Optimization of Land Use Structure Based on Ecological GREEN Equivalent

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ABSTRACT   Optimization of land use structure consists of economic and social ar d ecological optimization. Applying the minds of system engineering and principles of ecology, this paper presents such thoughts: the optimal forest-coverage rate calculated according to the reality of a district is set as main standard of ecological rationality in the district; through considering the value of ecosystem services of the land with GREEN equivalent (mainly cultivated land and grassland) and based on the rule, GREEN equivalent, this paper introduces the area conversion between woodland and cultivated land, also between woodland and grassland; this paper establishes a multi-dimension controlling model of optimization of land use structure. In addition, a multi-objective linear programming model for optimization of land use structure is designed. In the end, this paper tests and verifies this theory of ecological optimization, taking Qionghai city in Hainan Province as an example.

1 Introduction

The general goal of land use is to get continuously increasing and integrative benefits with social, economic and ecological features. Land use planning must be carried out according to the demands of social and economic development and, environment protection to realize the optimal allocation of land resources. Optimization of land use structure means to find the best land use structure (components and proportions of all kinds of land uses) which can bring better or best social, economic and ecological benefits by some methods[1]. Therefore when we deal with land use decision-making, we should make overall plan and take all factors into consideration and harmonize the correlations of all kinds of land use in the light of developmental planning of regional economy and society. Only in this way, sustainable land use and regional development can be guaranteed.

In recent years, with the rapid growth of the economy and the population, and the continuous development of industrialization and urbanization, the problem in land use in China is getting more and more rigorous. Especially as a populous country with relatively short of land resources, China must pay great attention to rationality of land use. Therefore optimization and adjustment of land use structure is the key point to enhance land use management, as well as the hot point for the research of land use.

Now in researches on rationality of land use structure, the methods of system engineering to discuss the economic output of the land use are mostly adopted, but not attach enough importance to ecological benefit and reasonable way to practise it. In the performance of the integrate system of society-economy - ecosystem , we must realize its complex characteristics . It

is necessary to figure out the standard of ecological performance and to set down a specific way for measuring it.

2 "GREEN equivalent" and the ecological standard of optimization of land use structure

2.1 About "GREEN equivalent"

The concept of "GREEN equivalent" is introduced to the quantitative research of ecological standard. As the pillar of the earth ecosystem, forest plays an important role, viz. keeping water and soil, improving climate, maintaining landscape and purifying the pollution, and so forth, i. e. ecological performance of forest. But nowadays, it is inevitable to destroy the forest ecosystem on account of exploitation and construction. At the beginning some scholars brought forward that compensation for the ecological function of destroyed forest should be executed. It was necessary to compare the equivalent of ecological function to set down the compensating ways. Thus the concept of "GREEN equivalent" was produced.

"GREEN amount" is the equivalent of ecological function as forest, and its main body can be other plants. In brief, "GREEN amount" is the value that measures the intensity of ecosystem services of forest and other plants in a unit area. "GREEN equivalent (related to GREEN amount)" stands for: the GREEN amount that can guarantee coequal photo-synthesis and befitting layout which can commute the ecological function of quantitative forest[2], and its essence is a ratio of "GREEN amount" between one land use type and forest.

2.2 Ecological function of all kinds of ecosystem

From the points of view of the botany and ecology, all kinds of plants take on ecological function as forest. According to the principles of "GREEN equivalent", land use types can be classified as follows:

1) The land use having GREEN equivalent includes cultivated land, garden plot, woodland,

grassland and part of unused land. The value of ecosystem services can be assessed, for their mechanism is similar to the forest's.

2) The land use with implicit GREEN equivalent primarily contains the water area. Water area takes on ecological function, such as being landscape, regulating the constitution of atmosphere, decontaminating air pollution, etc. But this function is difficult to be analyzed qualitatively.

3) The land use without GREEN equivalent includes residence, industrial land or mining area, traffic land and part of unused land. The value of ecosystem services is regarded as zero.

Now there are many methods of assessing the ecological function of forest, for example, the substitute method of engineering, integral method of expenditure and benefit, and cost method of forestation, and so on[3]. Because of the countability of this value, there is a possibility to do a quantitative research on GREEN equivalent of other plants.

