

Integrated energy and economic evaluation of three typical rocky desertification control modes in karst areas of Guizhou Province, China



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ABSTRACT

Guizhou Province of China is a key karst area and is facing serious rocky desertification. Controlling the rocky desertification in karst areas in Guizhou has been formally established as a national goal. After decades of experience, some control modes are now recognized for their ability to reduce desertification and to provide income for the local community. However, a unified, integrated ecological and economic evaluation of these modes is lacking. The current study evaluated three modes (planting systems) and compared these modes with the planting of corn (CP), a traditional crop in this region. The three typical modes were pepper planting (PP), pitaya cultivation (PC), and honeysuckle-plum inter-planting (HPIP). Furthermore, the ecological and economic effects of adding livestock and biogas subsystems to the PP mode were quantified. The results showed that the PP mode provided the highest ecological-economic benefits, while the HPIP mode provided the highest ecological benefits. The addition of the livestock subsystem to the PP mode could improve the economic benefit density of the system with a tradeoff of environmental loading, while the addition of the biogas subsystem could partially correct for this. We suggest that local governments strengthen the technology support for these modes in order to expand the production chains; this will include the development of processing facilities for livestock, biogas, and crops. Local governments should also help farmers maintain markets, create new markets (by branding the products, for example), and establish a short-term labor supply for crop harvesting.

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1. Introduction

Rocky desertification transforms a karst area covered by vegetation and soil into a rocky landscape almost devoid of soil and vegetation (Yuan, 1997). It has occurred in karst areas in the Mediterranean basin (Yassoglou, 2000), the Dinaric Karst (Gams and Gabrovec, 1999), and southwest China (Yuan, 1997) because of the fragile ecological environments and human disturbance (Jiang

et al., 2014). Rocky desertification can result in natural disasters such as landslides, debris flow, droughts, and floods that seriously affect the regional residents and hinder the coordinated development of the local society, economy, and ecology (Ren, 2005; Xiong and Chi, 2015).

Humans have long attempted to control rocky desertification in the fragile karst areas. In 1150 AD, for example, the government of Trieste, Italy restricted the cutting of trees for firewood and prohibited the breeding of goats (Ford and Williams, 2007); around 1250 years BP, Arabs used terrace farming and an irrigation-based sustainable agricultural system in the Mediterranean area (Yassoglou, 2000); and the establishment of olive groves with understory vegetation is considered one of the most land-protective

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systems in the Mediterranean region (Kosmas et al., 1996).

Research on the control of rocky desertification in China began in the 1980s, and some mode were developed, included the returning of farmland to forests and grassland, afforestation, and the preservation of hillsides for forest conservation (Cai and Lu, 2002; Chen and Liang, 2002). Other modes included eco-economic governance (Su et al., 2002), three-dimensional ecological agriculture, migration development, and agroforestry management (Zuo, 2010). A recent report, however, indicated that these modes failed to fundamentally change local ecological, economic, and social conditions and that rocky desertification and rural poverty still restrict the harmonious development of the karst areas in southwest China (Zuo, 2014).

Although many karst management modes were evaluated in China with the aim of clarifying the ecological benefits (Chen et al., 2007a,b; Long et al., 2005; Wu et al., 2009), economic benefits (Li et al., 2010) and sustainability (Deng et al., 2012; Peng and Xiong, 2003), these evaluations have shortcomings. Most of the economic studies have failed to consider ecology, and most of the ecological studies have ignored the economic needs of local populations. Although some environmental–economic methods based on integrated indices of ecology, economy, and society have been used for quantitative evaluation, they have disadvantages. The environmental–economic methods, which quantifies the ecological benefits based on market value, alternative cost, payment invention, and opportunity cost (Yao et al., 2009), is restricted by the subjective opinion of people, the technology level, and the economic development degree etc. Consequently, it fails to objectively evaluate the value of natural resources and the ecological benefits of controlling rocky desertification. Integrated indices include dozens of indicators in different proportions, e.g., forest coverage, soil erosion ratio, rocky desertification degree, grain output, economic forest and grass income, per capita GDP, per capita arable land for economic benefits, total labor capacity, the number of people with junior high school or higher education, and the number of people who are illiterate or semi-illiterate (Deng et al., 2012). These indices seem to be comprehensive but they are difficult to objectively quantify and they fail to determine the true ecological–economic benefits of the control modes (Zhang et al., 2010). Furthermore, the indices that are used differ among researchers, making it difficult to compare the results from different studies (Zuo, 2014). Therefore, a unified method of assessing energy flow, material flow, and money flow is needed to objectively and quantitatively evaluate rocky desertification control modes.

The idea of emergy, which was introduced by H. T. Odum and his colleagues and students in the early 1980s, is defined as one kind of energy previously used directly and indirectly for the production of another kind of energy, material, or service (Odum, 1996). As a biophysical donor-based valuation method, emergy evaluation can access different qualities and types of energies, materials, and information with a common unit, the solar equivalent joule (sej). Some scientists use emergy evaluation to link the environment and economy because it can objectively account for the contributions to a system/process from both the environment and the economy on an equal basis, i.e., in terms of emergy. After over 30 years of development, emergy evaluation has become a mature ecological–economic tool that has been widely used for evaluating many kinds of ecological–economic systems and processes (Campbell and Ohrt, 2009; Lu et al., 2002, 2006; 2010; Tilley and Brown, 2006). Although some previous studies have used emergy evaluation to assess karst provinces (Li and Luo, 2015; Li, 2014; Li et al., 2015; Luo et al., 2012), countries (Dai and Zhou, 2005; Luo et al., 2011a,b), agricultural systems (Han et al., 2010; Yang et al., 2012), and the ecological and economic characteristics of integrated farming-stockbreeding biogas systems in karst areas (Chen and

Chen, 2012, 2014; Yang and Chen, 2014), the concept of emergy has not been used to evaluate the ecological–economic benefits of the rocky desertification management modes.

Southwest China has the world's largest contiguous karst areas, and these karst areas experience serious conflicts between human development and ecosystem preservation; Guizhou Province is located in the center of this region (Zuo, 2010). Zhenfeng, Guanling Buyi and Miao Autonomous Counties are typical plateau–canyon karst areas in Guizhou Province. The local people have developed three well-known rocky desertification control modes, i.e., the pepper planting (PP) mode, the honeysuckle-plum inter-planting (HPIP) mode, and the pitaya cultivation (PC) mode (Deng, 2014; Peng et al., 2013). These modes, however, have not been quantitatively evaluated from an integrated ecological and economic perspective. Consequently, it is unclear which of them is better and how they could be optimized. An integrated emergy and economic evaluation of these three typical rocky desertification control modes was done in the current study. The study had the following objectives: (1) to identify which of the three rocky desertification control modes is best; (2) to determine the value of adding ecological engineering subsystems to the PP mode; and (3) to optimize the modes and make recommendations in support of local sustainable development.

2. Materials and methods

2.1. Study area description

The PP mode was studied in Yindongwan Village ($25^{\circ}37'17''$ – $25^{\circ}40'10''$ N, $105^{\circ}39'27''$ – $105^{\circ}41'25''$ E), Beipanjiang Town, Zhenfeng County. The PC mode was studied in Xiagu Village ($25^{\circ}40'15''$ – $25^{\circ}42'13''$ N, $105^{\circ}36'45''$ – $105^{\circ}40'2''$ E), Guanling Buyi and Miao Autonomous County. These two study sites are divided by the Huajiang River and located in opposite, and both of them are extremely developed karst area. The area receives an annual average solar radiation of $4.17E + 09$ J/m² and an annual average rainfall of 1100 mm, which occurs mainly from May to October. The annual average temperature is 18.4 °C. This area has a south subtropical dry and hot valley climate with a warm–dry winter and spring, and a hot–wet summer and autumn. The elevation ranges from 500 to 1200 m.

The HPIP mode was studied in Niuping Village, Min'gu Town, Zhenfeng County ($25^{\circ}21'29''$ – $25^{\circ}24'55''$ N, $105^{\circ}39'46''$ – $105^{\circ}41'43''$ E). This area receives an annual average solar radiation of $4.17E + 09$ J/m²; the annual average rainfall is 1412 mm, and the annual average temperature is 16.4 °C. The area has a mountain microclimate without cold winters or hot summers. Its average elevation is about 1500 m.

Corn planting (CP) was also studied as an experimental control. CP was developed in the area before ecological approaches to rocky desertification control (such as PP, PC, and HPIP) were developed. CP was studied in Maomaozhai Village, northeast of Beipanjiang Town, Zhenfeng County ($25^{\circ}36'23''$ – $25^{\circ}38'53''$ N, $105^{\circ}36'19''$ – $105^{\circ}39'2''$ E). This area has an annual average solar radiation of $4.17E + 09$ J/m² and an annual average rainfall of 1400 mm. The area has a perennial mild climate without cold winters or hot summers. The location of each of the four study sites is indicated in Fig. 1.

2.2. Description of the desertification control modes

2.2.1. The pepper planting (PP) mode

In the PP mode, farmers cultivate Chinese pepper (*Zanthoxylum bungeanum* Maxim), which is a small tree or shrub, in the rocky desertification areas without altering the primitive topography. The mode was developed in 1992 and is locally referred to as the

