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Estimation of the ecological-economic benefits of two *Spartina alterniflora* plantations in North Jiangsu, China

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Abstract

This paper describes three levels of ecological-economic benefits of two *Spartina alterniflora* plantations in Jiangsu Province, China, with the practical values calculation. The first natural value, about 1500 yuan ha⁻¹ year⁻¹, which was the highest values of the plantation in natural situation came from the saved expense in sea shore bank protection. The second developed values, about 90 000 yuan ha⁻¹ year⁻¹, came from the *Spartina* extract which contains many nutrients and bioactive materials and can be used for some functional foods. The third value of usage, about 81 000 yuan ha⁻¹ year⁻¹, was from the grass residue in extraction procedures which can be used for the culture of mushrooms and for the ruminant's fodder after mushrooms were harvested. The total value, that is the ecological-economic benefits of *Spartina*, was estimated to be about 172 500 yuan ha⁻¹ year⁻¹ (equal to US\$ 20 058 ha⁻¹ year⁻¹). This ecological engineering not only supplies higher economic benefits but also protects the plant resource and the coastal environment. © 1997 Elsevier Science B.V.

Keywords: Ecological benefit; Economic benefit; *Spartina alterniflora*; Bank protection; *Spartina* extract; Residue use

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1. Introduction

Spartina tidal salt marshes mainly occur in the coastal regions of temperate countries including Britain, Ireland, France, Netherlands, Germany, Denmark, Australia, New Zealand and the United States (Ranwell, 1967). These marshes have higher productivity in the coastal ecosystems, so are important nursery grounds and sources of nutrients for aquatic organisms, also provide food and habitat for wildlife, reduce shoreline erosion and assimilate excess nutrients from pollutants such as sewage and agricultural drainage. So Dr. Chung-Hsin Chung introduced *Spartina anglica* in 1963 and *S. alterniflora* in 1980 respectively, and so far two species of *Spartina* have been developed to 40 000 ha (Qin and Chung, 1992). Before 1985 we had exploited *Spartina* plantations for natural and ecological uses, e.g., in accretion for reclamation, amelioration of saline soils, green manure, animal fodder and especially in seashore stabilization (Chung, 1990). Many local people thought *Spartina* was a 'special talisman' to resist typhoon. The good example was that in Qidong County, Jiangsu Province. A 380-m experimental area was turfed on the face of an earth sea wall with *Spartina* sods. This area remained intact following a typhoon attack with windspeeds of 28 m s^{-1} . It withstood a more severe typhoon in 1981, during which, by contrast, 10–15 cm of soil was scoured from unvegetated salt flats (Cao and Zhuo, 1985).

Since 1985 we have developed more uses of *Spartina* including its food uses and grass residue uses which enrich the *Spartina* ecological engineering that is the design of human society with its natural environment for the benefit of both (Mitsch, 1988) and enhancing the practical values from *Spartina*. Exact evaluation of *Spartina* is difficult. Odum (1971) suggested an 'ecosystem' approach for translating the total work of nature into monetary terms to prevent the conflicting of many uses with others. Odum and Odum (1972) suggested that the ratio of gross national product to national energy consumption can be used to equate energy with money in salt marsh ecosystems. So it means that approximately 10^4 kcal is the equivalent of one dollar. This paper introduces another estimation of the ecological-economic benefits in the salt marshes of Jiangsu Province, China, with the practical values statistics for three levels' of comprehensive utilization of *Spartina* without any contradictions between every two levels.

2. Study area

Two *Spartina alterniflora* plantations, the practical examples which we have worked on for 10 years, are at the estuary of Old Yellow River, Binhai County, and the estuary of Shuangyang River, Sheyang County, both in the northern part of the Jiangsu Province. Two plantations were transplanted in 1985–1987 and have developed over 200 and 400 ha so far (Fig. 1). The coordinates of Binhai County is 34.2°N and 119.8°E ; the estuary of the Old Yellow River is in the northeast of the county. The coordinates of Sheyang County is 33.7°N and 120.2°E ; the estuary of Shuangyang River is also in the northeast of that county. Both counties belong

to the warm temperature zone with monsoon climate. Binhai and Sheyang annual average temperature is 13.8 and 14.5°C, respectively. The lowest monthly average temperature is 0 and 0.8°C and the highest is 27 and 26.7°C. The annual precipitation is 981.5 and 1014 mm, the annual sun shine is 2342.3 and 2320.4 h and annual frost free period is 214.5 and 220.5 days. Both counties are affected by typhoons once a year. The heights of the tidal land surface in the two estuaries are –1–1.5 m in reference to the Yellow Sea zero point. The normal tide position is 1.6 m, the spring tide position is 3.45 m and the neap tide position is –0.89 m at both estuaries. The thickness of the soil where *Spartina* is growing is 0.5–1 m and the soil is composed of major powder sand and thin sludge layer. The salt content in the soil is about 1.5% and the major elements are chlorides.

