by the canopy of the plantations accounted for 11.45% of the annual rainfall, the total runoff for 23.71%, the total evaporation and transpiration for 63.24%, the soil moisture storage for 1.6%. Analysis of the 40-year rainfall data in the 19 counties of Hainan Island during 1951—1990 showed that the large-scale substitution of the natural vegetation with the rubber plantations had no significant effect on the local rainfall in Hainan Island. The main reasons are (1) 80% of the rainfall in Hainan is brought by typhoons; (2) the proportion of 11.6% rubber plantations in total forest coverage in Hainan is not enough to influence the local rainfall in Hainan Island; and (3) although the rubber plantation is artificial vegetation, it has the similar function to the tropical rain forest. Analysis of the total water resource and total GDP of Hainan in 1997 showed that the economic benefit resulted from the water resource was 1.0 RMB Yuan/m^3. The value of hydrological of the rubber plantation in Hainan was 113.9 million RMB Yuan/a when compared with the tropical rain forest. The paper reaches conclusion that the hydrological eco-service function of rubber plantation has been enhanced after transformed from natural vegetation, which includes the natural service and powerful social service.

Keywords: eco-service; rubber plantation; hydrological function; Hainan Island

Introduction

The rubber tree(*Hevea brasiliensis*) is a latex-producing arbor species, which grows typically in the tropics. It began to be introduced from Brazil to grow in Hainan in 1906, but was planted only in a small area. Rubber plantations(a kind of economic forest) in Hainan only covered 1900 hm^2 until 1950. From 1951, the Chinese government decided to grow rubber trees on large scales in south China for the need to develop the national economy. By 1999, rubber plantation area in Hainan was up to 370000 hm^2, which is 11.6% of the total area of Hainan Island. It is a typical case study on substitution of natural vegetation with artificial vegetation.

It is well known that the rubber tree is not only a natural ecological resource, but also can have influential functions of eco-service. The functions of eco-service mean that the ecosystems provide visible and invisible natural products and environmental benefits to maintain the functions of production, consumption, circulation, restoration and coordination of the human society (Wang, 2001). The eco-service include synthesis of biomass, maintenance of biodiversity, conservation of water and soil, regulation of climate, maintenance of soil fertility, purification of environmental pollution, storing of the necessary nutrients, promotion of element circulation, maintenance of chemical balance and stability of atmosphere, etc. In the past, many researches were made on biomass synthesis of the rubber tree such as latex production and rubber wood, and very few researches were done on the other ecological functions of the rubber tree. There were even some misunderstandings about the rubber tree. In this paper, the authors intend to discuss the functions of eco-service of the rubber plantations in Hainan, especially to determine the parameters of contribution of the rubber plantations to the environmental change in Hainan based on the analysis of the demand for rubber resource. Emphasis is laid on analyzing the hydrological function of the rubber plantations and its contribution to the local economic development in Hainan. This will lay a good foundation for further researches on other functions of the rubber plantations in Hainan.

1 Materials and methods

1.1 Outline of the natural ecologic environments in Hainan

Hainan Island is situated between 18°20′ and 20°10′ north latitudes, 108°37′ and 111°03′ east

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longitudes with a total area of 33920 km^2. It forms China's southernmost Hainan Province, which has 19 counties or cities and 2 million km^2 of marine area as well as many archipelagoes. Hainan Island is separated from the mainland of China by the Qiongzhou Strait.

Hainan Island is endowed with a tropical monsoon climate, the average annual temperature being 23—25℃, the average temperature of the coldest month is 17—20℃, the annual cumulative temperature of > 10℃ is 8200—9200℃, and the annual rainfall is 1600—2500 mm in more than 2/3 of the island. It is a district most characteristic of tropical climate in China.