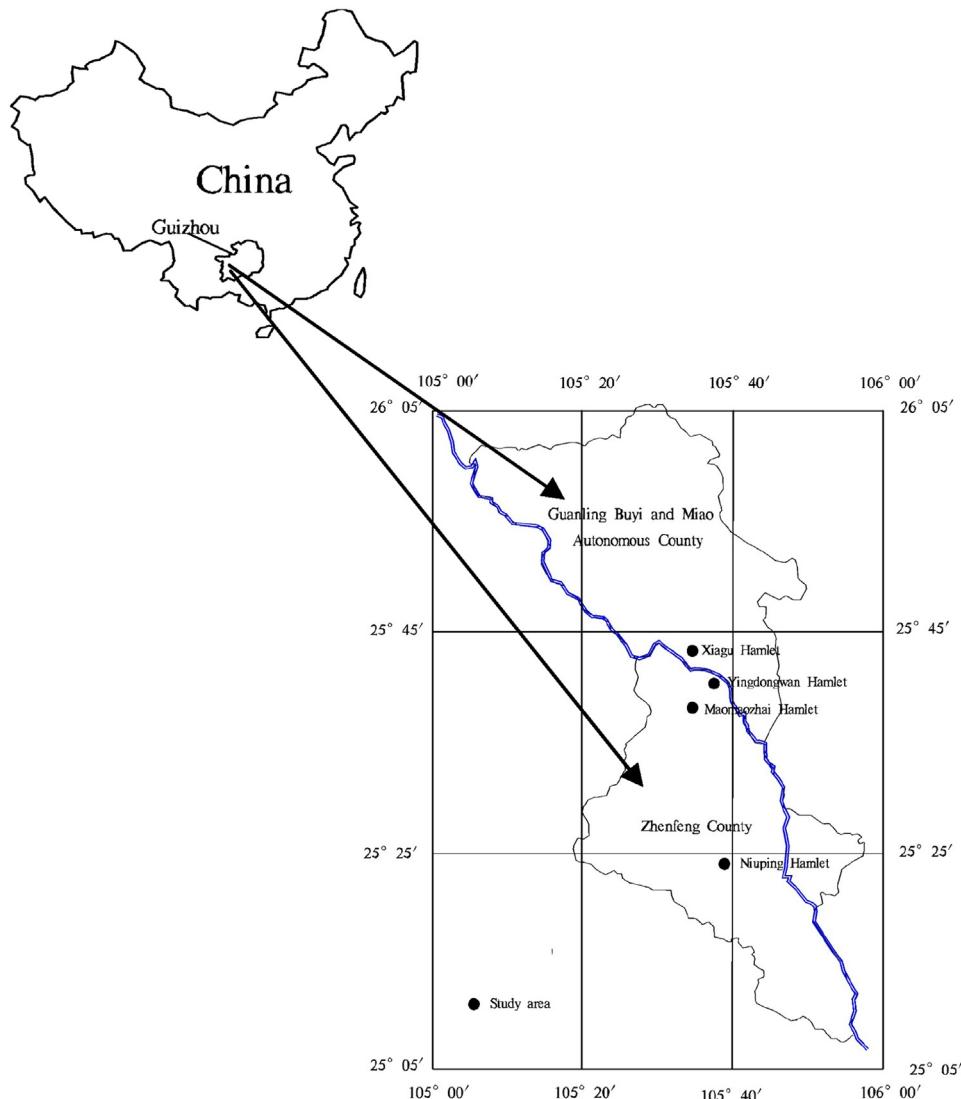


Fig. 1. The location of the study sites.

“Dingtan mode” (Deng, 2014). The pepper is harvested from July to September. The farmers prune the trees annually to improve their structure and to increase ventilation and light penetration.

2.2.2. The pitaya cultivation (PC) mode

In the PC mode, farmers grow pitaya vines (*Hylocereus undulatus* Britt), also known as dragon fruit, on artificial terraces converted from sloping-land. Being developed in 2008, this mode is highly regarded for the production of sweet pitaya pulp and for the demonstration garden of rocky desertification ecological control in Bangui Village (Yi, 2014). The pitaya fruits can be harvested 1 year after the vines are planted. The vines bloom since May every year, and the fruit are harvested 6 to 10 times from May to November (Wang et al., 2012).

2.2.3. The honeysuckle-plum inter-planting (HPIP) mode

In the HPIP mode, which is also known as the “Pingshang mode”, farmers plant honeysuckle (*Lonicera fulvotomentosa* Hsu et S. C. Cheng) and plum (*Prunus salicifolia* Lindl) in the limited space among stones. This mode was first practiced in 2000. Honeysuckle can be harvested in the third or fourth year after planting, and the

plants flower from May to July (Huang and Chen, 2003). Plums can be harvested in the third year after planting, and the harvest period lasts only about 20 days, from late May to early June (Chen and Yang, 2012; Peng et al., 1995).

2.2.4. The corn planting (CP) mode (as an experimental control)

In the CP mode, farmers cultivate corn (*Zea mays L.*) in the karst lands. The corn is harvested annually from July to August. Corn is the main food crop in the area, and as noted earlier, was planted before ecological management was considered (Yi, 2014).

Although the PP, PC, and HPIP modes were developed in different years, they were all in full crop production at the time of this research. Background information on the four modes is provided in Table 1, and photographs of the modes are provided in Fig. 2.

2.2.5. The ecological engineering subsystems

In the region, two ecological engineering subsystems (livestock and biogas subsystems) have often been added to the PP mode to improve its economic performance and to make full use of the materials. In these subsystems, the manure from the livestock subsystem

Table 1

Background information for the four kinds of planting modes that were surveyed.

Modes	Repetitions	Area (mu)	Unit price for buying labor (yuan/d/person)	Price (yuan/kg)				
				2012	2013	2014	2015	2016
Pepper planting (PP) mode	^a liang Luo	65	60–80	50–60 (Dried)	50–60 (Dried)	50–60 (Dried)	50–60 (Dried)	50–60 (Dried)
	^a yuan Luo	18						
	^a xing Luo	25						
	^b xiang Luo	21						
	^a zhong Luo	22						
	^a xiang Yu	6.5	80–100	20–30	20–30	20–30	20–30	8–10
Pitaya cultivation (PC) mode	^a ronguang	12						
	^a fu Zheng	40						
	^a quan Ren	18						
	^b lin Zheng	30						
	^a yun Ai	6	30–40 (Honeysuckle)	30–35 (Dried)	20–25 (Dried)	20–25 (Dried)	10–15 (Dried)	8–10 (Dried)
	^a Wang	8	60–80 (plum)	3–5 (plum)	3–5 (plum)	3–5 (plum)	3–5 (plum)	3–5 (plum)
Honeysuckle-plum inter-planting (HPIP) mode	^a hua Xia	30						
	^a mei Luo	8						
	^a changang	17						
	^a kang Zeng	50						
	^a wen Zeng	4.5						
	^b pin Liang	3	0	3–5	3–5	3–5	3–5	3–5
Corn planting (CP) mode	^a lun Zhang	3						
	^a zhangLiang	2						
	^b guang Liang	3						

^a A word of the name of the surveyed omitted for privacy; mu: a traditional unit of area (=0.0667 ha). The same as the follows.

is used as a fertilizer for the pepper plants (referred to as the pepper planting-livestock or PPL mode) or is used to produce biogas (referred to as the pepper planting-livestock-biogas or PPLB mode). The biogas is used by the farmers for cooking and lighting. Background information on the PPL and PPLB modes is provided in Table 2.

2.3. Energy analysis

The energy evaluation was based on the 12.0E + 24 seJ/yr planetary baseline (Brown et al., 2016), and all coded unit energy values (UEVs) were converted to this baseline if they were not on it



The PP mode



The PC mode



The HPIP mode



The CP mode

Fig. 2. Photographs of the four planting modes in 2014.

Table 2

Background information for the three kinds of the pepper ecological engineering modes that were surveyed.

Modes	Repetitions	Area (mu)	Breeding species and quantities		Size of biogas digester (m ³)
			chicken	pig	cattle
Pepper planting (PP) mode	*liang Luo	65			
	*yuan Luo	18			
	*xing Luo	25			
	*xiang Luo	21			
	*zhong Luo	22			
Pepper planting-livestock (PPL) mode	*chang Wang	42	4600	1	
	*hui Hu	15	30	1	6
	*xian Yuan	12	70	2	6
	*yuan Zhang	35	60	2	6
Pepper planting-livestock- biogas (PPLB) mode	*xing Luo	33	120	3	8
	*zhong Hu	45	120	1	14
	*xing Ran	22	55	2	8
	*jin Luo	30	40	1	8
	*xiang Hu	23	150	14	16 (8 × 2)
	*chang Lou	34	50		8

already. Energy of all products or services was calculated with the following equation:

$$\text{Energy (sej)} = \text{products or services (J or g or kg or \$)} \\ \times \text{UEVs (sej/J or sej/g or sej/kg or sej/\$)}$$

According to Yang et al. (2010), the fraction of renewable resources in the total consumption of the Chinese economy decreased from 36.9% in 1978 to 11.9% in 2005. Thus, 90% of the energy input required for labor was assumed to be F_N in this study, and the remaining 10% was classified as F_R (Lu et al., 2014). Based on the Chinese energy/currency ratio ($7.27E+11$ sej yuan⁻¹) calculated by Yang et al. (2010) in 2005 and the linear correlation between the energy/money ratio and GDP found by Campbell and Lu (2007), the Chinese energy/currency ratio in 2013 was set at $4.37E+11$ sej yuan⁻¹, because the Chinese GDP smoothing index of year 2005–2013 was 2.155 (China Statistical Yearbook, 2014), and was converted to $12.0E+24$ sej yr⁻¹ baseline from $9.26E+24$ sej yr⁻¹.

All data were converted into per ha per year. SPSS22.0 statistical software was used to analyze the variance of the energy and economic indices.

The commonly used indices in energy evaluation were calculated in this study. The specific formulas and the meanings of the indices are provided in Table 3.

2.4. Economic analysis

In the economic analysis, the economic output/input ratio, the economic benefits per unit (EBU), and the economic pure benefit per unit (EPBU) were calculated. The economic output/input ratio is a measure of the economic cost efficiency, while EBU and EPBU, defined as the economic output minus input, are indicators of the net economic benefits of the system.

2.5. Data collection and sample measurement

There were four main sources of data for this paper. The first source was the statistics departments of the local governments. The second was the input and output data of the rural households in 2013 obtained via farmer interview with 4–7 replicate farmers for each mode. The third source was the existing literature about solar

Table 3

Energy evaluation indices.

Indices	Function	Meaning
Em-Power Density (EPD) ^a	U/area	measures the intensity of economic development and the level of economic development
Emergency Self-sufficiency Ratio (ESR) ^a	I/U	measures the degree of self-sufficiency and dependence on the outside world
Emergency Exchange Ratio (EER) ^a	(price × energy/ money ratio)/Y ₁	measures the real exchange gains of the system
Emergency Yield Ratio (EYR) ^a	Y ₁ /F	measures the net contribution to the economy beyond its own operation
Environmental Loading Ratio (ELR) ^a	(N + F _N)/(R + F _R)	reflects the system's environmental stress and sustainability
Emergency Restoration Ratio (ERR) ^b	Y ₂ /F	measures the ecological benefits of rocky desertification control
Emergency Benefit Ratio (EBR) ^b	(Y ₁ +Y ₂)/F	measures ecological and economic benefits of rocky desertification control
Emergency Index for Sustainable Development (EISD) ^c	EER × EYR/ELR	measures the sustainability of the system
Emergency Sustainability Index (ESI) ^d	ELR/ELR	measures the sustainability of the system

I: Natural Resources. R: Renewable natural resources. N: non-renewable natural resources.

