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Ecological models for rehabilitation of degraded hilly lands in Southern China

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Abstract

Rapid population growth and the intensification of agriculture and industry have exacerbated the widespread problems of deforestation and soil degradation in Heshan City, Guangdong since 1958. The destruction of natural ecosystems and the increasing area of degraded ecosystems are the key factors limiting the development of sustainable agriculture. To effectively use the resources of the ecosystem, the forest-fruit-grass-fish agroforestry ecosystem was set up based on the principle of ecology and geographic conditions in Heshan in 1984. The ecosystem is composed of four major subsystems in a watershed: the forest on the top, the orchard in the middle, the grass on the foot, and the fishpond at the bottom. The ecological effects such as soil nutrient cycle, soil microbes, and soil enzymes activity have developed toward beneficial circulation ever since the beginning. The nutrient cycling in the agroforestry was in good balance, while the productivity and the solar energy utilization efficiency are higher than those of other agricultural models. The forest-fruit-grass-fish complex ecosystem stemmed from the practice of restoration and reconstruction of degraded ecosystems is an agroforestry model with high yield, high quality and high efficiency in hilly areas, and an efficient approach to enhance the development of local agricultural economy.

Key words: Agroforestry, ecosystem, degraded hilly land, rehabilitation

Introduction

Rapid population growth and the intensification of agriculture and industry have exacerbated the widespread problems of deforestation, soil degradation, change in climate and the decrease of biodiversity in South China since 1958. Up to now, the degraded hilly land covers an area of approximately 47 million hectares in South China, which is about 70% of the total land area in the region. The area of degraded ecosystems is so great that it may shake the basis of sustainable development of the region (Parham, 1993; Yu et al., 1995).

Although there are four beneficial natural conditions such as the good climate, the potential land resources for agriculture, rich water resources and abundant biological resources in South China, however, there exist several serious limiting factors such as undeveloped technology, water loss, soil erosion, seasonal drought and soil fertility deterioration (Gong, 1992; Ren and Peng, 2000). In order to make better use of the degraded hilly land, it is necessary, following the principle and method of ecology to establish some artificial agroforestry ecosystem models (Fonzen and Oberholzer,1984; Boehnert,1988; Nair,1989; Baumer, 1990; Kerkhof, 1990). The project aimed to establish optimum models for land use and management and to choose suitable species for land rehabilitation and sustainable development in South China.

Methods

Site description

The experimental plot is situated in Heshan Hilly Land Comprehensive Experimental Station of the Chinese Academy of Sciences, Heshan City, Guangdong Provinces, South China, 112°55'E and 22°40'N (Fig 1). Heshan city is an agricultural region of dense population and insufficiency of fuel, fodder and fertilizer. There are 7.5×10^4 ha degraded hilly lands, which is about 55% of the total land area in the city. The hills are found in the 30-300 m altitude range.

It is warm, rainy and without snow in the area. The mean annual temperature is 21.7!.The mean monthly temperature in the warmest month is 29.2! and in the coldest month, 12.6!. The mean annual hours of sunshine are 1797.8 h. The mean annual solar radiation is 4355 MJ/(m^2 a). The total quantity of rain ranges from 1400-2000 mm, with an average 1700mm. There is distinct alternation of humid and dry seasons. The annual evaporation is 1679mm.

The soil is reddish red earth and is intermediate between laterite and red earth. Two subtypes of soil, reddish red earth derived from sandy shale on the slope and sandy earth on the ravine, are distinguished. The depth of organic matter of soil on the slope is not similar in different elevation, direction and declamation of the slope; it is thicker in shady

Fig 1 Study site

Map showing the location of Guangdong province (left). Picture (right) shows the station & experimental site

Tab 1 Chemical elements of soil in the experimental plot.

Vegetation	Depth (cm)	pH	Organic matter (%)	Total N (%)	Total P (%)	Available P (mg/kg)	Available K (mg/kg)
Secondary forest	1-3	4.4	2.48	0.122	0.038	Trace	6.4
	5-12	4.5	1.62	0.078	0.030	Trace	4.2
	15-30	4.7	1.16	0.048	0.028	Trace	2.8
	35-60	4.8	1.17	0.047	0.026	Trace	2.6
	70-100	5.0	0.78	0.034	0.031	Trace	2.6
Hilly land	5-15	4.5	1.64	0.066	0.016	0	4.4
	22-28	4.6	1.01	0.038	0.018	0	2.8
	35-50	4.8	0.64	0.035	0.020	Trace	3.1
	80-	5.0	0.56	0.028	0.022	Trace	1.5

slope and lower slope. The soils severely degrade with human disturbance, only containing organic matter 0.56-1.64% in 0-70 cm depth. The soils have a very low capacity to retain moisture and nutrients (Tab 1) (Yu, 1990). The total amount of soil microbe is only 2 million/g dry soil, bacteria accounts for 71%, fungi accounts for 9%, and actinomycetes accounts for 20% In addition; they are prone to serious erosion hazards if not managed carefully.