2.3 Ecological standard of optimization of land use structure

The U N set the forest-coverage rate of 20 percent as the average minimum standard. But in different areas, due to the difference of terrain, relief, precipitation and sluice ability of soil, the most suitable forest-coverage rate is not the same. In our country, the research on the lowest forest-coverage rate was paid attention to until the 1980's. In 1995, Zhangjian presented the thoughts that the optimal forest-coverage rate should be calculated according to the reality of a district starting off with the attribute of forest. On the basis of the data from the region of low mountains and hills in Sichuan Basin, they applied certain method to elicit that the optimal forest-coverage rate for districts of middle-low mountains, low mountains, hills, hillocks, and plains should reach 57%, 46%, 44%, 31% and 13%[4]. The case verified that their methods are rational and doable.

Zhangjian's method(ways and means of calculating the optimal forest-coverage rate according to the amount of precipitation, the sluice ability and moisture content of soil in this district) is used for reference here. Limited by the length of the paper,

its concrete principles and calculating formulae are omitted (please consult it in Reference [4]). The calculated result is set as main standard of ecological rationality of the district.

Of course, it is not all-around that the ecological rationality of land use structure is measured only by the optimal forest-coverage rate. But in a sense, the forest-coverage rate may reflect the ecological condition of a district, such as the virescence level, amount of soil and water loss, quality of atmosphere, and so on. Furthermore, in order to simplify the problem, the optimal forest-coverage rate is only set as an advised index.

In reality, the average forest-coverage rate of our country is only 11. 5%[5], even in some area it is less than 11. 5%. So it is necessary to adopt means to increase the forest-coverage rate. In addition, the value of ecosystem services can not be removed or saved and benefits only by indigene and the contemporary. But any one at any time and in any district has the rights and interests of ecological consumption. Thus the value of ecosystem services of other land should be developed fully to meet people's need of GREEN consumption. So the forest-coverage rate is based on GREEN equivalent here. It can be stated as Eq. (1):

$$r = (S_f + S_{c\&g})/S_t \qquad (1)$$

where r represents the forest-coverage rate based on GREEN equivalent; S_f denotes the area of forest of the district; $S_{c\&g}$ denotes the area of forest converted from cultivated land and grassland in light of the rule of GREEN equivalent.

The so-called "conversion" means calculating the area of cultivated land or grassland that takes on the same ecological function as forest in a certain area. Therefore, the key of this research is to seek the conversion between woodland and cultivated land, also between woodland and grassland, sequentially to assess their value of ecosystem services. This is actually the innovation of this research combined with ecology.

3　Assessing method of GREEN equivalent of cultivated land and grassland

3.1　Principles and feasibility of assessment

In recent years, the environment is worse and worse. Man has attached much importance to ecological research. Scientists have gained some fruits in research of accounting the value of ecosystem services of forest and can convert this value to cash currency. From the points of view of biology and ecology and using the foregone results of researches on forest ecosystem services for reference, this research will assess the value of ecosystem services of other land with GREEN equivalent (mainly cultivated land and grassland).

Because of the composition and machanism of ecosystem services action of crops and grass are similar to that of woods, this method for assessing is reasonable and doable.

3.2　Assessing method of GREEN equivalent of cultivated land and grassland

3. 2. 1　Total score of ecosystem services of forest, cultivated land and grassland

1) Choosing and marking the index

Index system of ecosystem services is a complex soft system, and the index must be typical, representative and systemic. It is comprehensive to consider the aspects of atmosphere, water, space, soil, and biont in choosing the index of ecosystem services[6].

The ecological functions of different ecosystems are not the same. Japanese experts compared them according to a survey result. Their conclusion is made based on the research in the same area, it is forest that takes on the strongest ecological function, and afterwards is natural meadow, paddy field, grassland, garden plot and common glebe[2]. The detail data is listed in Table 1.