F: Purchase resources. F_R: Renewable purchase resources.

F_N: Non-renewable purchase resources. U = I + F. Y₁ = U, system outputs.

Y₂: The ecological benefits for water conservation (W_C), soil reinforcement (S_R) and fertility (F_E), carbon fixation (C_F), and oxygen production (O_P). Y₂ = W_C + S_R + F_E + C_F + O_P.

^a Odum, 1996.

^b Lu et al., 2006.

^c Lu et al., 2003.

^d Brown and Ulgiati, 1997.

radiation, evapotranspiration, soil erosion data, etc. The fourth source was the supplementary soil samples collected and assessed in the current study. These samples were collected in the field, transported to the laboratory, and measured for bulk density, water content, total nitrogen, total phosphorus, total potassium, and organic matter content in 2015. The bulk density of soil was measured by the ring knife method. The soil water content was measured by oven-drying 10 g of fresh soil sample at 105 °C for 24 h. Total nitrogen and total phosphorus were determined by the indophenol blue colorimetric method and Mo-Sb colorimetric method after digestion by H₂SO₄, respectively. Total potassium was analyzed by acid dissolution ICP emission spectrometry. Total organic carbon was determined by the K₂Cr₂O₇ titration method (Liu et al., 1996).

If data from 2013 were lacking, data from papers published as close to 2013 as possible were coded. The coded data are noted in Appendix A.1–A.6 for energy accounting, and in Appendix B.1–B.6 for economic accounting.

3. Results

3.1. Energy analysis

3.1.1. Emergency input structure

Among the four modes, the empower density was highest for CP ($1827.79 E+10^{13}$ sej/ha/yr), followed by PC ($1567.61 E+10^{13}$ sej/ha/yr), HPIP ($846.34 E+10^{13}$ sej/ha/yr), and PP ($467.63 E+10^{13}$ sej/ha/yr) (Fig. 3). The main energy inputs to the four planting modes were fertilizer and labor, indicating that the local planting systems were mainly dependent on fertilizer and labor. Fertilizer represented a greater percentage of the total input to the PP and CP modes than labor, while labor represented a greater percentage of

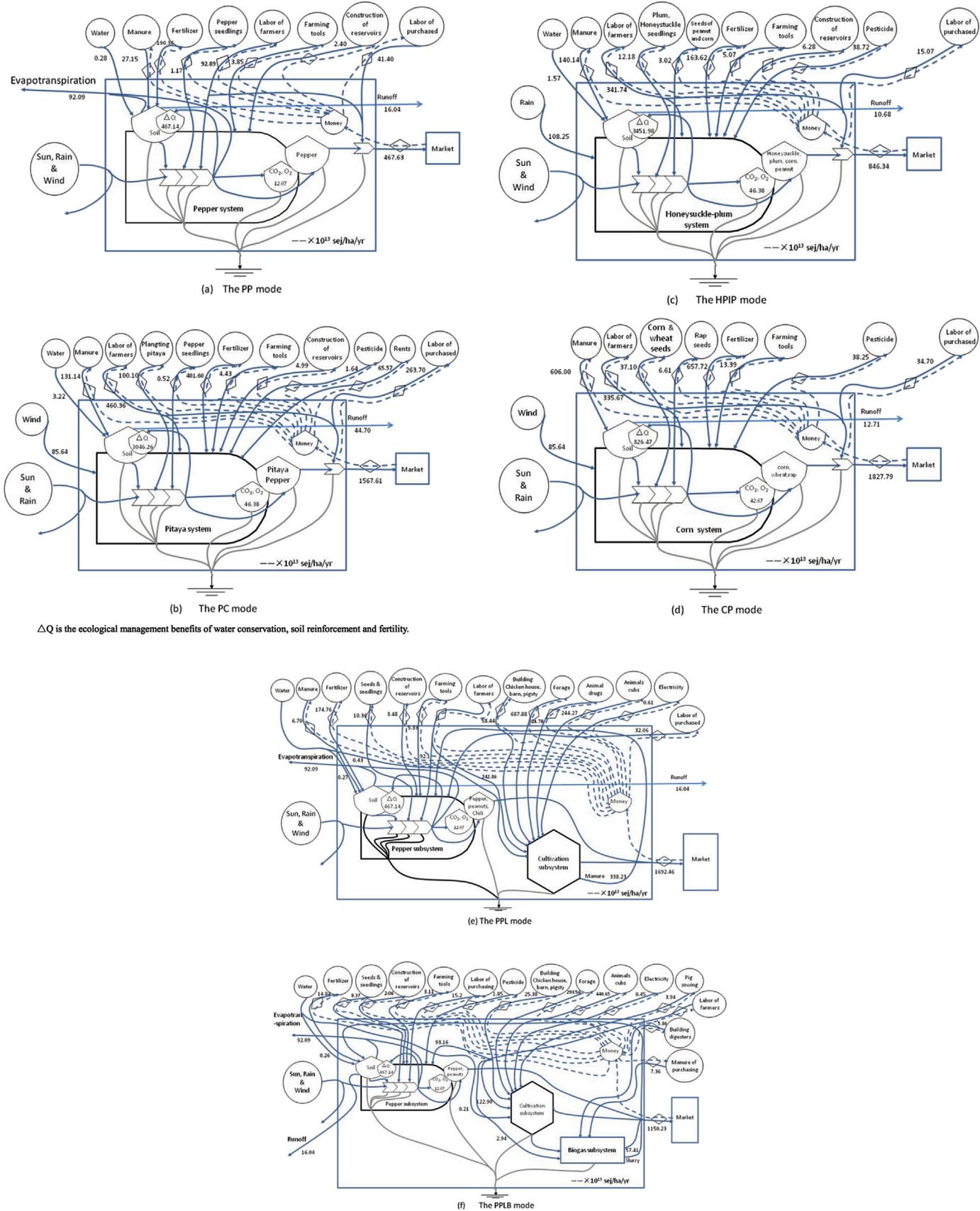


Fig. 3. The energy system diagrams of the six modes.

the total input to the PC and HPIP modes than fertilizer. The percentage of natural renewable resources among total inputs was highest for the PP mode (19.7%), followed by the HPIP (12.99%), PC (5.5%), and CP (4.7%) modes (Fig. 4).

When the livestock and biogas subsystems were added to the PP mode, the percentage of total energy inputs represented by natural resources decreased to 6.4% for the PPL mode and to 9.5% for the PPLB mode. The energy inputs were larger to the livestock subsystem than to the planting and biogas subsystems of the PPL and PPLB modes due to the large energy inputs of forage (40.69% for PPL, 25.52% for PPLB) and animal cubs (14.45% for PPL, 38.31% for PPLB). The addition of the biogas subsystem did not greatly increase the load of the system, i.e., the addition only required a 0.8% increase of energy inputs (Fig. 5). The livestock subsystem of the PPL mode provided a manure feedback of $338.23 \text{ E}+10^{13} \text{ sej/ha/yr}$ to the planting subsystem, and the biogas subsystem of the PPLB mode provided a feedback of $57.41 \text{ E}+10^{13} \text{ sej/ha/yr}$ to the planting subsystem (Fig. 3).

3.1.2. Em-power density (EPD)

Among the four modes, the EPD was highest for CP ($18.27\text{E}+10^{11} \text{ sej ha}^{-1} \text{ yr}^{-1} \text{ m}^{-2}$), followed by PC ($15.67 \text{ E}+10^{11} \text{ sej ha}^{-1} \text{ yr}^{-1} \text{ m}^{-2}$), HPIP ($8.46\text{E}+10^{11} \text{ sej ha}^{-1} \text{ yr}^{-1} \text{ m}^{-2}$), and PP ($4.67\text{E}+10^{11} \text{ sej ha}^{-1} \text{ yr}^{-1} \text{ m}^{-2}$) (Table 4). This indicated that the degree of economic development degree was higher for the CP and PC modes than for the HPIP and PP modes.

The addition of livestock subsystem made the EPD of the PPL mode ($16.92 \text{ E}+10^{11} \text{ sej ha}^{-1} \text{ yr}^{-1} \text{ m}^{-2}$) much higher than that of the PP mode (Table 5), while the addition of the biogas subsystem decreased the EPD of the PPLB mode ($11.50 \text{ E}+10^{11} \text{ sej ha}^{-1} \text{ yr}^{-1} \text{ m}^{-2}$). The introduction of biogas subsystem increased the internal feedback of

the system and improved the utilization of its internal resources.

3.1.3. Energy self-sufficiency ratio (ESR)

Among the four modes, the ESR was higher for PP (0.25) and HPIP (0.15) than for PC (0.09) and CP (0.06), which indicated that utilization of local resources was greater for the PP and HPIP modes than for the PC and CP modes (Table 4).

Among the three modes involving pepper planting, the ESR was highest for PP (0.25), followed by PPLB (0.16) and PPL (0.08) (Table 5). Addition of the livestock subsystem to the PP mode (resulting in the PPL mode) decreased the dependence of the system on local resources (a 16.8% decrease) because the livestock subsystem requires the purchase of external forage and immature animals. The addition of the biogas subsystem increased the internal cycling in the system, which consequently improved the ESR of the system to a certain extent.

3.1.4. Energy exchange ratio (EER)

Among the four modes, the EER was highest for PP (3.76), followed by PC (1.28), HPIP (1.19), and CP (0.46) (Table 4). Farmers were benefit from trading off their pepper, dragon fruit, honeysuckle, and plums on market. In contrast, the energy buying power of the corn price was less than half of the energy used for the production of corn, which meant farmers got an ecological–economic loss for sale them on the market.