The climax vegetation in the region was lower subtropical monsoon evergreen broad-leaved forest in history. Due to human disturbance, the vegetation has reverted to grassland with sparse pine, over a large area. The common species on upper slopes are *Baeckea frutescens* and *Eriachne pallescens* and on lower slopes, *Rhodomyrtus tomentosa* and *Dicranopteris linearis*. Soil erosion often occurred in the upper hill slopes. The agroforestry practices that are commonly found in the area are the use of shrubs for live fences around farmlands, pasture in forest area and the use of strips of multipurpose trees and shrubs around sloping fields.

The area is densely populated, with more than 360 persons/km^2 and an annual population growth rate of more than 0.125%. Seventy-five percent of the people have to make their livelihood from agriculture and related activities.

Study methods

The data presented here are based on the case study conducted by the staff in Heshan Hillyland Comprehensive Experimental Station (Yu & Peng, 1996).

In 1983, a permanent plot (10000m^2) was established and was annually chosen for the census of trees. The scientific names of tree species, height, diameter at breast height (DBH, only for tree), and growth status (live or dead) of each individual quadrate were recorded in every investigation.

The biomass and productivity of vegetation was estimated using standard methods. Trees and lianas of the same species and range of size classes as in the study

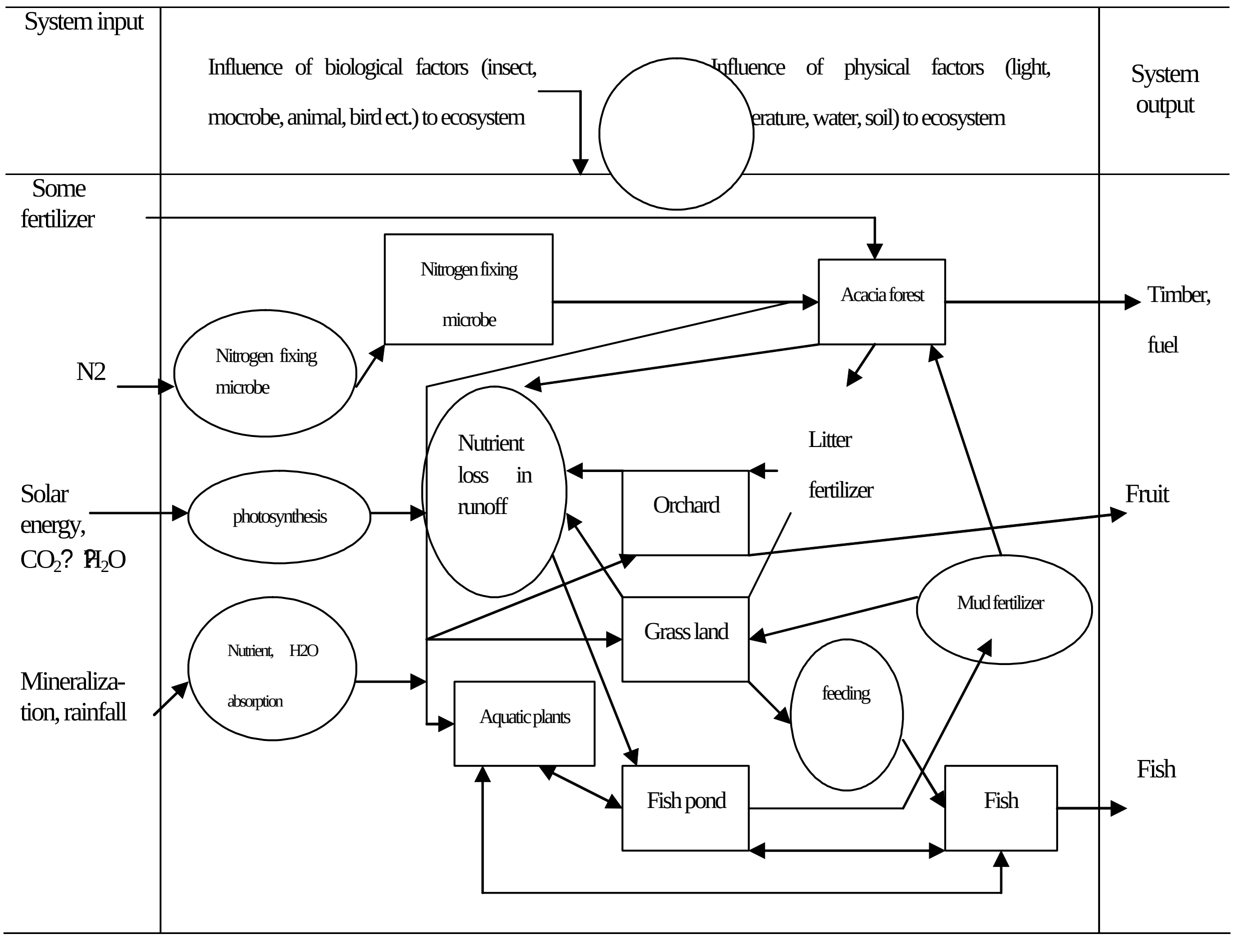

Table 2. Growth and yield of the forest, orchard, grassland and fishpond sub-ecosystem

		1987	1988	1989	1998
Growth of forest	Height (m)	8.40	8.93	9.65	12.00
(Planted in 1983)	Diameter (cm)	6.21	7.23	7.36	11.4
Yield of orange (t/(ha.a))		-	0.140	0.389	0.60
Yield of grass (t/(ha.a))		16.8	16.8*	16.8*	16.8*
Yield of fish (t/(ha.a))**		2.09	0.75*	0.75*	2.67

Note: *estimating figures. **The fishpond was dug in 1986; the fishes had been fed since 1987. The number of fishes was decrease by the insufficiency of water after leakage of the pond in 1988-1989. Therefore the yield of fish was lower than 1987.

watershed were harvested in a nearby area. The biomass of the trees and lianas was divided into its components and dried, and regression equations based on diameter and height (trees) and diameter alone (lianas) were developed for each component (leaves, branches, stems, and roots). Similarly for shrubs, but in this case, regression equations were based on height. Maximum biomass of the herbaceous layer was determined by harvesting $1m^2$ quadrats in the small watershed. Productivity in living plants was estimated as the difference in the biomass at the beginning of the study and one year later.