The topography of Hainan Island is high in the middle and low around, from the mountains in the middle to hills; terraces and plains around, forming stratified distributions vertically and ring distributions horizontally. The mountainous areas above 800 m altitude amount to 6067 km^2, 17.9% of the total area of the island. The Five-Finger Mountain is the highest with the altitude of 1867 m above sea level. The mountainous areas between 500—800 m altitudes amount to 2585.4 km^2, 7.6% of the total area of the island. The hilly land with an altitude of between 100 m and 500 m covers 4497.7 km^2, 13.3% of the total. The terrace covers 11052.4 km^2, 32.6% of the total, and the coastal plain covers 7878.7 km^2, 23.2% of the total.

The main soils of Hainan Island can be divided into 4 types based on their parent materials: (1) Laterite, which is developed from basalt, is characterized by high N and Mn but extremely low P and K. It is mainly distributed in the north and northeast parts of Hainan. (2) The soil developed from granite is characterized by moderate to slightly low N, low P, rich K and slightly low Mn. It is mainly distributed in the middle part of Hainan and roundabouts. This kind of soil is important for rubber growing. (3) The soil developed from metamorphic rock is characterized by low N, extremely low P, slightly low Mn, but relatively rich K. It is mainly distributed in the west and northwest parts of Hainan. (4) The soil derived from sandstone, shale, marine deposits and river alluvia is deficient in fertility. It is mainly distributed in river plains and coastal areas.

Hainan Island is rich in plant resources and biodiversities. Statistics show that there are more than 4680 species of wild vascular plants found in Hainan, which is 17.0% of the country total. They belong to 259 families and 347 genera. There are 600 species endemic in Hainan. There are 83% of plant species belonging to tropical and subtropical plants, and 91 species are listed as the second and third categories of national protected plants.

The total volume of water resource is large in Hainan Island, but it is difficult to be utilized. There are 154 rivers and streams in Hainan directly flowing into the sea, among which 38 rivers have a drainage area larger than 100 km^2 respectively. The rivers with a drainage area of larger than 3000 km^2 are Nandujiang River, Changhuajiang River and Wanquan River. The surface runoff is mainly in these 3 big rivers, which accounts for 53% of the average annual runoff in Hainan. The rainfall in Hainan Province is mainly monsoon and typhoon rain. The annual total rainfall is about 58.5 billion m^3. The available surface water resource is about 11.4 billion m^3/a. The average annual water volume flowing into the sea is 19.4 billion m^3. The total ground water volume of the island is about 7.9 billion m^3/a which about 1.1 billion m^3 is available. The radial rivers formed due to topography flow into the sea without tributaries. Availability of these rivers is low because they are short with high drops, and the rainfall period is concentrated. Besides, the ground water in Hainan are not stored and distributed evenly due to different rock characters, geologic structures and topographies. Water consumption is concentrated in the industrial areas of towns and cities. These lead to serious water shortage in some districts. As pointed out by the "Masterplan of the environment and natural resources in Hainan" compiled by the British Environmental Resources Company and supported by the Asia Development Bank, water resource and biodiversity are two of the most important problems in the development of Hainan. Water shortage will limit the development of all industries, but biodiversity will provide many opportunities for sustainable prosperity of Hainan in the future.

1.2 Methods of data collecting

The hydrological materials of the rubber plantation are 3-year data of positional observations at the Experimental Farm of CATAS(the Chinese Academy of Tropical Agricultural Sciences), Danzhou, Hainan by the Rubber Cultivation Research Institute(RCRI) in 1997—1999.

The data of water loss and soil erosion in the rubber plantation are data of positional observation made by the Rubber Cultivation Research Institute in 1994—1995.

The rainfall data of the island in 1951—1990 are from the Meteorological Bureau of Hainan Province.

The rubber plantation area and production data in the past years are supplied by the South Subtropical Crops Development Center of Agricultural Ministry.

2 Results

2.1 Hydrological dynamic characteristics of the rubber plantation

The rubber plantations are an artificial tropical plant community similar to the tropical monsoon forest. It is a most representative artificial stand in Hainan Island. Its composition, outer structure and growing environment are characteristic of tropical forest. Researches on the hydrological dynamic characteristics and process of this community will reveal the influence of the rubber plantation on the local water circulation in Hainan Island and its hydrological effect, which will help to exert the hydrological functions of the rubber plantation such as intercepting and storing of rainfall, increasing of soil permeability, regulating and storing of runoff, delaying of stream production and concourse process. The hydrological dynamic characteristics of the rubber plantation are illustrated with the rubber plantations at the Experimental Farm of CATAS as an example.