Among the three modes involving pepper planting, the EER was highest for PP (3.76), followed by PPLB (3.33) and PPL (3.13). The farmers of all the three pepper modes received more than three times economic rewards for their inputs due to the high price of their pepper on the market. The EER decreased 16.8% when the livestock subsystem was added to the PP mode, but increased 6.4%

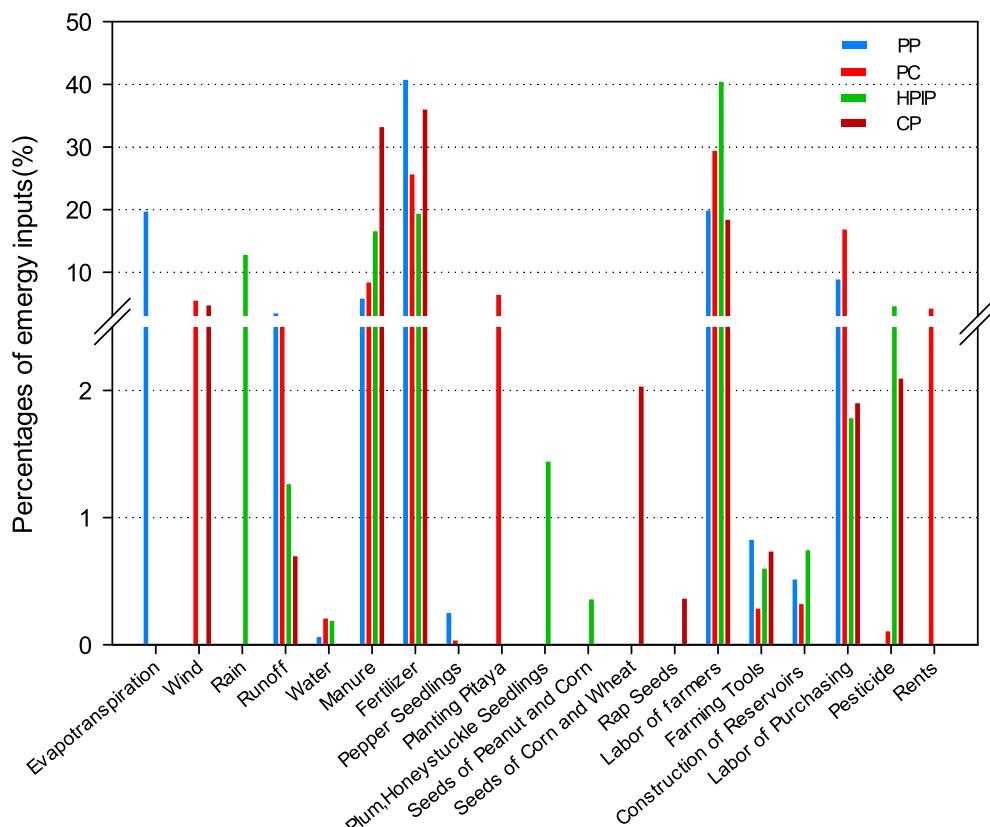
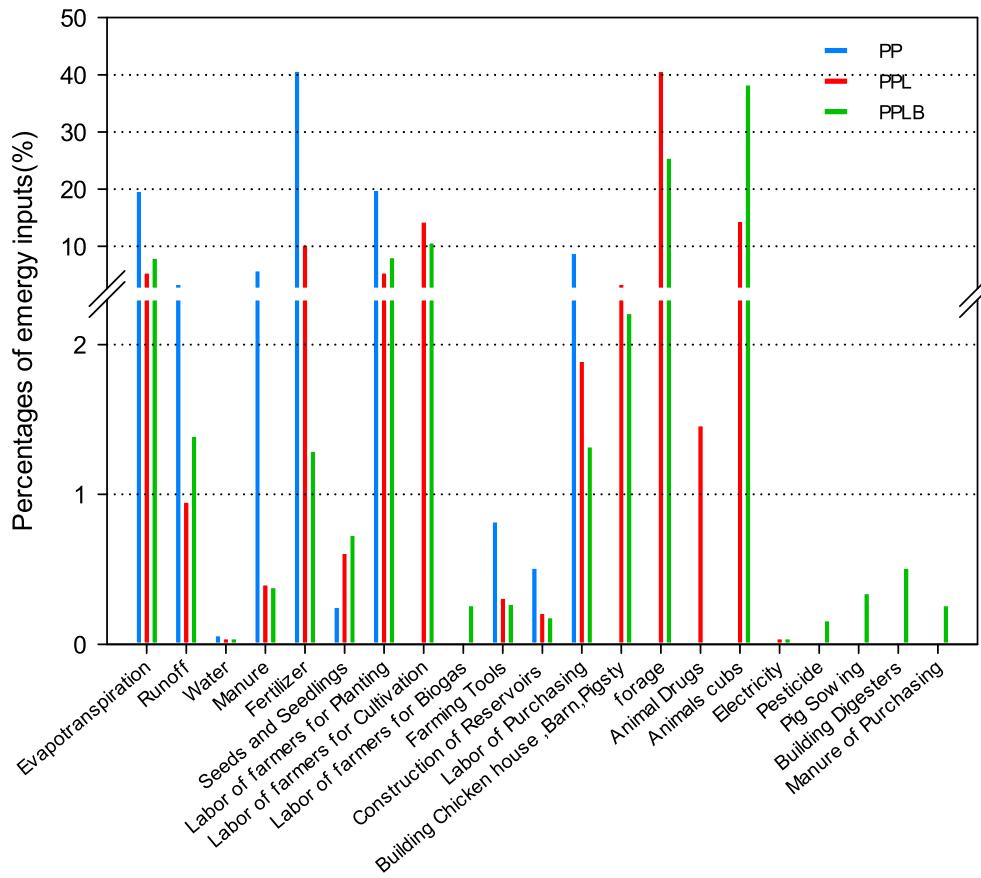


Fig. 4. Energy inputs percentages of the four planting modes.

**Fig. 5.** Energy inputs percentages of the three pepper modes.**Table 4**
Indices for the energy evaluation of the four planting modes.

Indices	PP	PC	HPIP	CP
Em-Power Density (EPD) (*E+11)	4.67 ± 0.6	15.67 ± 2.5	8.46 ± 0.9	18.27 ± 3.4
Energy Self-sufficiency Ratio (ESR)	0.25 ± 0.04	0.09 ± 0.02	0.15 ± 0.02	0.06 ± 0.01
Energy Exchange Ratio (EER)	3.76 ± 1.46	1.28 ± 0.42	1.19 ± 0.56	0.46 ± 0.88
Energy Yield Ratio (EYR)	1.36 ± 0.08	1.10 ± 0.02	1.18 ± 0.29	1.06 ± 0.1
Environmental Loading Ratio (ELR)	2.72 ± 0.4	6.10 ± 1.67	2.92 ± 0.71	2.60 ± 0.25
Energy Restoration Ratio (ERR)	1.59 ± 0.4	2.46 ± 0.47	5.40 ± 0.85	0.57 ± 0.11
Energy Benefit Ratio (EBR)	2.95 ± 0.4	3.57 ± 0.49	6.58 ± 0.88	1.64 ± 0.13
Energy Sustainability Index (ESI)	0.60 ± 0.2	0.26 ± 0.08	0.49 ± 0.09	0.42 ± 0.04
Energy Index for Sustainable Development (EISD)	3.17 ± 2.0	0.25 ± 0.08	0.49 ± 0.17	0.19 ± 0.04

when the biogas subsystem was added to the PPL mode (Table 5).

3.1.5. Energy yield ratio (EYR)

Among the four modes, the EYR was highest for PP (1.36), followed by HPIP (1.18), PC (1.10), and CP (1.06) (Table 4). This indicates that the highest energy output per unit economic energy input was obtained with the PP mode.

Among the three modes involving pepper, the EYR was highest for PP (1.36), followed by PPLB (1.23) and PPL (1.09) (Table 5). The purchased input percentages of the PP, PPL, and PPLB modes were 76.8, 93.6, and 90.5%, respectively. This indicates that the biogas subsystem of the PPLB mode reduced the percentage of the

purchased input by 3.1% relative to the PPL mode.

3.1.6. Environmental loading ratio (ELR)

Among the four modes, the ELR was highest for PC (6.10), followed by HPIP (2.92), PP (2.72), and CP (2.60) (Table 4). This indicated that the dragon fruit cultivation (the PC mode) had the highest dependence on non-renewable resources, the lowest utilization rate of renewable environmental resources, and the largest pressure on the environment. ELR was lowest for the CP mode because corn cultivation required the purchase of substantial quantities of manure, 68% of which was considered to be a renewable resource.

Among the three modes involving pepper, the ELR was highest for PPL (11.91), followed by PPLB (8.47) and PP (2.72) (Table 5).

Table 5
Indices for the energy evaluation of the pepper ecological engineering modes.

Indices	PP	PPL	PPLB
Em-Power Density (EPD) (*E+11)	4.67 ± 0.6	16.92 ± 4.3	11.50 ± 3.5
Energy Self-sufficiency Ratio (ESR)	0.25 ± 0.04	0.08 ± 0.03	0.16 ± 0.06
Energy Exchange Ratio (EER)	3.76 ± 1.46	3.13 ± 0.36	3.33 ± 1.14
Energy Yield Ratio (EYR)	1.36 ± 0.08	1.09 ± 0.03	1.23 ± 0.09
Environmental Loading Ratio (ELR)	2.72 ± 0.4	11.91 ± 3.8	8.47 ± 2.8
Energy Restoration Ratio (ERR)	1.59 ± 0.4	0.41 ± 0.1	1.00 ± 0.4
Energy Benefit Ratio (EBR)	2.95 ± 0.4	1.50 ± 0.2	2.23 ± 0.5
Energy Sustainability Index (ESI)	0.60 ± 0.2	0.13 ± 0.5	0.33 ± 0.2
Energy Index for Sustainable Development (EISD)	3.17 ± 2.0	0.45 ± 0.2	1.48 ± 0.7

Table 6

Indices for the economic evaluation of the planting modes.

Indices	PP	PC	HPIP	CP
Input with I_f (I) (yuan.yr ⁻¹ .ha ⁻¹)	11308.22	56373.93	27821.26	40765.81
Input without I_f (I_a) (yuan.yr ⁻¹ .ha ⁻¹)	4876.15	24574.1	3236.06	5903.13
Output (O) (yuan.yr ⁻¹ .ha ⁻¹)	32498.29	50528.85	25820.59	18487.5
Economic Output/Input with I_f (O/I)	2.77 ± 0.4	0.81 ± 0.3	0.85 ± 0.4	0.46 ± 0.1
Economic Output/Input without I_f (O/I _a)	7.68 ± 1.7	2.30 ± 0.6	7.29 ± 1.8	3.33 ± 0.7
Economic benefit per unit (EBU, O-I) (yuan.yr ⁻¹ .ha ⁻¹)	21190.07 ± 6477.3	-5845.08 ± 18141.9	-2000.68 ± 13270.9	-22278.31 ± 5275.6
Economic pure benefit per unit (EPBU, O-I _a) (yuan.yr ⁻¹ .ha ⁻¹)	27622.14 ± 6356.9	25954.74 ± 17264.3	22584.53 ± 11040.5	12584.38 ± 4909.7

 I_a is the actual economic input of the systems, I_f is the input for free of the systems which was converted to the market value. $I = I_a + I_f$.