Samples for soil were collected once every year. In each sample period, one composite sample of seven cores to 10 cm depth was taken from each of the sub-ecosystem. Plant samples were collected when biomass was detected. All plant materials and soils were dried to a constant weight at 40! immediately after collection. Soil samples were ground to pass through a 2mm mesh sieve. Plant samples were ground to pass a 0.15 mm mesh sieve. Sub samples of plant and soil materials were dried to 105!, and all results are reported on 105! basis. All N concentrations in plant and soil material were determined with semimicro- Kjeldahl digestion followed by detection of ammonium with a Wescan ammonia analyzer. Nutrient analyses for other elements (P, K, Ca, and Mg) were detected by the method of ionic plasma emission spectroscopy.

Results

Productivity of the ecosystem

The agroforest ecosystem is composed by forest, orchard, grassland and fishpond sub-ecosystems. The productivities of those sub-systems are quite different because of different species and structure (Table 2).

Forest

The community structure, biomass and net primary productivity of the *Acacia mangium* and *Acacia auriculaeformis* mixed plantation sub-ecosystem had been determined and studied since 1983(Fig 3, Tab 2). The density of Acacia tree is about 1100 individuals/ha. The total biomass of the plantation in tree layer was 196.94 t/ha in 1998, in which the stem was 80.75 t/ha, the branch was 55.14 t/ha, the leaf was 19.69 t/ha, and the root was 41.36 t/ha. The biomass of the plantation increased fast between 1 and 7 years, while increased slowly between 7 and 11 years. It indicated that the plants had developed a deeper root system and made full use of the soil moisture. The biomass of the plantation fluctuated slightly after 11 years. The net primary productivity of the 11 years old plantation was 10.66 t/(ha·a). The *Acacia mangium* and *Acacia auriculaeformis* were quick-growth species because of high activity of nitrogen fixation (3.3-4.6 um C_2H_4/g fresh nodule.hour) and photosynthetic rate (9.52-12.15 mgCO_2 /dm^2.hour); they were good pioneer species before 11 years old in unfertile soil of South China. In addition, the farmers for their multiple outputs such as fodder, fuel, fruits, timber, fence etc prefer these perennial woody species.