3. Methods

3.1. Field design and determination

In the spring of 1985 we began planting *Spartina* in two experimental fields at the estuary of Old Yellow River (p1) and at the estuary of Sheyang River (p2) (Fig. 1). Both plantations lay in tidal land 100 m away from the sea. Both fields were 500 m wide; p1 was 3000 m long and p2 was 6000 m long. The spacing between rows and

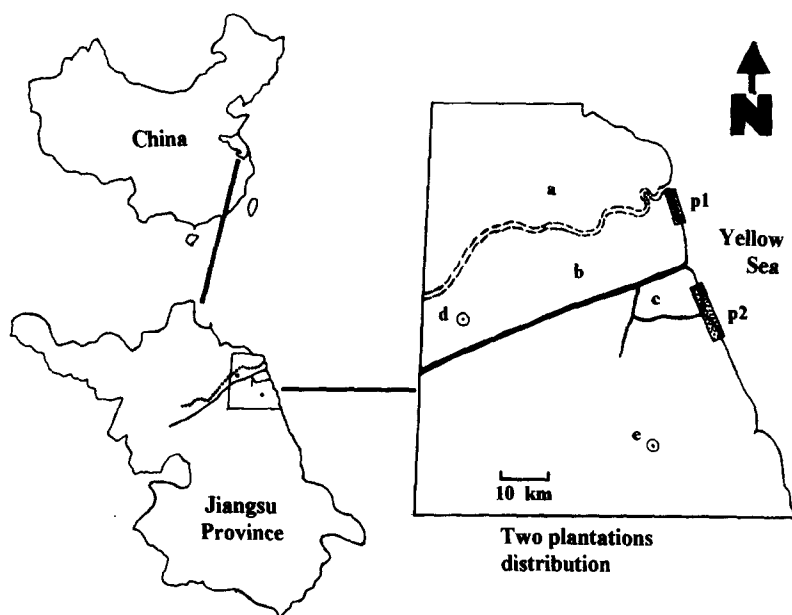


Fig. 1. The position of *S. alterniflora* plantations at the estuary of Old Yellow River and the estuary of Shuangyang River, Jiangsu Province: (a) Old Yellow River; (b) North Jiangsu irrigation canal; (c) Shuangyang River; (d) Binhai County; (e) Sheyang County; (p1) the planting field at the estuary of old Yellow River; (p2) the planting field at the estuary of Shuangyang River.

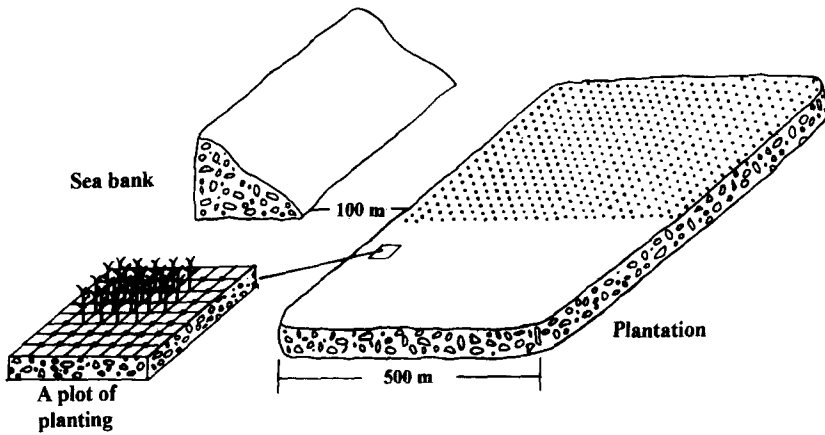


Fig. 2. The design of *Spartina* plantation at two estuaries in North Jiangsu.

between shoots in both fields were 1 m (Fig. 2). In the 3 years that followed two dense plantations were formed and so far their areas have developed over 200 and 400 ha, respectively. Every year the total biomass of both plantations was determined and the lengths of the damaged bank and the cost of repairing the bank were investigated to estimate the first benefit of *Spartina*.