2) Calculating the total score of ecosystem services of forest, cultivated land and grassland

Because the weight of all kinds of ecological

Table 1 Score of ecological function of different ecosystems

	Function	Woodland	Paddy field	Common glebe	Natural meadow	Grassland
Atmosphere	Improving the composition of atmosphere	9.54	6.15	5.80	6.04	6.44
	Purifying atmosphere	9.05	6.30	5.80	5.28	5.33
	Moderating climate	9.37	6.20	5.40	5.23	4.90
	Preventing noise	9.10	4.10	4.00	4.13	3.70
Water	Warding flood off	9.67	7.80	5.80	7.18	6.30
	Keeping water	9.74	7.40	5.30	6.85	6.20
	Purifying water	9.05	7.30	6.70	8.15	6.43
	Preventing sands and soil from cracking	9.27	8.13	5.40	7.73	7.18
Soil	Preventing the earth surface from being eroded	9.31	8.75	5.30	8.38	7.73
	Preventing the earth surface from sinking	6.76	8.05	5.25	6.78	6.20
	Purifying contamination	8.27	8.00	8.10	7.28	7.40
Space	Averting calamity	9.24	7.90	7.30	7.50	7.60
	Providing refuge	8.77	7.00	9.50	9.25	6.75
	Maintaining landscape	9.22	7.40	7.00	9.45	7.93
	Maintaining space for amusement	8.88	3.73	4.70	9.45	8.70
Biont	Protecting biofacies	8.92	4.90	4.60	6.63	5.10
	Averting baneful creatures and plants	6.30	6.00	6.00	5.68	6.18

Note:①This table was made according to the result of agricultural environment evaluation by Japanese survey team. ②The values in the table are relative because the weight of all kinds of ecological functions have been penetrated through marking. ③This table is based on the assumption that all kinds of plants are in the average growing state and grow the whole year in the same area. ④The meanings of these values are: 10 means that the ecological function is huge; 7.5-big; 5-lesser; 2.5-tiny; 0-noneffective.

Table 2 Average GREEN equivalent of cultivated land and grassland

Region	Northeast and northwest of China	North of China		Southeast and southwest of China	
Frequency of ripening	Once a year	Twice a year	Thrice two year	Twice a year	Thrice a year
Parameter of growth period relative to the period of one year	0.46	0.67	0.50	0.67	0.83
Average GREEN equivalent of paddy field (radix = 0.77)	0.35	0.50	0.38	0.50	0.62
Average GREEN equivalent of glebe (radix = 0.68)	0.29	0.42	0.32	0.42	0.52
Average GREEN equivalent of natural meadow(radix = 0.76)	0.35	0.51	0.38	0.51	0.63
Average GREEN equivalent of grassland (radix = 0.73)	0.34	0.49	0.37	0.49	0.61

Note:①The parameter of growth period relative to the period of one year = length of growth period (month) / 12 (month). ②The frequency of ripening and length of growth period are made in light of experts' advice.

functions have been penetrated through the marks in Table 1, the total score of each kind of land is the sum of these marks and can be expressed in Eq. (2).

$$P = \sum_{i=1}^{17} F_i \qquad (2)$$

where P is the total score of ecosystem services; F is the mark of each index; i is the number of index.

From those values, the total score of ecosystem services of forest, cultivated land and grassland in the same area can be calculated, which are 150.46, 115.11, 101.95, 114.16 and 110.07 respectively.

3.2.2 Calculating the average GREEN equivalent of cultivated land and grassland

On the basis of the precondition of growing all year and according to the calculating result of GREEN equivalent of ecosystem services, if the GREEN equivalent of woodland is set as 1, then those of paddy field, common glebe, natural meadow and grassland are 0.77, 0.68, 0.76 and 0.73,

respectively. But the climate is discrepant in different regions, so the GREEN equivalent of the plants in different districts is different, either is those of plants in the same district and at different time. Taking the difference of length of growth period and the frequency of ripening into account, it is sound to multiply the above result of the GREEN e-quivalent by the parameter of growth period relative to the period of one year, so that the average GREEN equivalent of cultivated land and grassland can be numerated.

4 A multi-dimensional controlling mode of optimization of land use structure based on ecological standard

From the point of view of sustainable development, the optimization of land use structure is multi-dimensional. On one hand, it is both temporal and spatial. On the other hand, it is both in quantity and in quality. These aspects can be recapitulated as follows.