The raw amounts are noted in Appendix B.1–B.6. The same as Table 7.

Table 7

Indices for the economic evaluation of the pepper ecological engineering modes.

Indices	PP	PPL	PPLB
Input with I_f (I) (yuan.yr ⁻¹ .ha ⁻¹)	11308.22	68497.56	32384.57
Input without I_f (I_a) (yuan.yr ⁻¹ .ha ⁻¹)	4876.15	47544.44	18684.34
Output (O) (yuan.yr ⁻¹ .ha ⁻¹)	32498.29	116245	59929.29
Economic Output/Input with I_f (O/I)	2.77 ± 0.4	1.76 ± 0.4	2.32 ± 0.5
Economic Output/Input without I_f (O/I _a)	7.68 ± 1.7	2.50 ± 0.5	8.38 ± 3.5
Economic benefit per unit (EBU, O-I) (yuan.yr ⁻¹ .ha ⁻¹)	21190.07 ± 6477.3	47747.44 ± 30292.1	27544.72 ± 9548.3
Economic pure benefit per unit (EPBU, O-I _a) (yuan.yr ⁻¹ .ha ⁻¹)	27622.14 ± 6356.9	68700.56 ± 27532.6	41244.95 ± 9994.3

3.1.7. Energy restoration ratio (ERR)

Among the four modes, the ERR was highest for HPIP (5.40), followed by PC (2.46), PP (1.59), and CP (0.57) (Table 4). This indicated that the ecological benefits were greater with the three ecological management modes (HPIP, PC, and PP) than with the traditional cropping system (CP) and that rocky desertification control was best with the HPIP mode.

Among the three modes involving pepper, the ERR was highest for PP (1.59), followed by PPLB (1.0) and PPL (0.41) (Table 5). The livestock subsystem and the biogas subsystem did not increase the ecological control benefits. Because addition of livestock and biogas subsystems increased the total energy inputs to the PP and PPL modes but did not change the ecological benefits of the pepper planting subsystem (479.21×10^{13} sej/ha/yr), the ERR was lower for the PPL and PPLB modes than for the PP mode.

3.1.8. Energy benefit ratio (EBR)

Among the four modes, the EBR was highest for HPIP (6.58), followed by PC (3.57), PP (2.95), and CP (1.64) (Table 4). This indicated that integrated ecological–economic benefits were greater for the three rocky desertification control modes (HPIP, PC, and PP) than for the traditional agricultural system (CP). Furthermore, the ecological and economic benefits were highest for the HPIP mode.

Among the three modes involving pepper, EBR was highest for PP (2.95), followed by PPL (1.5) and PPLB (2.23) (Table 5).

3.1.9. Energy sustainability index (ESI)

Among the four modes, the ESI was highest for PP (0.60), followed by HPIP (0.49), CP (0.42), and PC (0.26) (Table 4). The PC mode had the lowest ESI because it had the highest ELR, i.e., its ELR was 2.24 times greater than that of the PP mode. As a result, the ESI of the PC mode was only 0.43 times that of the PP mode.

Among the three modes involving pepper, the ESI was highest for PP (0.6), followed by PPLB (0.33) and PPL (0.13) (Table 5). The introduction of the livestock subsystem did not support the sustainable development capacity of the pepper planting system, but

the addition of the biogas subsystem partly made up for this.

3.1.10. Energy index for sustainable development (EISD)

Among the four modes, the PP mode had the highest EISD (3.17), which was 6.47, 12.68, and 16.68 times greater than that of the HPIP (0.49), PC (0.25), and CP (0.19) modes, respectively. Although the ESI was higher for the CP mode than for the PC mode, the EISD was higher for the PC mode than for the CP mode due to the high EER of the dragon fruit, which was 2.78 times greater than that of corn.

Among the three modes involving pepper, EISD was highest for the PP mode (3.17), followed by the PPLB (1.48) and PPL (0.45) modes. This order resulted from ELR and EER values, which were 4.38 and 0.83 times greater, respectively, for the PPL than for the PP mode; as a consequence, the EISD of the PPL mode was only 14.2% of that of the PP mode.

3.2. Economic benefits

The PP mode had the lowest economic input (11,308.22 yuan yr⁻¹ ha⁻¹) but the highest economic output/input ratio (2.77) and the highest economic benefits per unit (EBU, 21,190.07 yuan yr⁻¹ ha⁻¹), while the CP mode had the lowest economic output/input ratio (0.46) and the lowest EBU (-22,278.31 yuan yr⁻¹ ha⁻¹). The PC mode had the highest economic input (56,373.93 yuan yr⁻¹ ha⁻¹) but had a negative EBU (-5845.08 yuan yr⁻¹ ha⁻¹). For the HPIP mode, the EBU was -2000.68 yuan yr⁻¹ ha⁻¹, and the economic output/input ratio was 0.85 (Table 6). The PC, HPIP, and CP modes had economic deficit problems if the labor from the farmers and the poultry manure from the breeding were included in the costs; the CP mode had the worst economic situation. If the labor from the farmers and the poultry manure from the breeding subsystem were not included in the cost, all four modes had positive economic benefit, and the PP mode had the highest economic benefit (27622.14 yuan yr⁻¹ ha⁻¹) (Table 6).

Although the economic output/input ratio decreased from 2.77

to 1.76 with the introduction of the livestock subsystem to the PP mode, the EBU of the PPL mode was one times higher than that of the PP mode. The economic input of the PPLB mode was only 0.47 times that of the PPL mode, but the economic output/input ratio was 1.32 times greater for the PPLB mode than for the PPL mode (**Table 7**). This indicated that the economic viability was greater for the PPLB mode than for the PPL mode, i.e., the PPLB mode required a lower economic investment but generated a higher economic output. If the labor from the farmers was not included in the cost, the PPLB mode had the highest economic output/input ratio (8.38), while the PPL mode had the highest EPBU (68700.56 yuan $\text{yr}^{-1} \text{ha}^{-1}$) (**Table 6**).

4. Discussion

4.1. Comparison of the three typical modes and the traditional mode

4.1.1. Energy indices

The three typical rocky desertification control modes (PP, PC, and HPIP) were superior to the traditional planting of corn (the CP mode), and the best control was provided by the PP mode. Because their resilience low, karst ecosystems are quite fragile. Karst areas will experience drought if it doesn't rain for 10 days and will be flooded if it rains heavily. It is therefore difficult to determine how to achieve ecological management while considering the survival demands of the farmers. Fortunately, all five indices (ESI, EISD, ESR, EER, and EYR) indicated that all three rocky desertification control modes were more sustainable than a traditional cropping system (represented by the planting of corn in this study). Among the four modes, the PP mode was the most sustainable; it had the highest ESI and EISD due to its highest EYR, EER, and lower ELR.

Pepper products provide local farmers with high economic benefits from pepper planting. The PP mode had the highest EER among the three control modes due to the well-known superior quality of its pepper products and the mode itself, i.e., "Dingtan" pepper was certified as a China Geographical Indications Product (CGIP) in 2008, and Zhenfeng County is considered the "Chinese pepper town" because of "Dingtan" pepper produced there (*Zhou, 2009*).

The PP mode also had the highest EYR among the three control modes because fewer energy inputs were purchased for the PP mode than for the other modes. However, the highest percentage of natural renewable resource inputs was only 19.7% for the PP mode, which is much lower than that of the biogas-linked agrosystem with planting, breeding, aquaculture, and biogas subsystems (BLAS) (43% renewable resource inputs) in Gongcheng Yao Autonomous County (a karst area in south China) (*Chen and Chen, 2012*). The percentage of natural renewable resource inputs was also higher for the sustainable, integrated agricultural mode (SIAM) (35.43%) in Yichun County of Tongchuan City, Shanxi Province, China, where the average annual rainfall is 0.709 m, and the annual solar radiation is approximately $5.27\text{E}+09 \text{ J/m}^2$ (*Wu et al., 2015*). In other words, although the temperature and hydrology conditions are not worse for the area practicing the PP mode than for areas practicing the BLAS or SIAM modes, the natural renewable resources utilization ratio is lower for the PP mode. This suggests that the local government should improve the utilization rate of the local natural resources, especially the abundant water and heat resources.

From a solely ecological perspective, the HPIP mode was better than the others as indicated by the ERR and EBR. Because of the

inter-planting of herbal and woody plants, the HPIP mode had superior conservation of water and soil than the other modes. However, the honeysuckle price has decreased substantially in recent years (**Table 2**) because the variety of honeysuckle under growing was fund different from the variety demanded by pharmaceutical companies. Given the decline in honeysuckle price and demand, the local government should identify the pharmaceutical values of the existing variety and should then brand that variety. The government could also replace the existing varieties with the varieties demanded by the pharmaceutical companies.

The price of pitaya also declined in 2016 (**Table 2**). If these ecological management modes are affected by large market fluctuations, the enthusiasm of farmers for practicing these modes will be reduced. Furthermore, the harvest time of honeysuckle and plum overlap and is short, which results in labor shortages. In some cases, some honeysuckles were not harvested because the price was too low. In order to enhance the enthusiasm of farmers for practicing these modes, the local government needs to further extending the industrial chain of the main products from these control modes, broadening the sales channels, researching and developing processed products and increasing market demanding based on the local agricultural characteristics. At the same time, a labor market could be established to avoid labor shortages.

4.1.2. Economic indices

If labor input from the farmers and the manure from their farms are included in market prices, the PC, HPIP, and CP modes (but not the PP mode) resulted in financial loss as indicated by both the economic output/input ratio and the EBU. The EPBU showed that the farmers can obtain economic income if labor input from the farmers themselves and the manure from their farms are not counted. In other words, the income of the PC, HPIP, and CP modes is actually a relatively lower reward for their own labor and manure inputs.

4.2. Comparison of the three pepper modes

4.2.1. Energy indices

The PP mode was improved by simultaneously adding both the livestock and biogas subsystems rather than adding only the livestock subsystem. ESI, EISD, ESR, EER, EYR, ERR, and EBR indicated that the PP mode was more sustainable than the PPL and PPLB modes. In the PPL mode, the livestock subsystem reduced the purchase of non-renewable resources such as fertilizer by 30.5%, while the inputs of forage and immature animals increased non-renewable resources by 55.14% (**Fig. 5**). Thus, the ELR was 3.38 times higher for the PPL mode than for the PP mode. The biogas subsystem increased the energy output of biogas by $44.3 \times 10^{13} \text{ sej/ha/yr}$ relative to the PPL mode (**Fig. 3**); because of the recycling of the byproducts (manure) from the livestock subsystem, EYR was 12.8% higher for the PPLB mode than for the PPL mode (**Table 5**).