3.2. Laboratory work

Each year after the period when the typhoon and the big storms pass North Jiangsu (until September) analysis was done. This is a good time to use *Spartina* culms, which contain more nutrients and bioactive materials. We paid special attention to the grass effective contents and their functions to develop its extract's benefits. We also found that the extracted grass residue had good nutrients and could be used for mushroom culture and fodder. Therefore, we designed a series of laboratory experiments.

3.2.1. Preparation of the *Spartina* extract

In order to use the nutrients of *Spartina* the important thing is to get its extract. The simple procedure used is as follows: the culm's fragment is soaked in boiling water for 1 h, the thin extract is then concentrated to a dark brown liquid with specific gravity of 1.25. This *Spartina* extract liquid is called biomineral liquid (BML) (Qin and Xie, 1988).

3.2.2. Analysis of bioactive materials and nutrients

There are rich bioactive materials and nutrients not only in BML, but also in the grass residue. They are the basis of developing second and third benefits of *Spartina*.

3.2.2.1. *Analysis of bioactive materials.* VB₁, VB₂, VB₆ and VPP were determined with the HPLC method (Zang et al., 1992) and VC was determined using ultraviolet spectrophotometry (Law, 1986). Flavonoids and polyphenols were determined using aluminium chloride colorimetry and ferrous tartrate colorimetry, respectively (Zang and Qin, 1992).

3.2.2.2. *The analysis of nutrients.* The methods of analysis for the common nutrients were as follows: anthrone colorimetry for sugar, electro-conductivity method for salt, diffusion absorption method for protein and ICP method for minerals (Qin and Xie, 1990). Iodometry to titrate could be used for the analysis of cellulose contents and anthrone colorimetry was used to determine the sugar in the hydrolyzates as a good analysis method for other polysaccharides (Huang, 1979).

3.2.3. BML function test

In order to develop BML as a new functional food additive, we designed a series of function tests of which two were important: the first was the BML effect test on average life span of the fruit fly (Jiang and Qin, 1995) and the second was the BML effect test on phagocytic rate of polymorphonuclear leukocytes of rats in vitro (Jiang and Qin, 1992).

3.3. Calculation method

The total ecological-economic benefits of *Spartina* plantations come from three levels of value. The estimation of the benefit of each level originates from our research work and practical utilization. Therefore we arrive at three equations for *Spartina*.

The equation for the first seashore protection value is

$$B_1 = (T_i E_f - F_p) M_s \quad (1)$$

where T_i is the coefficient of typhoon damage, E_f is the coefficient environment factors, F_p is the coefficient of planting fee and M_s is the saving money per hectare of the plant.

The equation for the second extraction value is

$$B_2 = W C_g P_n \quad (2)$$

where W is the total biomass of *Spartina* culm per ha and per year, C_g the coefficient of change from grass to BML and P_n is the profit of BML.

The third residue value equation is

$$B_3 = R_u W (1 - C_g) (P_{r_1} + P_{r_2}) \quad (3)$$

where R_u is the residue use ratio, P_{r_1} is the net profit of the residue from mushroom, P_{r_2} is the net profit of the residue from fodder and W and C_g are as in Eq. (2).

4. Results

4.1. First seashore protection value

Although *S. alterniflora* has many uses in natural situation including the benefits to biodiversity, stability and sustained development in salt marsh system, we find that the highest value of the plantation is from the saved expenses in seashore protection. Before 1985 when a typhoon attacked the coastal region near the estuaries of the Old Yellow River and of the Shuangyang River, several kilometers of stone bank were broken severely and the local government had to spend about 5 million yuan to repair the damage bank every year. In the spring of 1985 we planted two *Spartina* belts, with a total length of 9 km, near the two estuaries and where the typhoon's damage was less serious than in 1984. In the following 2 years the *Spartina* plantations developed better and better, reducing the damage of the bank in the typhoon season. Since 1988 there has not been any significant bank damage because the breaches have been filled by thick *Spartina* shoots.