4.1 Optimization of land use structure based on different spatial administrative levels

Optimization of land use structure based on different spatial administrative levels can be expressed by Fig. 1.
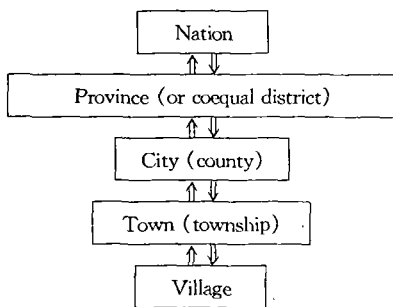

Fig. 1 Bilateral optimizing process of land use structure based on different spatial administrative levels

This is a bilateral optimizing process because it consists of not only decomposing and setting down of index but also gathering and feedback of performance. Traditional optimization of land use structure usually adopts the former, and how to combine the latter with the former is being studied, so it is a

key problem to seek the balance between them.

4.2 Optimization of land use structure at different time

Some factors that influence land use are variational with the lapse of time, and they are unknown in advance. So the control of variable should be altered while optimizing the land use structure. It can be comprehended that in different time slot T_1 and T_2, the aggregation of influential factors changes ($K_1 \rightarrow K_2$), and the aggregation of index also changes ($B_1 \rightarrow B_2$), sequentially the land use structure should be adjusted accordingly ($G_1 \rightarrow G_2$) that is shown in the sketch map (Fig. 2) below.
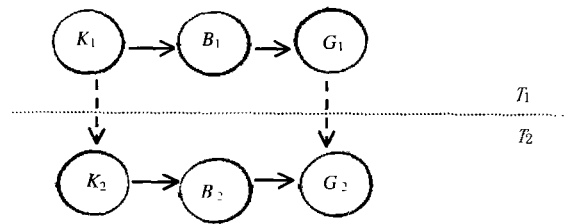

Fig. 2 Optimization of land use structure at different time

4.3 A model of optimization of land use structure based on the standard of GREEN equivalent and optimal forest-coverage rate

Ecological optimization is mainly taken into account in this model frame (Fig. 3).

In this frame, the steps of ecological optimization are described as follows.

The mathematic model of ecological optimization of land use structure is assumed to be established in a region. Supposing S_t is the total area of the district; r_{opt} is the optimal forest-coverage rate; S_f is the area of forest calculated in accordance with r_{opt}; s_f is the real area of forest; s_i is the area of land use type whose number of land use type is i (i is an integer, $i \in [1, 4]$), then the model can be expressed as follows:

1) $S_f = S_t \times r_{opt}, \bar{x} = 1$

where $\bar{x}$ is the GREEN equivalent related with S_f.

2) $x_f = \dfrac{s_f}{S_f} \times 100\%$

where x_f represents the actual GREEN equivalent of forest of the region.

Here, x is the GREEN equivalent of the region,

and it is the sum of all the land with GREEN equivalent.