Fruit

The density of fruit tree (*Citrus spp.*) is about 110 individuals/ha. The average height of tree was with 2.4m, average DBH with 9.0cm and crown with $5.5m^2$ in 1998. Based on stratified harvest methods of 3 standard sample trees, The total biomass of the orchard in tree layer was 16.0 t/ha, in which the stem and branch was 7.9 t/ha, the leaf was 3.4 t/ha, and the root was 4.7 t/ha. The orchard begun to provide fruits since 1988 with yield of 0.140 t/(ha.a) in 1988, 0.389 t/(ha.a) in 1989.The fruits yield sustained about 0.600 t/(ha.a) after 1990. It was pity that all these orange trees were infected disease in 1997 and were cleared in 1998. We changed them into litchi and longan trees after 1999.

Grass

Elephant grass was planted round the fishpond. They formed dense canopy only one year old in 1984. The mean height of the community was 1.2m. We studied three standard quadrats of 1*1 m^2 and found that their biomass were 5300g, 7000g and 4300g, respectively. We can estimate that the biomass of grassland was 5.6 t/ha. We cut the grass thrice per year, which means that the net primary productivity was about 16.8 t/(ha.a).

Fish

Grass carp was fed after the fishpond was dug in 1986. The yield was about 2.09 t/ha in 1987. The number of fishes decreased as a result of the insufficiency of water after the leakage of the pond in 1988-1989; therefore, the yield of fish was only 0.75 t/ha in 1988-1989. The fish yield sustained more than 2.67 t/ha after 1990.

Soil microbe and fertility

Soil microbe and soil fertility of those sub-ecosystems were determined in 1989. The results are showed in Tab 3. The amount and structure of soil microbe and fertility of those sub-ecosystems were not the same. The performance of orchard showed best and the forest followed the orchard. Compared with bare land and secondary forest at the same station, the agroforest ecosystem is intervenient. It means that the soil of bare land is degraded, and the soil of agroforestry ecosystem get improved, and the secondary forest with less human disturbance is not degraded. Agroforestry ecosystem is one kind of rehabilitation model with soil improvement (Yu, 1990).

Nutrient elements standing stocks and nutrient element balance in agroforestry ecosystem

Nutrient elements standing stocks in the agroforestry ecosystem are showed in Tab 4. Soil compartment was the largest pool for nutrients. N standing stock in forest is more

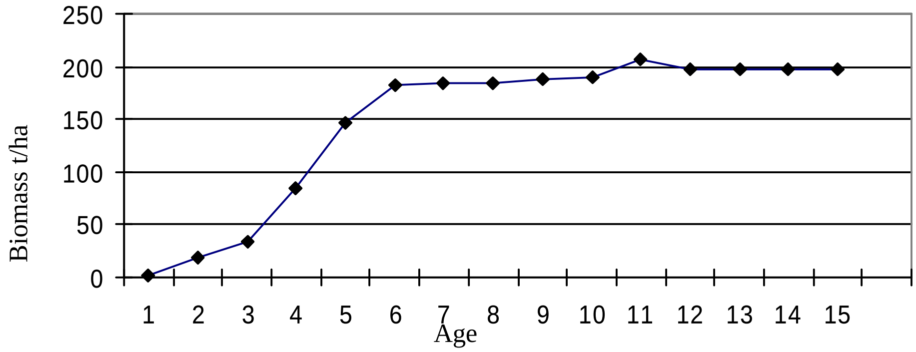

Figure 3. The dynamics of biomass of *Acacia mangium* plantation during its development

Table 3. Soil microbe and soil fertility of the agroforestry ecosystem

Items		Forest	Orchard	Grass	Fish pond	Bare land	Secondary forest
Microbial groups	Total amount (million/g dry soil)	3.08	6.48	2.01	1.46	1.12	7.72
	Percentage of bacteria (%)	79.9	70.2	70.8	67.1	32.1	74.6
Activities of soil enzyme	Proteinase (mg/(g 24h))	1.00	0.70	0.82	0.43	0.90	1.85
	Urease (mg/(g 24h))	0.72	0.74	0.71	0.10	0.66	0.74
Soil fertility	Organic matter (%)	1.81	1.55	1.57	-	1.57	2.48
	Total N (%)	0.105	0.106	0.105	-	0.076	0.122