According to our design (Fig. 2) the plantation width was 500 m, producing along the sea bank at every 20 m a planting plot of 1 ha. From Table 1 we can find that 50 ha (1000 × 500 m) of *Spartina* can protect 1000 m of bank from typhoons and storms and can save the repairing cost of 530 000 yuan. Therefore, each hectare of this plant can save at least 10 000 yuan. Since 1984 we have found that there are a number of factors affecting seashore protection, such as sedimentation, ocean current and human disturbance. For this reason we should add some coefficients

Table 1

The costs of repairing damage of the bank by typhoons and storms and *Spartina* biomass at the two estuaries from 1984 to 1988

Years		The length of damages bank ^b (m)	The expense of repairing bank (yuan)	<i>Spartina</i> biomass (averages) (g m ⁻² , dw)	Typhoon or storm force level (on the Beaufort Scale)
1984	P1	3,000	1,600,000	0	9
	P2	6,000	3,200,000	0	9
1985	P1	1,500	800,000	421	10
	P2	2,500	1,330,000	458	10
1986	P1	600	320,000	2,302	9
	P2	1,000	530,000	2,618	9
1987	P1	200	110,000	3,180	9
	P2	300	160,000	3,365	9
1988	P1	0	0	5,241	10
	P2	0	0	5,416	10

^a Since 1988 the development of *Spartina* has been stable and there has not been any expense of repairing the bank at the two estuaries.

^b P1 and P2, are the two planting areas at the estuaries of the Old Yellow River and Shuangyang River, respectively since 1984.

Table 2
The contents of a few bioactive materials in *S. alterniflora* extraction (BML) during the autumn and winter between 1992 and 1995

Months ^a	VB ₁ (mg/100 g)	VB ₂ (mg/100 g)	VB ₆ (mg/100 g)	VPP (mg/100 g)	VC (mg/100 g)	Flavonoids (mg/g)	Polyphenols (mg/g)
August	5.19	0.284	1.23	32.65	22.32	4.67	21.9
September	6.04	0.388	1.26	33.58	27.04	5.86	23.2
October	6.36	0.392	1.30	38.56	26.67	6.26	23.6
November	6.23	0.363	1.27	35.92	23.54	5.33	23.1
December	5.39	0.287	1.25	34.21	22.41	4.87	22.4
January	3.52	0.216	1.11	32.99	13.54	4.52	21.8

^a The data for August to December were the averages of observations from 1992 to 1994, the data for January were collected in 1993-1995.

Table 3
The comparison of a few nutrients in the extracts of three plants culms from the two estuaries in 1991

Plants	Total soluble sugar (%)			Total salt (%)			Elements in 1:400 dilution			
							Fe (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Zn (mg/kg)
<i>Spartina alterniflora</i>	17.8			21.0		1.5	0.48	0.07	0.30	0.50
<i>Phragmites communis</i>	18.0			7.1		1.3	0.02	0.02	0.10	0.40
<i>Triticum aestivum</i>	3.4			5.3		0.7	0.02	0.03	0.07	0.28

^a The data represent 4 months averages collected from September to December in 1991, sampled at 15 places at the estuaries of the Old Yellow River and Shuangyang River.

Table 4

The effect of BML on the average life span of the fruit fly

Groups	Concentration (mg/ml)	No. of flies	Average life span of fly (days)	Life prolongation (days)	P1 ^a	P2 ^a
Control	Distilled water	100	29.30 ± 14.98			
American ginseng extract	0.345	100	36.40 ± 15.05	7.10	<0.01	
BML	0.024	100	40.60 ± 11.95	11.30	<0.01	<0.05

^a By the F test, P1 compared with control group and P2 compared with group of American ginseng extract.

representing these factors in our estimation of the first value. By the practical facts and our experiences, considering the 'Green Great Wall' (*Spartina* plantation) and the stone breakwater together resisting typhoons and storms we assume T_i (the coefficient of *Spartina* resisting a typhoon) to be 0.5, and considering the environment factors affecting the plant we also assume E_t to be 0.5. Besides, the labor wage must be deducted also, F_p (the coefficient of planting fee) is therefore taken as 0.1. According to per hectare of the plant in the two estuaries saving the repairing expense (M_s) as 10 000 yuan, we can get the first benefit of *S. alterniflora* from Eq. (1) as follows:

$$B_1 = (T_i \times E_t - F_p)M_s = (0.5 \times 0.5 - 0.1)10\,000 \text{ yuan ha}^{-1} \text{ year}^{-1} \\ = 1500 \text{ yuan ha}^{-1} \text{ year}^{-1}$$

4.2. Second extraction value

The end of September is the best time to use *Spartina* culms as the typhoon season has passed and the first benefit of *Spartina* has been gained. From this time to the end of December *Spartina* shoots contain more nutrients and bioactive materials than other plants (as is shown in Tables 2 and 3).