3) $x \geqslant \bar{x}$

The meaning of this formula is to compare x with $\bar{x}$. If $x \geqslant \bar{x}$, the land use structure of the district comes up to the ecological standard. If $x < \bar{x}$, the land use structure should be adjusted, and the steps
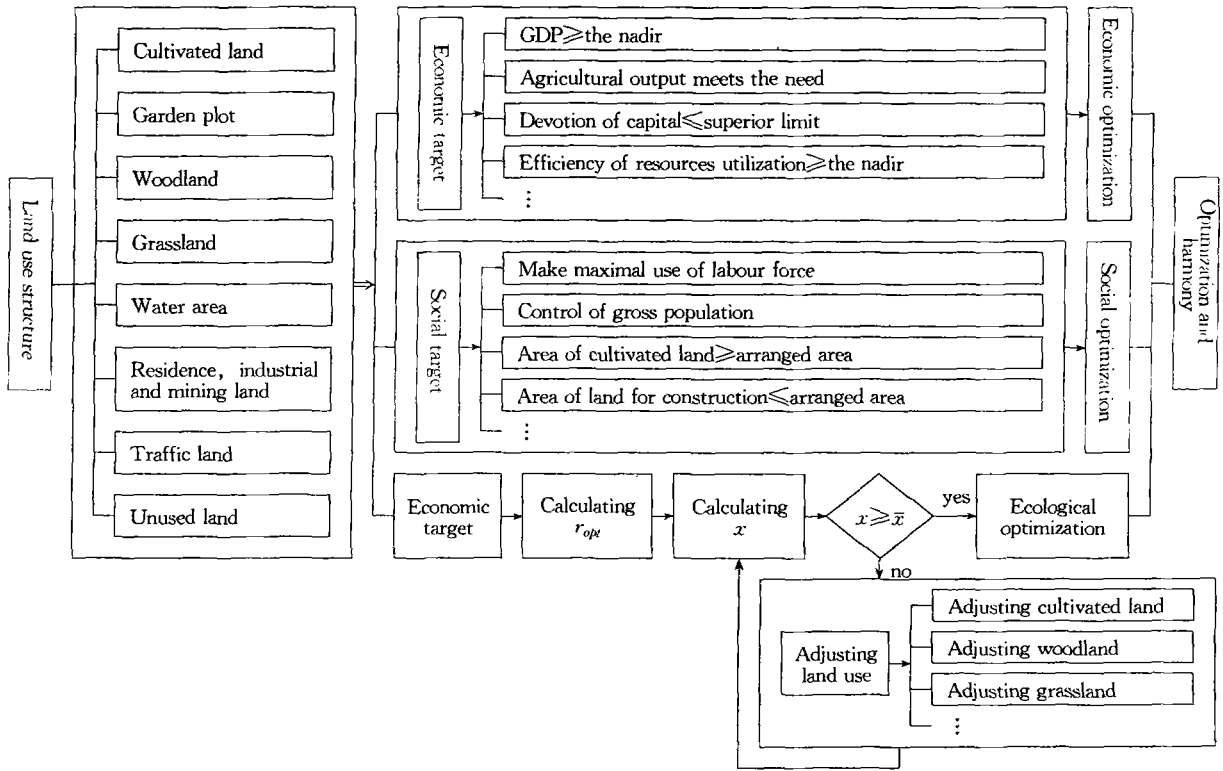

Fig. 3 Systemic frame of optimization of land use structure based on the fixed ecological standard[7-9]

from 1) to 4) should be redone until $x \geqslant \bar{x}$.

4.4 Multi-objective linear programming model for optimization of land use structure

It has been proved in practice that linear programming is a valid method for optimization of land use structure. Considering the optimization and uni-

fication of the three profit, this paper designs a multi-objective linear programming model(Fig. 4).

This model will put stress on maximization of e-clolgical benefit based on GREEN equivalent,as an unified scale. While without it, this model only pays attention to maximization of economic benefit in normal cases.
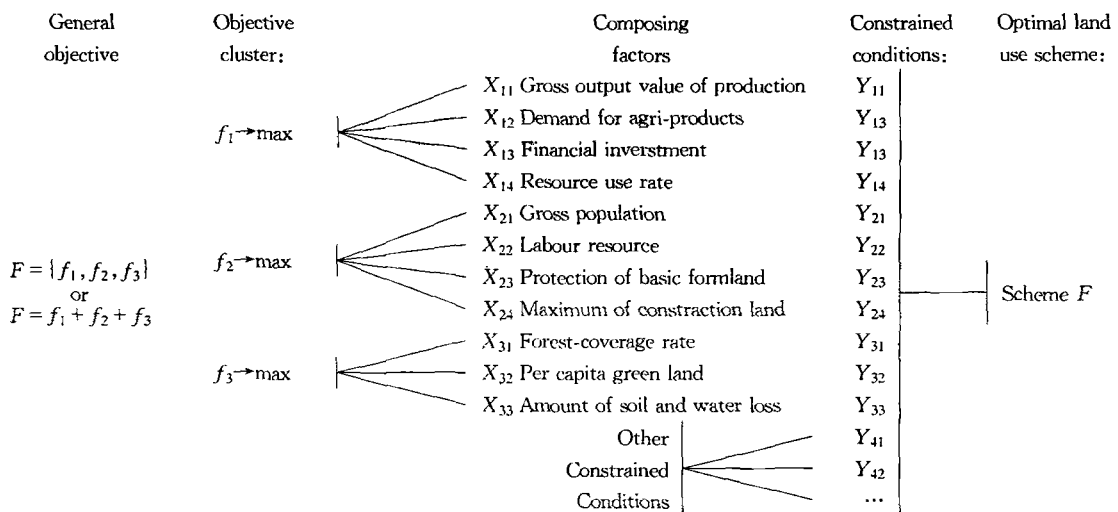

Fig. 4 Multi-objective linear programming molde for optimization of land use structure

It is necessary to explain that "other constrained conditions" are composed of the sum area of land, the land suitability evaluation and non-negative constrain, etc.