Tab 4. Nutrient elements standing stocks in agroforestry ecosystem (kg/ha)

		N	P	K	Ca	Mg
Forest	Tree layer	249	32	158	344	86
	Shrub layer	17	3	22	19	8
	Herb layer	7	2	8	2	3
	Litter layer	201	12	20	73	19
	Soil? 0-30cm? ?	5223	595	296	120	35
	Total	5697	644	504	558	151
Orchard	Fruit tree	91	32	113	191	31
	Grass	33	20	152	46	14
	Soil? 0-30cm? ?	3829	2310	383	629	189
	Total	3953	2362	648	866	234
Grass land	Grass	56	66	400	48	46
	Soil? 0-30cm? ?	3678	1331	334	630	149
	Total	3734	1397	734	678	195
Fish pond	Fish	54	7	-	-	-
	Water	7	-	23	13	4
	Mud	5778	1688	476	694	145
	Total	5839	1695	499	707	149

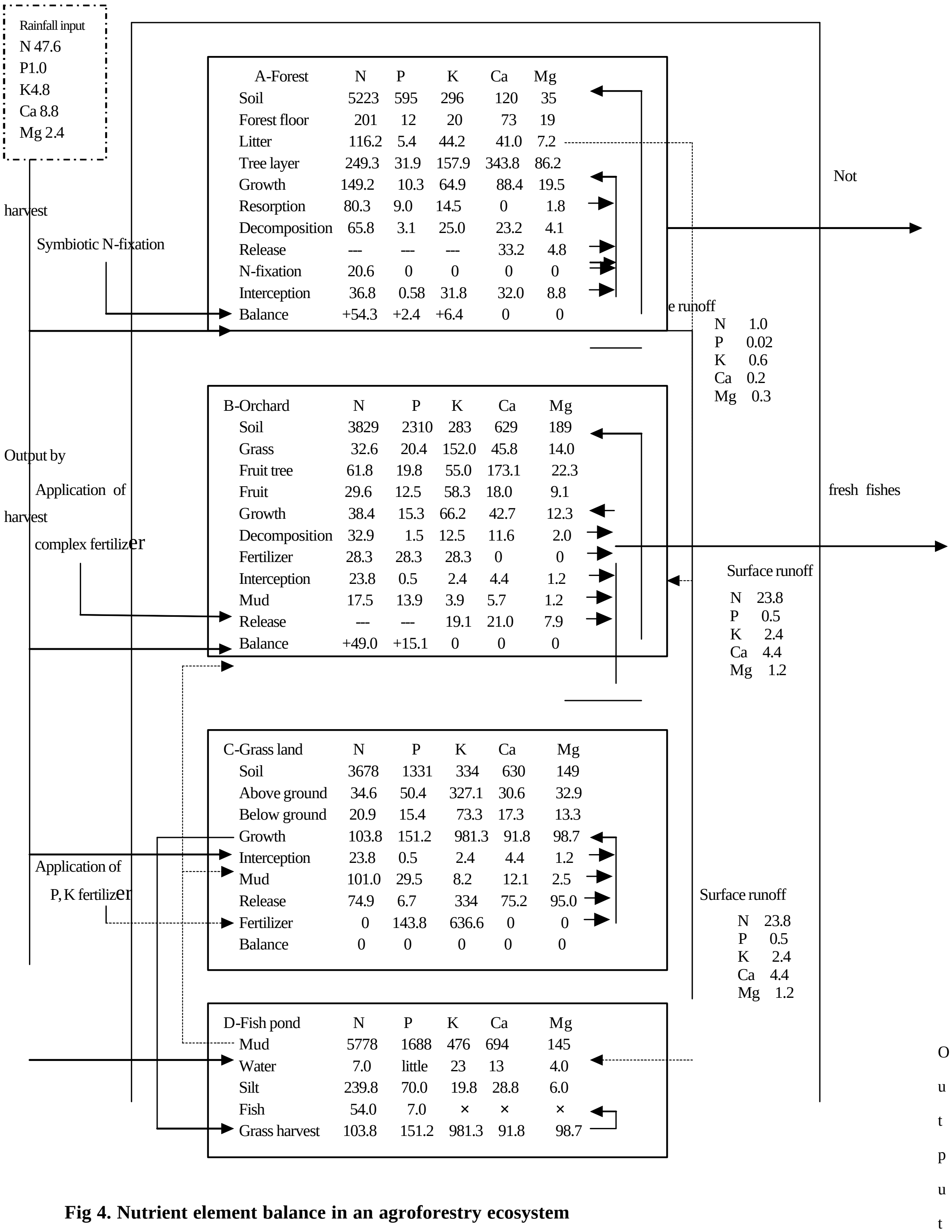

Fig 4. Nutrient element balance in an agroforestry ecosystem

is more than that in orchard and grassland. P standing stock in orchard is more than that in grassland and forest. K standing stock in grassland is more than that in orchard and forest. It means that different plant has different stock capacity of nutrient in vegetation system. We may make full use of some high potential nutrient stock plant in agroforestry ecosystem (Ding,1995).

Nutrient element balance in the agroforestry ecosystem is showed in Figure 4. The nutrient cycling in forest subecosystyem was in good balance, with N, P and K in positive balance even after moving one-third of the total litter from forest to orchard. The nutrient balance in grassland sub ecosystem was negative for soil pool; application of fertilizer is needed for keeping the nutrient balance. It should be encouraged to apply fishpond mud in orchard and grassland to increase the soil fertility (Ding,1995).

Conclusion and discussion

This low-input integrated production ecosystem has been functioning for 15 years. The value of tree and grass is lower, but their greatest contribution is their protective function in reducing erosion hazards and thereby making fruit and fish production possible on the slopes. The price of fruit and fish is higher than crop. In addition, the fishpond can provide water to irrigate the fruit trees in drought season and mud to fertilize the fruit trees. The model has been extended to a larger area of 0.4×10^4 ha since 1989 and great ecological and social effects also have been achieved. The urbanization has become evident and fast in the region since 1978. More and more factories and buildings took the place of agriculture fields in the flatland. Many farmers gave up rice in the flatlands and extended dry farming system to hilly lands and forests, causing more soil erosion and great firewood shortage, overgrazing of pastures, decline in soil fertility and crop-production level, and so on. Farmers attempts to identify appropriate agricultural systems for different localities and to improve them for high productivity and better economic returns. The agroforestry ecosystems of hill farming system can avoid the destroying factors and improve the land use, so the farmers gradually adopted the systems in practice and improve sub-ecosystems (Lamd & Tomlinson, 1994).