We succeeded in developing a new functional food additive, BML from *Spartina* culms (Qin and Xie, 1988, 1990). BML can significantly lengthen the life span of

Table 5

Differences of phagocytic rate of polymorphonuclear leukocyte among three groups of rats in vitro

Groups	Phagocytic rate of polymorphonuclear leukocyte in vitro (%)	P1 ^b	P2 ^b
Control	68.60 ± 9.54		
Jianlibao drink ^a	70.40 ± 5.32	>0.05	
BMW (1/400 of BML)	91.90 ± 4.43	<0.01	<0.01

^a Jianlibao drink is a popular sports drink in China.

^b By the F test, P1 compared with control group and P2 compared with the Jianlibao drink group.

Table 6
Analysis of residue nutrients of *S. alterniflora* grass (%)

Residues ^a	Crude protein	Cellulose	Other polysaccharide
Extracted residue	10.16 ± 0.24	29.86 ± 0.34	21.44 ± 1.24
The last residue ^b	19.28 ± 0.89	33.46 ± 1.62	18.84 ± 0.16

^a The residue analysis was sampled ten times in the BML workshop in 1992.

^b The last residue refers to the grass residue after harvesting mushrooms.

fruit fly and increase the phagocytic rate of polymorphonuclear leukocyte in vitro (as shown in Tables 4 and 5). In 1990 the Chinese Ministry of Health approved using BML for food production and so far there has been a series of biomineral products in China.

It is obvious that the second value of the grass depends on its extract (BML). The net profit of BML (P_n) is 30 yuan/kg after deducing the cost of harvesting and processing *Spartina*, the coefficient of change from the grass to BML (C_g) is 0.1 by production procedure, and the total biomass of the grass culm (W) is about 30 000 kg ha⁻¹ year⁻¹, so we can get the second benefit of *S. alterniflora* from Eq. (2) as follows:

$$B_2 = W \times C_g P_n = 30\,000 \times 0.1 \times 30 = 90\,000 \text{ yuan ha}^{-1} \text{ year}^{-1}$$

4.3. Third residue value

The residue of the extracted grass has good nutrition value (as shown in Table 6) and can be utilized. The third utilization of *Spartina* includes two respects: one is the culture of mushrooms on the grass residue medium and the other is the fodder use of the last residue after mushroom harvested.

Because the residue use ratio (R_u) is 0.5, after deducing the processing cost the net profit of the grass residue is 5 yuan/kg (P_{r_1} from mushroom) adding 1 yuan/kg (P_{r_2} from the fodder), and as $1 - C_g$ means the coefficient of change from grass to residue, we can get the third benefit of *S. alterniflora* from Eq. (3) as follows:

$$\begin{aligned} B_3 &= R_u W (1 - C_g) (P_{r_1} + P_{r_2}) = 0.5 \times 30\,000 (1 - 0.1) (5 + 1) \\ &= 81\,000 \text{ yuan ha}^{-1} \text{ year}^{-1} \end{aligned}$$

4.4. The ecological-economic benefits of *S. alterniflora*

To sum up, the three levels of utilization of *Spartina* is a good way to exploit the resource plant's benefits. It is obvious that the total ecological-economic benefits of *S. alterniflora* plantations are the sum of three levels of benefits. The model sketch is shown in Fig. 3 and the total equation is as follows:

$$\begin{aligned} B &= B_1 + B_2 + B_3 = (T_i E_f - F_p) M_s + W \times C_g P_n + R_u W (1 - C_g) (P_{r_1} + P_{r_2}) \\ &= 1500 + 90\,000 + 81\,000 = 172\,500 \text{ yuan ha}^{-1} \text{ year}^{-1} \\ &= \text{US\$}20\,058 \text{ ha}^{-1} \text{ year}^{-1} \end{aligned}$$

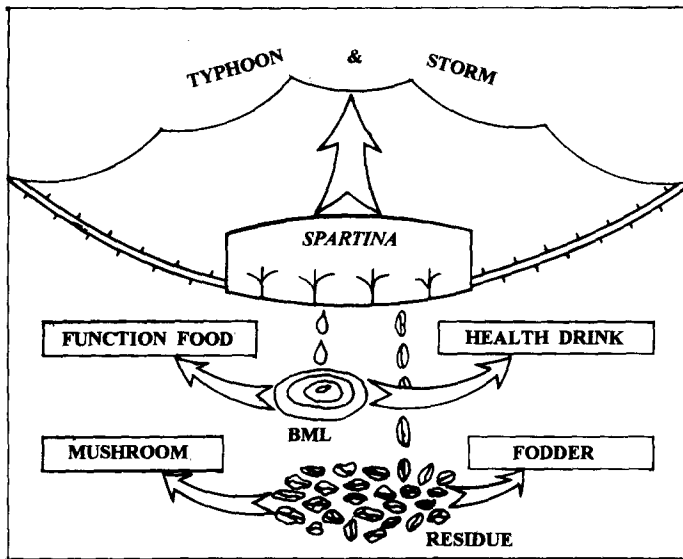


Fig. 3. Model of the three levels of usage of *S. alterniflora* plantation.