The sustainability of both the PP and PPLB modes needs to be improved, although both have certain advantages compared with some other agro-ecosystems in karst areas. The PP mode was more sustainable than the biogas-linked agricultural system in Gongcheng Yao Autonomous County of China, i.e., it had higher values for EYR, ELR, and ESI (*Yang and Chen, 2014*). The PP mode, however, was inferior to the BLAS planting subsystem (*Chen and Chen, 2012*) and the complex biogas system (CBS) composed by planting, aquaculture, breeding, and biogas subsystems at Gongcheng Yao

Autonomous County of China (Chen and Chen, 2014). The EYR, ELR, and ESI values for the PPLB mode are superior to those for the biogas-linked agricultural system (Yang and Chen, 2014) but inferior to those for the BLAS (Chen and Chen, 2012), the CBS (Chen and Chen, 2014), and the SIAM (Wu et al., 2015). The local government can improve the planting and management technology by enhancing the cooperation between universities and research institutes and by training the farmers. These rocky desertification control modes can provide substantial economic benefits to local farmers while simultaneously protecting the environment and consequently improving regional sustainable development in the karst areas.

4.2.2. Economic indices

The introduction of the two ecological engineering subsystems, livestock and biogas subsystems, could improve the economic viability of the PP mode. The EBU of the PPL and PPLB modes were 2.25 and 1.3 times higher, respectively, than that of the PP mode.

To reduce poverty among local farmers and to improve regional sustainability, both livestock and biogas subsystems should be simultaneously added to the planting systems. The economic performances of the four planting modes were inferior to those of the PPL and PPLB modes. The government can expand the production chains (such as the livestock, biogas, and agricultural product processing) to support the markets for products in combination with poverty alleviation. Considering that the demands for chemical fertilizers, immature animals, and forage are large, the local poverty alleviation sectors may consider providing immature animals (cattle, pigs, and chickens), forages, and fertilizers as subsidies to the farmers.

Among the three pepper modes, the PPLB mode had the highest economic output/input ratio, and the PPL mode had the highest EPBU without accounting for labor input from the farmers themselves. This means that the PPL and PPLB modes are better options than the PP mode. The government should encourage local farmers to adopt the PPL and PPLB modes.

5. Conclusion

It is difficult to develop suitable systems for rocky desertification control in karst areas because karst environments are very fragile. The ecological–economic performances of all three rocky desertification control modes were superior to that of the traditional corn planting system. The PP mode was the most sustainable among the four pure planting modes, while the HPIP mode was the best in terms of ecological benefits.

Appendix A.1

Energy analysis table of the PP method in 2013 (/ha/yr).

Item	Raw amounts					EUVs (sej.unit ⁻¹)	Solar energy (sej)					Average (sej)	
	1	2	3	4	5		1	2	3	4	5		
Input													
Renewable resource (R)													
Solar radiation (J) ¹	2.92E+13	2.92E+13	2.92E+13	2.92E+13	2.92E+13	1.00E+00 ^a	2.92E+13	2.92E+13	2.92E+13	2.92E+13	2.92E+13	2.92E+13	
Wind (J) ²	4.50E+11	4.50E+11	4.50E+11	4.50E+11	4.50E+11	1.90E+03 ^a	8.56E+14	8.56E+14	8.56E+14	8.56E+14	8.56E+14	8.56E+14	
Rain (chemical) (J) ³	3.93E+10	3.93E+10	3.93E+10	3.93E+10	3.93E+10	2.35E+04 ^a	9.21E+14	9.21E+14	9.21E+14	9.21E+14	9.21E+14	9.21E+14	
Water (for irrigation) (J)	1.33E+08	1.00E+08	1.22E+08	1.19E+08	1.13E+08	2.35E+04 ^a	3.11E+12	2.35E+12	2.86E+12	2.80E+12	2.65E+12	2.75E+12	
Subtotal,							9.24E+14	9.23E+14	9.24E+14	9.24E+14	9.24E+14	9.24E+14	
R = Rain + Water													
Nonrenewable resource (N)													
Loss of topsoil													
Total N (g)	4.26E+03	4.26E+03	4.26E+03	4.26E+03	4.26E+03	4.64E+08 ^b	1.98E+12	1.98E+12	1.98E+12	1.98E+12	1.98E+12	1.98E+12	
Total P (g)	1.42E+03	1.42E+03	1.42E+03	1.42E+03	1.42E+03	5.07E+09 ^b	7.20E+12	7.20E+12	7.20E+12	7.20E+12	7.20E+12	7.20E+12	

Adding the livestock subsystem to the PP mode can improve its annual economic output per unit area but decrease its economic output/input ratio and sustainable development capacity. If the labor from farmers is not counted in the cost, the PPL mode had the highest economic output/input ratio, i.e., the addition of the biogas subsystem can improve the economic output/input ratio and the sustainability of the PPL mode to a certain extent. Thus, farmers should simultaneously add the livestock and biogas subsystems to the PP mode in order to achieve both economic and environmental benefits.

Based on the results, we suggest that local governments improve the technology support for these modes, e.g., the local governments should identify the pharmaceutical values of the currently planted varieties in order to decrease marketing risk or replace the existing varieties with the varieties demanded by the pharmaceutical companies. Local governments should also help farmers in expanding the production chains of these modes; for example, local governments could develop factories for processing agricultural products and encourage farmers to add livestock and biogas subsystems into their planting systems simultaneously. The government should also help farmers expand their markets by establishing and promoting brands for honeysuckle, plum, and pitaya. Finally, the government should establish a short-term supply of migrant workers in support of the honeysuckle-plum industry.

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Appendix

Appendix A.1 (continued)

Item	Raw amounts					EUVs (sej.unit ⁻¹)	Solar energy (sej)					Average (sej)
	1	2	3	4	5		1	2	3	4	5	
Total K (g)	7.93E+03	7.93E+03	7.93E+03	7.93E+03	7.93E+03	1.31E+09 ^c	1.04E+13	1.04E+13	1.04E+13	1.04E+13	1.04E+13	1.04E+13
Organic (J)	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	9.41E+04 ^d	1.41E+14	1.41E+14	1.41E+14	1.41E+14	1.41E+14	1.41E+14
Subtotal (Total N + Total P + Total K + Organic)							1.60E+14	1.60E+14	1.60E+14	1.60E+14	1.60E+14	1.60E+14
Local resource (I), I = R + N							1.08E+15	1.08E+15	1.08E+15	1.08E+15	1.08E+15	1.08E+15
Purchased renewable resource (F _R)												
Labor (10%) # (J)	6.63E+07	6.21E+07	4.18E+07	5.62E+07	7.84E+07	2.20E+06 ^e	1.46E+14	1.37E+14	9.21E+13	1.24E+14	1.73E+14	1.34E+14
Manure (68%)## (J)	1.19E+09	7.77E+09	6.65E+09	6.57E+09	4.20E+09	3.50E+04 ^f	4.18E+13	2.72E+14	2.33E+14	2.30E+14	1.47E+14	1.85E+14
Subtotal							1.88E+14	4.09E+14	3.25E+14	3.54E+14	3.20E+14	3.19E+14
Purchased nonrenewable resource (F _N)												
Pepper seedling (yuan)	2.78E+01	2.63E+01	2.55E+01	2.78E+01	2.63E+01	4.37E+11*	1.21E+13	1.15E+13	1.11E+13	1.21E+13	1.15E+13	1.17E+13
Labor (90%)# (J)	5.97E+08	5.59E+08	3.76E+08	5.06E+08	7.05E+08	2.20E+06 ^e	1.31E+15	1.23E+15	8.29E+14	1.11E+15	1.55E+15	1.21E+15
Farming tools (yuan)	4.62E+01	1.08E+02	9.00E+01	1.07E+02	8.86E+01	4.37E+11*	2.02E+13	4.74E+13	3.93E+13	4.68E+13	3.87E+13	3.85E+13
Construction of reservoirs (yuan)	3.85E+01	6.94E+01	5.00E+01	5.95E+01	5.68E+01	4.37E+11*	1.68E+13	3.04E+13	2.19E+13	2.60E+13	2.48E+13	2.40E+13
Fertilizer (kg)	0.00E+00	6.67E+02	6.60E+02	1.07E+03	2.73E+02	3.56E+12 ^g	0.00E+00	2.38E+15	2.35E+15	3.82E+15	9.72E+14	1.90E+15
Manure (32%)## (J)	5.62E+08	3.66E+09	3.13E+09	3.09E+09	1.98E+09	3.50E+04 ^f	1.96E+13	1.28E+14	1.09E+14	1.08E+14	6.92E+13	8.69E+13
Subtotal							1.38E+15	3.82E+15	3.36E+15	5.13E+15	2.67E+15	3.27E+15
Purchased resource (F), F=F _R +F _N							1.57E+15	4.23E+15	3.69E+15	5.48E+15	2.99E+15	3.59E+15
Total input (U), U=I+F							2.66E+15	5.32E+15	4.77E+15	6.56E+15	4.07E+15	4.68E+15
Yield (Y₁), Y₁=U							2.66E+15	5.32E+15	4.77E+15	6.56E+15	4.07E+15	4.68E+15
Pepper												
Ecological benefits (Y ₂)												
Water conservation (W _C) ³	3.93E+10	3.93E+10	3.93E+10	3.93E+10	3.93E+10	2.35E+04 ^a	9.21E+14	9.21E+14	9.21E+14	9.21E+14	9.21E+14	9.21E+14
Soil reinforcement (S _R) ⁴												
Total N (g)	2.56E+03	2.56E+03	2.56E+03	2.56E+03	2.56E+03	4.64E+08 ^b	1.19E+12	1.19E+12	1.19E+12	1.19E+12	1.19E+12	1.19E+12
Total P (g)	8.52E+02	8.52E+02	8.52E+02	8.52E+02	8.52E+02	5.07E+09 ^b	4.32E+12	4.32E+12	4.32E+12	4.32E+12	4.32E+12	4.32E+12
Total K (g)	4.76E+03	4.76E+03	4.76E+03	4.76E+03	4.76E+03	1.31E+09 ^c	6.23E+12	6.23E+12	6.23E+12	6.23E+12	6.23E+12	6.23E+12
Organic (J)	8.98E+08	8.98E+08	8.98E+08	8.98E+08	8.98E+08	9.41E+04 ^d	8.45E+13	8.45E+13	8.45E+13	8.45E+13	8.45E+13	8.45E+13
subtotal							9.62E+13	9.62E+13	9.62E+13	9.62E+13	9.62E+13	9.62E+13
Fertility (F _E) ⁵												
Total N (g)	4.46E+03	4.46E+03	4.46E+03	4.46E+03	4.46E+03	4.64E+08 ^b	2.07E+12	2.07E+12	2.07E+12	2.07E+12	2.07E+12	2.07E+12
Total P (g)	1.50E+04	1.50E+04	1.50E+04	1.50E+04	1.50E+04	5.07E+09 ^b	7.60E+13	7.60E+13	7.60E+13	7.60E+13	7.60E+13	7.60E+13
Total K (g)	-1.46E+04	-1.46E+04	-1.46E+04	-1.46E+04	-1.46E+04	1.31E+09 ^c	-1.91E+13	-1.91E+13	-1.91E+13	-1.91E+13	-1.91E+13	-1.91E+13
Organic (J)	3.82E+10	3.82E+10	3.82E+10	3.82E+10	3.82E+10	9.41E+04 ^d	3.60E+15	3.60E+15	3.60E+15	3.60E+15	3.60E+15	3.60E+15
subtotal							3.65E+15	3.65E+15	3.65E+15	3.65E+15	3.65E+15	3.65E+15
Carbon fixation (C _F) (g) ⁶	1.70E+07	1.70E+07	1.70E+07	1.70E+07	1.70E+07	6.19E+06 ^b	1.05E+14	1.05E+14	1.05E+14	1.05E+14	1.05E+14	1.05E+14
Oxygen production (O _P) (g) ⁶	1.25E+07	1.25E+07	1.25E+07	1.25E+07	1.25E+07	1.22E+06 ^b	1.53E+13	1.53E+13	1.53E+13	1.53E+13	1.53E+13	1.53E+13
Total Y ₂ =W _C +S _R +F _E +C _F +O _P							4.79E+15	4.79E+15	4.79E+15	4.79E+15	4.79E+15	4.79E+15
Indices												
Em-Power Density (EPD)							2.65E+11	5.31E+11	4.77E+11	6.56E+11	4.07E+11	4.67E+11
Energy Self-sufficiency Ratio (ESR)							0.41	0.20	0.23	0.17	0.27	0.25
Energy Exchange Ratio (EER)							9.12	1.92	1.58	1.52	4.68	3.76
Energy Yield Ratio (EYR)							1.69	1.26	1.29	1.20	1.36	1.36
Environmental Loading Ratio (ELR)							1.39	2.99	2.82	4.14	2.28	2.72
Energy Restoration Ratio (ERR)							3.05	1.13	1.30	0.87	1.60	1.59
Energy Benefit Ratio (EBR)							4.74	2.39	2.59	2.07	2.97	2.95
Energy Sustainability Index (ESI)							1.22	0.42	0.46	0.29	0.60	0.60
Energy Index for Sustainable Development (EISD)							11.10	0.81	0.73	0.44	2.80	3.17