There are two sets of improvement possibilities of this system. An evident improvement in the recent past is that some farmers have begun to be interested in better inputs such as improved fruit tree varieties, better fruit trees, inputting concentrates and fodder to pond (as food of fishes to increase yields of fishes), use of fertilizers, etc. All these efforts have shown substantial improvement possibilities. Another way is to improve farming systems. Elements of improved farming systems include use of more fruit trees, adding one more component, intercropping vegetables or crop under fruit trees, incorporation of a variety of multipurpose trees in the forest area. Adding one more component means to add cattle, pig or chicken in the grassland, the manure of the animals can be put into pond to incubate microbe, and microbe and remant are the food of fishes. In the first several years, the orchard has no fruit harvest, intercropping vegetables or crop such as ginger, soybean between young fruit trees can increase income during early investment, and this intercropping continues for the next four or five years until the tree canopy closes. In addition, Intercropping of medicinal herbs with the tree species also seems to offer a viable possibility, especially in areas that are very unsuitable for crop production.

Besides the agroforestry model of forest-fruit-grass-fish, several other models have been built in Heshan and other places in South China, such as forest - fruit- livestock-fish, forest - fruit- poultry-fish, forest - fruit- vegetable-fish, forest - fruit- grass, forest - fruit- fish, etc. All these agroforestry models aim at establishing a rational ecosytstem having the sustainable effects of ecology, environmental conservation, and renewal of economy.
The tropics and subtropics in China are the regions most seriously stressed by human population and environment. The destruction of natural ecosystems and the increasing area of degraded ecosystems are the key factors limiting the development of agriculture. This long-term study on restoration ecology shows that integrated management has a great ecological, economic and social effect on the restoration and reconstruction of degraded ecosystems. The forest-fruit-grass-fish complex ecosystem stemmed from the practice of restoration and reconstruction of degraded ecosystems is an agroforestry model with high yield, high quality and high efficiency in hilly areas, and an efficient approach to enhance the development of local agricultural economy.

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