5. Discussion

5.1. A new estimation of *Spartina* benefits

To estimate the dollar value of *Spartina* marsh by Odum's suggestion of energy/money conversion there is a equation of *Spartina* benefits

$$B = W \times Q_w / Q_m \quad (4)$$

where W is the total biomass of *Spartina* culm, here is $30\,000 \text{ kg ha}^{-1} \text{ year}^{-1}$, Q_w is the coefficient of energy/biomass conversion, i.e. 4.1 kcal g^{-1} (Odum and Fanning, 1973) and here is 4.05 kcal g^{-1} (Qin and Xie, 1994), Q_m is the coefficient of energy/money conversion, i.e., $10^4 \text{ kcal US\$}^{-1}$. Eq. (4) gives the dollar value of *Spartina* as

$$B = W \times Q_w / Q_m = 30\,000 \times 4050 = \text{US\$ } 12\,150 \text{ ha}^{-1} \text{ year}^{-1}$$

This is a theoretical estimation. This paper introduces a new estimation of *Spartina*'s dollar value based on three levels of use of this plant. So we can get a higher dollar value of $\text{US\$ } 20\,058 \text{ ha}^{-1} \text{ year}^{-1}$ for the marsh plant (as shown in Table 7). We believe that the 'EMERGY' in *Spartina* will be exploited to its maximum and both people and environment will benefit much more (Odum, 1994), if the ecotechnology on *Spartina* ecosystem is superior to the present design.

Table 7
A comparison between two estimations of *Spartina* benefit

Estimations	Approaches	Calculation equations	Value (US\$ ha ⁻¹ yr ⁻¹)
Odums	Theoretical	$W \times Q_w / Q_m$	12 150
Qin et al.	Practical	$(T_i \times E_i - F_p)M_s + W \times C_g \times P_n + R_u$ $\times W(1 - C_g)(P_{r1} + P_{r2})$	20 058

5.2. The advantages of the three levels' uses of *S. alterniflora*

It is obvious that the development and utilization of *Spartina* involves ecological engineering, that is an 'environmental manipulation by man using small amounts of supplementary energy to control system in which the main energy drives are still coming from natural sources' (Odum, 1962; Odum et al., 1963). This engineering can minimize the cost of measures and their harm to environment (Uhlmann, 1983; Straskraba, 1985) and has three main advantages. First is the utilization with time difference. After September every year when the typhoon and big storms have passed in North Jiangsu, is the proper time to use *Spartina* culms and there is not any requirement for coastal bank protection. Secondly, it is favorable to the renewable resource, cutting *Spartina* culms can enhance the tillering rate and improve the shoot's photosynthesis of the following spring. Thirdly, the utilization of *Spartina* biomass and prevention of pollution is another advantage. The BML production can bring a large quantity of grass residue which has already been used for mushroom culture and for fodder. *Spartina* biomass can thus be digested completely and there is no wasted residue to pollute the production environment.

5.3. A better way to protect *Spartina* salt marsh

In the resource-diminishing world natural resource protection is not an easy subject. Among its foes, the more dangerous are some customary viewpoints and greedy actions for money in the existing world, especially in some developing countries. Some people only know to draw from nature but don't know how to nourish and moisten her, as in 'driving a horse quickly but feeding it nothing'. Some people even break a large area of resource to gain a few immediate interests, as in 'killing a hen to take an egg'. To stand against these wrongs, ecological education is not only needed for scientists, engineers and students, but urgently needed for governors and the common people. The best education is practical teaching, i.e., to introduce to them a good way and a good tool for gaining benefits for both human and environmental use. Ecotechnology offers us a very useful tool for better planning in the future (Mitsch and Jorgensen, 1989). For example, the three levels of usage of *Spartina* is one of the ecotechnologies. This engineering has been used in six cities of Jiangsu where *Spartina* plantations have grown and developed very well, an improved ecological-economic benefit has been obtained,

biodiversity has significantly improved, and natural resources have gained sustained development. We believe this choice will benefit 'Mother Nature' and our posterity.

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