2.1.1 Monthly rainfall dynamics

Distribution of rainfall is distinctly seasonal. The weather in the rainy season(from May to October) is often influenced by secondary high system, which results in long duration of typhoon and convergence belt activities. The climate is controlled by tropical monsoon. Monsoon rain, typhoon rain, thunderstorm and topographic rain take place frequently, which forms the season of concentrated rainfall distribution. Fig.1 shows the monthly rainfall in the 3 hydrological years from 1997 to 1999. The rainfalls in the rainy season accounted for 73.9%, 87.1% and 72.5% of the corresponding hydrological years respectively, with an average of 77.8%. The maximum monthly rainfall was 436.5 mm in May 1999. There were 6 months with more than 300 mm rainfall each in the 3 years. Rainfall is little in the dry season (from November to April). The month with minimum rainfall is January each year, the average rainfall being 20.7 mm. Except for April close to the rainy season and November after the end of the rainy season, rainfall distribution in December to March is very little. Sometimes even there is no rainfall in a month, for instance, November 1997. Generally, the annual rainfall is abundant, which provides good natural environmental resource for the rubber plantation to exert its production function and ecologic functions.

2.1.2 Dynamic characteristics of precipitation interception by the tree canopy

The precipitation interception of the rubber tree canopy is seasonal. The water-holding capacity of the canopy is low. The interception rate is always lower especially in the rainy season due to the high influence of rainfall intensity than that in the dry season(although the rubber tree has 1 or 2 months defoliation in the dry season). The average annual interception rate of the rubber tree canopy is 11.45% of the rainfall. The average interception rate is 8.7% in the rainy season while is 14.1% in the dry season. In the wet season, the raindrop is big, and the rainfall intensity and penetration are strong when there are heavy rain and rainstorms. This, with high humidity of the canopy leads to large runoff, thus reducing the interception rate of the canopy. However, the precipitation interception in the dry season is just the opposite of that in the wet season.

2.1.3 The runoff dynamic characteristics of the trunk

The runoff of the rubber trunk is seasonal and influenced markedly by rainfall. In the rainy season, the average runoff of the trunk counts 8% of the rainfall in the rainy season; in the dry season, the average runoff of the trunk

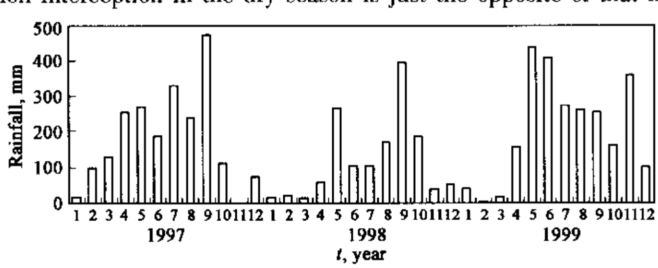

Fig.1 Monthly rainfall from 1997—1999

counts only 2.5% of the rainfall. The reasons are that the canopy, trunk and leaves are damp in the rainy season, which leads to larger runoff of the trunk; whereas the trunks, branches and leaves are relatively dry in the dry season, when there is some or little rainfall, the water falling on the tree is almost absorbed by the coarse thick bark, thus the runoff of the trunk is smaller.