Appendix A.2

Energy analysis table of the PC method in 2013 (/ha/yr).

Item	Raw amounts					EUVs (sej.unit ⁻¹)	Solar energy (sej)					Average (sej)
	1	2	3	4	5		1	2	3	4	5	
Input												
Renewable resource (R)												
Solar radiation (J) ¹	2.92E+13	2.92E+13	2.92E+13	2.92E+13	2.92E+13	1.00E+00 ^a	3.78E+13	3.78E+13	3.78E+13	3.78E+13	3.78E+13	3.78E+13
Wind (J) ²	4.50E+11	4.50E+11	4.50E+11	4.50E+11	4.50E+11	1.90E+03 ^a	8.56E+14	8.56E+14	8.56E+14	8.56E+14	8.56E+14	8.56E+14
Rain (chemical) (J) ^{7,8}	3.05E+10	3.05E+10	3.05E+10	3.05E+10	3.05E+10	2.35E+04 ^a	7.15E+14	7.15E+14	7.15E+14	7.15E+14	7.15E+14	7.15E+14
Water (for irrigation) (J)	4.73E+08	5.32E+08	5.91E+08	4.73E+08	5.91E+08	2.35E+04 ^a	1.11E+13	1.25E+13	1.39E+13	1.11E+13	1.39E+13	1.25E+13
Subtotal, R = Wind + Water							8.67E+14	8.69E+14	8.70E+14	8.67E+14	8.70E+14	8.69E+14
Nonrenewable resource (N)												
Loss of topsoil ⁹												
Total N (g)	8.21E+03	8.21E+03	8.21E+03	8.21E+03	8.21E+03	4.64E+08 ^b	3.81E+12	3.81E+12	3.81E+12	3.81E+12	3.81E+12	3.81E+12
Total P (g)	2.10E+03	2.10E+03	2.10E+03	2.10E+03	2.10E+03	5.07E+09 ^b	1.07E+13	1.07E+13	1.07E+13	1.07E+13	1.07E+13	1.07E+13
Total K (g)	4.44E+04	4.44E+04	4.44E+04	4.44E+04	4.44E+04	1.31E+09 ^c	5.81E+13	5.81E+13	5.81E+13	5.81E+13	5.81E+13	5.81E+13
Organic (J)	3.98E+09	3.98E+09	3.98E+09	3.98E+09	3.98E+09	9.41E+04 ^d	3.74E+14	3.74E+14	3.74E+14	3.74E+14	3.74E+14	3.74E+14
Subtotal (Total N + Total P + Total K + Organic)							4.47E+14	4.47E+14	4.47E+14	4.47E+14	4.47E+14	4.47E+14
Local resource (I), I = R + N							1.31E+15	1.32E+15	1.32E+15	1.31E+15	1.32E+15	1.32E+15
Purchased renewable resource (F _R)												
Labor (10%) [#] (J)	3.35E+08	2.09E+08	3.66E+08	2.09E+08	5.24E+08	2.20E+06 ^e	7.38E+14	4.60E+14	8.07E+14	4.60E+14	1.15E+15	7.24E+14
Manure (68%) ^{##} (J)	3.09E+10	8.32E+10	0.00E+00	1.23E+10	1.01E+09	3.50E+04 ^f	1.08E+15	2.91E+15	0.00E+00	4.29E+14	3.54E+13	8.92E+14
Water (of purchased) (yuan)	0.00E+00	0.00E+00	2.25E+02	0.00E+00	0.00E+00	4.37E+11 [*]	0.00E+00	0.00E+00	9.84E+13	0.00E+00	0.00E+00	1.97E+13
Subtotal							1.82E+15	3.37E+15	9.06E+14	8.90E+14	1.19E+15	1.64E+15
Purchased nonrenewable resource (F _N)												
Pepper seeding (yuan)	3.00E+01	3.00E+01	0.00E+00	0.00E+00	0.00E+00	4.37E+11 [*]	1.31E+13	1.31E+13	0.00E+00	0.00E+00	0.00E+00	5.25E+12
Labor (90%) [#] (J)	1.67E+09	1.04E+09	1.83E+09	1.04E+09	2.62E+09	2.20E+06 ^e	6.64E+15	4.14E+15	7.27E+15	4.14E+15	1.04E+16	6.52E+15
Farming tools (yuan)	1.38E+02	1.00E+02	9.38E+01	1.00E+02	7.50E+01	4.37E+11 [*]	6.05E+13	4.37E+13	4.10E+13	4.37E+13	3.28E+13	4.43E+13
Construction of reservoirs (yuan)	1.92E+02	2.08E+02	3.13E+01	1.39E+02	0.00E+00	4.37E+11 [*]	8.41E+13	9.11E+13	1.37E+13	6.07E+13	0.00E+00	4.99E+13
Compound fertilizer (kg)	0.00E+00	0.00E+00	1.13E+03	2.50E+02	2.00E+03	3.56E+12 ^g	0.00E+00	0.00E+00	4.01E+15	8.91E+14	7.13E+15	2.41E+15
Nitrogenous fertilizer (kg)	0.00E+00	2.50E+02	1.97E+02	0.00E+00	0.00E+00	4.83E+12 ^g	0.00E+00	1.21E+15	9.54E+14	0.00E+00	0.00E+00	4.32E+14
Potassium fertilizer (kg)	0.00E+00	0.00E+00	1.78E+02	0.00E+00	0.00E+00	1.40E+12 ^g	0.00E+00	0.00E+00	2.49E+14	0.00E+00	0.00E+00	4.97E+13
Organic fertilizer (J)	7.73E+10	0.00E+00	1.76E+10	5.00E+01	3.35E+10	3.50E+04 ^f	2.70E+15	0.00E+00	6.15E+14	1.75E+06	1.17E+15	8.98E+14
Potassium phosphate fertilizer												
K (g)	0.00E+00	2.50E+05	0.00E+00	0.00E+00	3.75E+05	1.31E+09 ^c	0.00E+00	3.27E+14	0.00E+00	0.00E+00	4.91E+14	1.64E+14
Cured tobacco fertilizer												
N (g)	0.00E+00	0.00E+00	0.00E+00	6.91E+04	0.00E+00	4.64E+08 ^b	0.00E+00	0.00E+00	0.00E+00	3.20E+13	0.00E+00	6.41E+12
P (g)	0.00E+00	0.00E+00	0.00E+00	1.28E+04	0.00E+00	5.07E+09 ^b	0.00E+00	0.00E+00	0.00E+00	6.49E+13	0.00E+00	1.30E+13
K (g)	0.00E+00	0.00E+00	0.00E+00	1.80E+05	0.00E+00	1.31E+09 ^c	0.00E+00	0.00E+00	0.00E+00	2.36E+14	0.00E+00	4.71E+13
Manure (32%) ^{##} (J)	1.46E+10	3.92E+10	0.00E+00	5.77E+09	4.76E+08	3.50E+04 ^f	5.09E+14	1.37E+15	0.00E+00	2.02E+14	1.67E+13	4.20E+14
Rents (yuan)	0.00E+00	0.00E+00	7.50E+03	0.00E+00	0.00E+00	4.37E+11 [*]	0.00E+00	0.00E+00	3.28E+15	0.00E+00	0.00E+00	6.56E+14
Planting pitaya (yuan)	2.08E+03	2.25E+03	2.25E+03	2.25E+03	2.63E+03	4.37E+11 [*]	9.08E+14	9.84E+14	9.84E+14	9.84E+14	1.15E+15	1.00E+15
Pesticide (yuan)	0.00E+00	1.88E+02	0.00E+00	0.00E+00	0.00E+00	4.37E+11 [*]	0.00E+00	8.20E+13	0.00E+00	0.00E+00	0.00E+00	1.64E+13
Subtotal							1.09E+16	8.26E+15	1.74E+16	6.66E+15	2.04E+16	1.27E+16