5 An application example of ecological optimization based on GREEN equivalent

Ecological optimization is the emphases of this paper, so only that of the above model is validated through example. Qionghai city in Hainan Province is chosen as the case of this experiment. The towns of Qionghai city are regarded as samples of the experiment and the actual data of land use are set as sample data. In order to illuminate the thought and method of ecological optimization clearly, exceptional samples (viz. farms, forestry centers, backwoods in the west of Qionghai city, and the three towns where the downtown lies) are eliminated, and Chaoyang town, in which the forest-coverage rate is the lowest among the surplus towns, is appointed as the idiographic object of the experiment. The process is described as follows.

1) General situation of Chaoyang town: Chaoyang town lies beside the lower reaches of Wanquan River and is close to South China Sea. The water resources of Chaoyang town are in abundance and the forest-coverage rate was 17.01% (including the part of garden plot of ligneous plants) according to the survey result in 1996. Actual data of land use of Chaoyang town are also taken from the survey result, listed in Table 3. Limited by the serviceability of the data, only the area of agricultural land is listed here.

Table 3   Actual data of land use of Chaoyang town (1996)

Land type	Cultivated land	Gardon plot	Woodland	Grassland	Total area	Note
Area/ha	899.47	37.78	471.34	0	2913.66	Cultivated land includes: Paddy field: 666.76 ha;
Percentage to total area/(%)	30.89	1.30	16.17	0	100	Glebe: 232.71 ha.

2) By using the correlative data about soil and precipitation provided by the agriculture bureau and adopting Zhangjian's method of calculating the optimal forest-coverage rate of a district, r_{min} of Chaoyang town is calculated to be 36.78%[4]. But Chaoyang town is close to the sea and the requirement of protective belt is large, the calculated result should be corrected by multiplying parameter $1.05(= 1 + x'$, where x' is the GREEN equivalent of protective belt commanded by the country). Ultimately the optimal forest-coverage rate of Chaoyang town is confirmed, $r_{opt} = 36.82\%$.

3) Calculating the GREEN equivalent of Chaoyang town $x = 0.92$.

4) $x < \bar{x}$. So it is required to adjust the land use.

5) In light of the strategy for development and the actuality of Chaoyang town, the area of grassland remains no changing, and only the woodland and cultivated land can be adjusted, the adjusting plan includes: ① increasing woodland for ecological commonweal by 129.5 ha to keep soil and water and to maintain ecological balance; increasing land of ligneous plants by 14.29 ha to provide wood, fruits and industrial raw material; decreasing woodland by 13.09 ha due to construction. In fact, woodland will increase by 130.70 ha. ② Area index of agricultural land in 2010 will be 901.72 ha. During this period, the decreased area will be 11.40 ha because of construction and destruction by disaster (6.67 ha glebe and 4.73 ha paddy field), and the increased area (mainly glebe) is 14.9 ha owing to exploitation and the reclamation. In fact, the cultivated land will only increase by 2.25 ha.

6) Calculating the GREEN equivalent again that $x = 1.03$.

7) $x > \bar{x}$. The land use structure comes up to ecological standard.

Verified by the experiment, this model of ecological optimization can control the ecology of a region effectively. While the process can be executed by computer programming and is very simple to be put into practice.

6 Conclusion

1) This research demonstrates the concept of "GREEN equivalent" applied to ecological optimization of land use structure first and brings forward the thoughts that ecological standards of different regions are not the same. It is of significance on the condition that the land use structure is unreasonable and forest-coverage rate is low in our country.

2) This research gives some modification to the model based on economic output by applying GREEN equivalent. And it can be applied to improve the rationality and accuracy of land use structure optimization.

3) The model based on GREEN equivalent can be used to establish an ecological warning system in order to improve land use management.

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