2.1.4 Estimation of annual evaporation and transpiration of the rubber plantation

Many researchers at home and abroad have studied methods for estimating or determining the evaporation and transpiration. Up to now, there is still not a universal estimation method or model because evaporation and transpiration of the forest are affected by many factors. The methods suitable for estimating the evaporation and transpiration are: micrometeorological methods (such as the energy balance-ripple comparison method, the aerodynamic method, the Penman-Monteith equation method), hydrological methods (such as the water balance method, the zero flux plane method, the Lysimeter determining method), physiological methods (such as the heat pulse method, the tracer isotope method, the stoma method, the air-conditioning chamber method) and empirical formula methods (mainly some empirical formulas relating to meteorological factors). In this paper, the Turc empirical formula (Wang, 2000) is used for estimating the evaporation and transpiration of the rubber plantation in Hainan:

$$E = P/[0.9 + (P/E_0)^n]^{1/n}.$$

Where E is the annual evaporation and transpiration (mm/a), P is the annual rainfall (mm/a), $n = 2$ is a constant, E_0 is the maximum annual evaporation and transpiration potential under the condition of enough soil moisture: $E_0 = 300 + 25T + 0.05T^3$ (Ma, 1993), where T is the average annual temperature.

The annual total evaporation and transpiration of the rubber plantation in Hainan is calculated as 1275.14 mm when the 3-year average temperature (24.025℃) and rainfall (2016.5 mm) in 1997—1999 are used in the above formula.

2.1.5 Loss of water in latex tapping

The rubber tree is a latex-producing arbor that grows typically in the tropics. Latex production is its most important economic character. Therefore, water and nutrients circulation in the rubber plantation ecosystem is closely connected with latex tapping. Taping is a process of cutting the latex vessels and letting the latex flow out of the wound. Latex is important industrial raw material after coagulation and concentration. Dry rubber content in the latex is about 30%, and the other 70% is water. Thus, latex exploitation results in transfer of a large amount of water from the rubber plantation ecosystem into the water circulation in the drainage ecosystem.

In 1997—1999, the average rubber yield of the rubber plantation was 1.032 t/hm^2, which meant that an average of 2.408 t/hm^2 water was lost from the rubber plantation (equivalent to 0.24 mm rainfall). The loss of this small amount of water is found negligible in the water circulation or water balance in the rubber plantation, but this loss might have significant impact in the nutrient circulation.

2.1.6 Dynamics of soil moisture in the rubber plantation

The water dynamics in the rubber plantation can reflect the comprehensive effect of the interaction between the soil, plant and climate. There are a lot of researches at home and abroad on the seasonal dynamics of soil moisture. The general result is that the seasonal dynamics of the soil moisture are closely correlated with climatic factors, especially rainfall, and are periodic but vary in vegetation types and localities. Fig.2 shows the average monthly dynamics of moisture content in the soil of 0—40 cm deep in the rubber plantation over the 3 years from 1997—1999. It can be seen from the figure that the moisture content in the soil of the rubber plantation is above 12% for all the months except January-April, and there is little variation. It is believed the exceptions are mainly due to much direct sunlight and larger evaporation in the plantations during the period from January to March which is the defoliation period of the rubber tree, and to the fact that it is dry season from January to April when there is little water supplementing to the soil although the temperature is lower than other months and evaporation and transpiration of the stand are smaller. Therefore, the soil moisture content from January to April is lower than that in other months.

The soil moisture storage variation of the rubber plantation can only be estimated roughly using the following method due to the lack of enough observation data.

Firstly, the average of the soil moisture contents from January to April is used as basic number. Secondly, the average of the soil moisture contents from May to December is calculated. Lastly, the difference in soil moisture content between May-December and January-April is used as the storage variation value of soil moisture content, and the variation value of soil moisture storage is calculated. The average variation of the soil moisture storage in 1997—1999 was 32.4 mm.

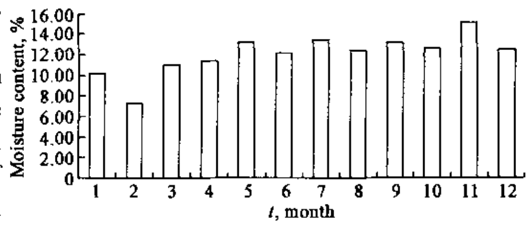

Fig.2 The average monthly dynamics content in the soil

2.1.7 Water balance in the rubber plantation

Table 1 shows the water balance in the rubber plantation ecosystem in 1997—1999. When the annual rainfall was 2016.50 mm, 11.4% of the rainfall was intercepted by the canopy of the plantation and 88.55% fell to the ground. Among the 88.55% of the rainfall, 26.78% ran off, 1.81% was conserved by the soil, 71.41% was lost due to evaporation. The result of 5-year observations of the tropical mountainous rain forest ecosystem in Hainan shows that when the average annual rainfall was 2668.3 mm, the canopy intercepted 14.3% of this rainfall and 85.7% fell to the ground(Chen, 1999). Among the 85.7% rainfall, 46.7% ran off (1.4% ran off from ground surface), 53.3% was lost through evaporation. It can be seen that there are some differences between the water balance in the rubber plantation and in the tropical mountainous rain forest. The interception rate by the canopy of the rubber plantation is lower than that of the mountainous rain forest. The evaporation and transpiration rate of the rubber plantation is higher than that of the mountainous rain forest. The difference is due to the fact that there is a thick cover of litters on the ground in the mountainous rain forest, which is multistory-structured with arbor, shrubs and grasses, whereas there are few litters on the ground in the rubber plantation, which is single-story-structured(even if some rubber plantations are strip-intercropped, they are still single-story-structured). Thus, the evaporation is larger in the rubber plantation. The runoff in the mountainous rain forest is obviously higher than that in the rubber plantation(this may be due to the difference resulted from different measuring methods). This is because that the rubber plantation land is gently sloped, which does not easily result in runoff, whereas the mountainous rain forest land is highly sloped, which easily results in ground surface runoff and underground runoff(Huang, 2000).

2.2 Effect of rubber growing on the regional rainfall

Table 1 Water balance in the rubber plantation ecosystem

Water	Balance, mm	Rainfall, %
Rainfall	2016.50	100.00
Rainfall incepted by the canopy	230.89	11.45
Rainfall falling to the plantation ground	1785.61	88.55
In which: Total runoff*	478.07	26.78
Soil moisture storage	32.40	1.81
Evaporation and transpiration	1275.14	71.41

* Total runoff contains ground surface runoff and underground runoff(the data in this table are results from estimation according to the rainfall intercepted by the canopy, the soil moisture storage and the evaporation and transpiration)

Large-scale rubber cultivation in Hainan Island began in the 1950s. Up to now, the rubber plantation area has extended to 370000 hm^2, which is 11.6% of the area of island. In order to find out whether the substitution of the natural vegetation (tropical rain forests, shrubs, herbs) with such large-scale rubber plantations has important effect on the local rainfall in Hainan, statistical analyses were made on the rainfall data of the 19 counties of Hainan during 1951—1990. The correlation coefficient between rubber area and annual rainfall is -0.11539, which shows negative relationship, but it does not reach the significant level($p < 0.05$).

Table 2 The average rainfall in Hainan Island during 1951—1990

Year	Rainfall, mm/a
1951—1960	1780.2
1961—1970	1635.0
1971—1980	1785.0
1981—1990	1600.0

Fig.3 shows the rainfall variation in Hainan Island during 1951—1990. The variation fluctuates irregularly. There is no obvious periodicity. Compared with the average annual rainfall, the variation is between -40%—50%, which shows that there is no obvious effect of large scale rubber growing on rainfall. This may be due to the fact that

80% rainfall in Hainan is brought by typhoon.

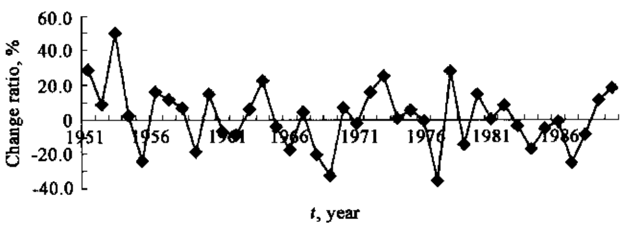

Fig.3 Annual change ratio of rainfall

Table 2 shows the average rainfall every 10-year during 1951—1990 in Hainan Island. It can be seen from the table that since 1951 when large scale rubber growing began in Hainan, there has been no regular increase or reduction of rainfall with continuous increase of rubber plantations in Hainan. On the contrary, the rainfall fluctuated periodically. The average rainfall in the 1950s was almost the same as that in the 1970s, which were 1780.2 mm and 1785.0 mm respectively. The average rainfall in the 1960s was very close to that in the 1980s, which were 1635.0 mm and 1600.0 mm respectively. There is a regular periodic variation every 10 years. It is believed the regular periodic fluctuation is not related with the large-scale rubber growing but to periodic variation of regional climate because forest area in Hainan is 1767232 hm^2 which covers 52.1% area of Hainan and the proportion of the 11.6% rubber plantation in the total forest coverage is relatively small and is not enough to influence the regional rainfall of Hainan Island. Moreover, the rubber plantation itself has the similar function of the tropical rain forest (Mo, 1983; Huang, 1988). Therefore, it can still exert the ecological function of the natural vegetation after it replaces the natural vegetation on large scales.

2.3 Soil and water conservation function of the rubber plantations in Hainan Island

Since early 1950s when large scale rubber growing began in Hainan Island, great attention has been paid to soil and water conservation. "Terracing" and "mulching" in the rubber plantations, some of the main measures, were included in the technical regulations and have been carried out strictly. The common terracing forms are:

Bench terracing: Bench terraced fields are built in the rubber growing areas where the rainfall intensity is relatively small or the soil permeability is relatively big, and in the hilly areas where the slope is less than 15℃. The terraced surface slopes slightly inwards with a width of 1.5—2.5 m.

Contoured terracing: Terraced fields around the mountain along the contour are built in the rubber growing areas with relatively high rainfall intensity, relatively small soil permeability or relatively steep slope and radiant temperature dropping in winter. The terraced fields slope inwards 12—15℃ with a width of 1.5—2.5m.

Furrow terracing: It is only suitable in the flat land where the slope is less than 3°.

The data in Table 3 show that the soil and water conservation effect of terraced rubber plantations is much better than that of non-terraced rubber plantations. It can be seen from Table 3 that the soil and water losses in the bench terraced fields, contour terraced fields and furrow-terraced fields of rubber plantations are only 1.8%, 5.85% and 28.64% of the control respectively; and the moisture contents in the soil 0—60 cm deep in the 3 terracing types of rubber plantations are 21.87%, 12.94% and 28.15% higher than that of the control. These show that the soil and water conservation function of the rubber plantation is greatly increased through "terracing". Table 4 reveals that the soil erosions in the various plants covered rubber plantations are much lower than that in the bare land(control), the minimum being only 9.7% of the control.

Table 3 The soil and water conservation effect of different terracing systems

Terracing type	Annual soil erosion, m^3/hm^2	Control, %	Moisture content in the soil of 0—40 cm deep, %	Control, %
Bench terracing	3.705	1.87	19.22	121.87
Contoured terracing	11.595	5.85	17.81	112.94
Furrow terracing	56.79	28.74	20.21	128.15
No terracing(control)	198.285	100.00	15.77	100.00

Note: The slope of the experiment fields is 4°—8°; the observation duration was 1 year(from September 1994 to September 1995)

Table 4 Soil and water conservation effect of different cover plants in the rubber plantation

	Eupatorium odoratum	Pueraria	Calopogonium mucunoides	Peanut + sweet potato	Bare land
Runoff, mm	313.9	160.8	145.9	193	371.4
Annual soil erosion, m^3/hm^2	18.00	5.13	2.955	5.76	30.6

According to the researches on shifting agriculture in Hainan(Chen, 1999), the annual soil erosions in semi-deciduous rain forests, the slash-and-burn land and the plundered wasteland were 0.06 m^3/hm^2, 32.08 m^3/hm^2 and 2.21 m^3/hm^2. Soil erosions in the slash-and-burn land are much higher than those in the bench terraced and contour terraced of the rubber plantations, and are also much higher than those in the rubber plantations with various cover plants, but are lower than those in furrow terraced rubber plantations. However, the soil erosions in rubber plantations with both terracing and cover plants are higher than those in the semi-deciduous rain forests, which may lead to the that the production activities of human beings result in soil and water loss and cause damage to the natural ecological environments(Wu, 1982).

However, since 1950s, there have been several serious destructions to the ecological environments in Hainan Island. The "Great Leap" in 1958, the "Great Culture Revolution" in 1966—1976 and the rural responsibility system in 1979 are some examples. If there were no large-scale rubber cultivation in Hainan Island, most of the land now planted with rubber trees would have become agriculture land or wasteland. It can be deducted from this that the soil and water conservation function of the rubber plantation is still very strong after proper measures(such as terracing and covering) are taken.

2.4 Effect of the hydrological eco-service of the rubber plantation on the local economic development in Hainan Island

2.4.1 The contribution rate of the water resource to the economic development in Hainan Island

The total water resource means the total ground surface water and underground water from local rainfall, excluding the water exchanging between the ground surface and the underground water. The total water resource in Hainan Island in 1997 was 40.97 billion m^3 (the recalculated 6.937 billion m^3 of river flow water is excluded).

Statistics show that the total water supply in Hainan Island in 1997 was 4.2377 billion m^3, among which 3.8641 billion m^3 was from ground surface water resource accounting for 91.2% of the total water supply; 373.6 million m^3 was from underground water accounting for 8.8%. Among the ground surface water supply, 73.3% was from reservoir projects, 18.7% was from water introducing projects, and 8% was from water pumping projects. Among the underground water supply, 50.6% was from shallow ground, 49.4% was from deep ground.

The total water consumption in the island in 1997 was 4.0741 billion m^3, among which agricultural water consumption was 3.2205 billion m^3 accounting for 79% of the total water consumption, water consumption in irrigated rice fields was 2.4367 billion m^3 accounting for 59.8% of the total water consumption, industrial water consumption was 337 million m^3 accounting for 8.3% of the total, industrial water consumption in cities and towns was 279.8 million m^3 accounting for 6.9%, water consumption in human living was 516.6 million m^3 accounting for 12.7% of the total, living water consumption in cities and towns was 302 million m^3 accounting for 7.4% of the total. If water consumption is divided into urban and rural part, rural water consumption was 3.4953 billion m^3 accounting for 85.7% of the total; urban water consumption was 581.8 million m^3 accounting for 14.3% of the total. Agriculture and countryside were the main water consumers.

The total GDP of Hainan Province in 1997 was 40.986 billion RMB Yuan, among which 15.128 billion RMB Yuan was from the first industry, 8.268 billion RMB Yuan was from the second industry, 17.59 billion RMB Yuan was from the third industry. According to the calculation of the total water resource of the island in 1997, the economic benefit brought about by the water resource was 1.0 RMB Yuan/m^3; according to calculation of the total water supply in the island in 1997, the economic benefit brought about by the water resource was 9.67 RMB Yuan/m^3; according to calculation of the actual water consumption in the island in 1997, the economic benefit brought about by the water resource was 10.06

RMB Yuan/m^3.

2.4.2 The effect of the hydrological eco-service of the rubber plantation on the local economic development

According to comparison of the water balance results in the rubber plantation in Table 1 with the hydrological function of the tropical rain forest, the total runoff(including soil moisture storage) in the rubber plantation was 18.11% less than that in the tropical rain forest, and the evaporation and transpiration in the rubber plantation was 18.11% more than that in the tropical rain forest, i.e. the annual ground surface water and underground water in the per-unit-area rubber plantation flowing out of the rubber plantation into the catchments as a total water resource was 18.11% less than that in the tropical rain forest. This shows that the hydrological eco-service function of the rubber plantation becomes weaker than that of the tropical rain forest. Loss of water in the rubber plantation was 3078.8 $m^3/(hm^2 \cdot a)$ more than that of the tropical rain forest when calculated at the average rainfall of 1700.05 mm in Hainan Island in the past 50 years. When calculated at the rubber plantation area of 370000 hm^2 in Hainan, the annual water resource lost due to rubber growing was 113.9 million m^3 (compared with the tropical rain forest), i.e. when converted at 1.0 RMB Yuan/m^3, the value of the hydrological eco-service of the rubber plantation in Hainan was equivalent to 113.9 million RMB Yuan/a compared with the tropical rain forest.

However, this problem also has two sides. Firstly, although the hydrological eco-service function of the rubber plantation is weaker when compared with the tropical rain forest, the social function of the rubber plantation is stronger than that of the tropical rain forest. Natural rubber industry has made enormous contribution to the national economic construction and national defense, and provided 2 million people with employments, and contributed to the social development and prosperity in the ethnic areas (Jiang, 1999; Yu, 1999). Therefore, it can reach that these embody the social functions(or part of them) converted from the eco-service functions of the rubber plantation, i.e. the strengthening of the social functions was achieved through the transferring of the eco-service functions of the rubber plantation.

Secondly, from the view of development of the human society, the process of development is the process of continuous reconstruction of the natural ecosystem. If there were not the reconstruction of the natural ecosystem, there would not have been the progress and development of the human society. On the contrary, if rubber trees had not been grown in Hainan Island, the natural vegetation would have been substituted by other artificial ecosystems (such as eucalyptus plantations, slash and burn land, rice fields and orchards) due to the continuous increase of population. According to the investigations in Xishuangbanna of Yunnan Province(Wang, 1984), the eco-service functions of these artificial ecosystems are much weaker than those of the rubber plantation. Thus, it can infer that the rubber plantation has protected the local environment to some extend.

At last, it seems reach conclusion that the hydrological eco-service of the rubber plantation has been enhanced after transformed from natural vegetation, which includes natural service and powerful social service.

3 Conclusion and discussion

The research on the hydrological dynamics and water balance of the forest ecosystem is a very complex process. The 3-year observation data and 40-year climate data were used for the analysis of the hydrological dynamic characteristics of the rubber plantation and estimation of the water balance in the rubber plantation. The results showed that the rainfall intercepted by the canopy accounts for 11.45% of the annual rainfall and that the rainfall falling to the plantation ground accounts for 88.55%(among which the total runoff accounts for 26.78%, the total evaporation and transpiration for 71.41%, the soil moisture storage for 1.81%).

The analyses of the rainfall data in the 19 counties of Hainan Island in the 40 years from 1951 to 1990 show that the large-scale substitution of the natural vegetation with the rubber plantation has no significant effect on the local rainfall in Hainan Island. The main reasons are (1) 80% of the rainfall in Hainan is brought by typhoon; (2) the proportion of 11.6% rubber plantation in the total forest coverage in Hainan is not enough to influence the local rainfall in Hainan Island; (3) although the rubber plantation is artificial vegetation, it has the ecological function similar to that of the tropical rain forest.

The analyses of the soil and water conservation effect of various terracing types and various cover plants in the rubber plantation and the comparison with the results of investigations on shifting agriculture show that soil erosions in the rubber plantation are much higher than those in the primitive tropical semi-deciduous monsoon forest, but much lower than those in the slash-and-burn land. Thus, it can be deducted that human activities will necessarily cause damage to the environment, but the damage or adverse impact may be minimized if proper measures are taken.

The analyses of the total water resource and the total GDP of Hainan Island in 1997 showed that the economic benefit brought about by water resource in Hainan Island was 1.0 RMB Yuan/m^3. The value of the hydrological eco-service of the rubber plantation in Hainan was 113.9 million RMB Yuan/a when compared with that of the tropical rain forest. This embodies the social functions (or part of them) converted from the eco-service of the rubber plantation, i.e. the strengthening of the social functions of the natural rubber industry was achieved through the transferring of its eco-service functions. However, the methods for accurate estimation are still to be further studied in the future.

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