Purchased resource (F), $F = F_R + F_N$						1.27E+16	1.16E+16	1.83E+16	7.55E+15	2.16E+16	1.44E+16
Total input (U), $U = I + F$						1.41E+16	1.30E+16	1.96E+16	8.86E+15	2.29E+16	1.57E+16
Yield (Y_1), $Y_1 = U$						1.41E+16	1.30E+16	1.96E+16	8.86E+15	2.29E+16	1.57E+16
Pitaya, Pepper											
Ecological benefits (Y_2)											
Water conservation (W_C) ³	3.05E+10	3.05E+10	3.05E+10	3.05E+10	3.05E+10	2.35E+04 ^a	7.15E+14	7.15E+14	7.15E+14	7.15E+14	7.15E+14
Soil reinforcement (S_R) ⁴											
Total N (g)	-3.51E+03	-3.51E+03	-3.51E+03	-3.51E+03	-3.51E+03	4.64E+08 ^b	-1.63E+12	-1.63E+12	-1.63E+12	-1.63E+12	-1.63E+12
Total P (g)	-8.98E+02	-8.98E+02	-8.98E+02	-8.98E+02	-8.98E+02	5.07E+09 ^b	-4.55E+12	-4.55E+12	-4.55E+12	-4.55E+12	-4.55E+12
Total K (g)	-1.90E+04	-1.90E+04	-1.90E+04	-1.90E+04	-1.90E+04	1.31E+09 ^c	-2.48E+13	-2.48E+13	-2.48E+13	-2.48E+13	-2.48E+13
Organic (J)	-1.70E+09	-1.70E+09	-1.70E+09	-1.70E+09	-1.70E+09	9.41E+04 ^d	-1.60E+14	-1.60E+14	-1.60E+14	-1.60E+14	-1.60E+14
subtotal							-1.91E+14	-1.91E+14	-1.91E+14	-1.91E+14	-1.91E+14
Fertility (F_E) ⁵											
Total N (g)	5.39E+05	5.39E+05	5.39E+05	5.39E+05	5.39E+05	4.64E+08 ^b	2.50E+14	2.50E+14	2.50E+14	2.50E+14	2.50E+14
Total P (g)	-5.99E+04	-5.99E+04	-5.99E+04	-5.99E+04	-5.99E+04	5.07E+09 ^b	-3.03E+14	-3.03E+14	-3.03E+14	-3.03E+14	-3.03E+14
Total K (g)	-2.97E+06	-2.97E+06	-2.97E+06	-2.97E+06	-2.97E+06	1.31E+09 ^c	-3.88E+15	-3.88E+15	-3.88E+15	-3.88E+15	-3.88E+15
Organic (J)	3.60E+11	3.60E+11	3.60E+11	3.60E+11	3.60E+11	9.41E+04 ^d	3.39E+16	3.39E+16	3.39E+16	3.39E+16	3.39E+16
subtotal							2.99E+16	2.99E+16	2.99E+16	2.99E+16	2.99E+16
Carbon fixation (C_F) (g) ⁶	6.54E+07	6.54E+07	6.54E+07	6.54E+07	6.54E+07	6.19E+06 ^b	4.05E+14	4.05E+14	4.05E+14	4.05E+14	4.05E+14
Oxygen production (O_P) (g) ⁶	4.81E+07	4.81E+07	4.81E+07	4.81E+07	4.81E+07	1.22E+06 ^b	5.88E+13	5.88E+13	5.88E+13	5.88E+13	5.88E+13
Total $Y_2 = W_C + S_R + F_E + C_F + O_P$						3.09E+16	3.09E+16	3.09E+16	3.09E+16	3.09E+16	3.09E+16
Indices											
Em-Power Density (EPD)						1.40E+12	1.29E+12	1.96E+12	8.86E+11	2.29E+12	1.57E+12
Emergency Self-sufficiency Ratio (ESR)						0.09	0.10	0.07	0.15	0.06	0.09
Emergency Exchange Ratio (EER)						0.18	0.57	1.34	1.73	2.58	1.28
Emergency Yield Ratio (EVR)						1.10	1.11	1.07	1.17	1.06	1.10
Environmental Loading Ratio (ELR)						4.23	2.05	10.07	4.04	10.12	6.10
Emergency Restoration Ratio (ERR)						2.43	2.66	1.69	4.10	1.43	2.46
Emergency Benefit Ratio (EBR)						3.53	3.77	2.76	5.27	2.50	3.57
Emergency Sustainability Index (ESI)						0.26	0.54	0.11	0.29	0.10	0.26
Emergency Index for Sustainable Development (EISD)						0.05	0.31	0.14	0.50	0.27	0.25

Appendix A.3

Energy analysis table of the HPIP method in 2013 (/ha/yr).

Item	Raw amounts							EUVs (sej.unit ⁻¹)	Solar energy (sej)							Average (sej)	
	1	2	3	4	5	6	7		1	2	3	4	5	6	7		
Input																	
Renewable resource (R)																	
Solar radiation (J) ¹	2.92E+13	2.92E+13	2.92E+13	2.92E+13	2.92E+13	2.92E+13	2.92E+13	1.00E+00 ^a	3.78E+13	3.78E+13	3.78E+13	3.78E+13	3.78E+13	3.78E+13	3.78E+13	3.78E+13	
Wind (J) ²	4.50E+11	4.50E+11	4.50E+11	4.50E+11	4.50E+11	4.50E+11	4.50E+11	1.90E+03 ^a	8.56E+14	8.56E+14	8.56E+14	8.56E+14	8.56E+14	8.56E+14	8.56E+14	8.56E+14	
Rain (chemical) (J) ¹²	4.62E+10	4.62E+10	4.62E+10	4.62E+10	4.62E+10	4.62E+10	4.62E+10	2.35E+04 ^a	1.08E+15	1.08E+15	1.08E+15	1.08E+15	1.08E+15	1.08E+15	1.08E+15	1.08E+15	
Water (for irrigation) (J)								2.35E+04 ^a	1.39E+13	1.11E+13	1.85E+13	1.48E+13	1.39E+13	1.85E+13	1.39E+13	1.49E+13	
Subtotal,									1.10E+15	1.09E+15	1.10E+15	1.10E+15	1.10E+15	1.10E+15	1.10E+15	1.10E+15	
R = Rain + Water																	
Nonrenewable resource (N)																	
Loss of topsoil ¹³																	
Total N (g)	2.05E+02	2.05E+02	2.05E+02	2.05E+02	2.05E+02	2.05E+02	2.05E+02	4.64E+08 ^b	9.51E+10	9.51E+10	9.51E+10	9.51E+10	9.51E+10	9.51E+10	9.51E+10	9.51E+10	
Total P (g)	1.99E+03	1.99E+03	1.99E+03	1.99E+03	1.99E+03	1.99E+03	1.99E+03	5.07E+09 ^b	1.01E+13	1.01E+13	1.01E+13	1.01E+13	1.01E+13	1.01E+13	1.01E+13	1.01E+13	
Total K (g)	1.61E+04	1.61E+04	1.61E+04	1.61E+04	1.61E+04	1.61E+04	1.61E+04	1.31E+09 ^c	2.11E+13	2.11E+13	2.11E+13	2.11E+13	2.11E+13	2.11E+13	2.11E+13	2.11E+13	
Organic (J)	8.03E+08	8.03E+08	8.03E+08	8.03E+08	8.03E+08	8.03E+08	8.03E+08	9.41E+04 ^d	7.55E+13	7.55E+13	7.55E+13	7.55E+13	7.55E+13	7.55E+13	7.55E+13	7.55E+13	
Subtotal (Total N + Total P + Total K + Organic)									1.07E+14	1.07E+14	1.07E+14	1.07E+14	1.07E+14	1.07E+14	1.07E+14	1.07E+14	
Local resource (I),										1.20E+15	1.20E+15	1.21E+15	1.20E+15	1.20E+15	1.21E+15	1.20E+15	1.20E+15
I = R + N																	
Purchased renewable resource (F _R)																	
Labor (10%) [#] (J)	1.57E+08	1.57E+08	1.62E+08	1.96E+08	1.54E+08	1.46E+08	1.63E+08	2.20E+06 ^e	3.45E+14	3.45E+14	3.57E+14	4.32E+14	3.38E+14	3.22E+14	3.58E+14	3.57E+14	
Manure (68%) ^{##} (J)	8.21E+10	5.65E+10	3.71E+10	2.52E+09	3.22E+09	7.54E+08	8.38E+09	3.50E+04 ^f	2.87E+15	1.98E+15	1.30E+15	8.83E+13	1.13E+14	2.64E+13	2.93E+14	9.53E+14	
Subtotal										3.22E+15	2.32E+15	1.66E+15	5.20E+14	4.51E+14	3.49E+14	6.51E+14	1.31E+15
Purchased nonrenewable resource (F _N)																	
honeysuckle seedlings (yuan)	3.75E+01	4.22E+01	3.75E+01	4.22E+01	4.19E+01	4.20E+01	4.17E+01	4.37E+11 [*]	1.64E+13	1.84E+13	1.64E+13	1.84E+13	1.83E+13	1.84E+13	1.82E+13	1.78E+13	
Plum seedlings (yuan)	6.88E+01	6.56E+01	7.50E+00	6.56E+01	1.32E+03	6.75E+01	6.67E+01	4.37E+11 [*]	3.01E+13	2.87E+13	3.28E+12	2.87E+13	5.79E+14	2.95E+13	2.91E+13	1.04E+14	
Seeds of peanut (yuan)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.32E+02	0.00E+00	0.00E+00	4.37E+11 [*]	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.79E+13	0.00E+00	0.00E+00	8.27E+12	
Seeds of corn (kg)	0.00E+00	5.63E+00	0.00E+00	0.00E+00	1.21E+02	0.00E+00	0.00E+00	1.21E+12 ^h	0.00E+00	6.79E+12	0.00E+00	0.00E+00	1.47E+14	0.00E+00	0.00E+00	2.19E+13	
Labor (90%) [#] (J)	1.41E+09	1.41E+09	1.46E+09	1.76E+09	1.38E+09	1.32E+09	1.46E+09	2.20E+06 ^e	3.11E+15	3.11E+15	3.21E+15	3.88E+15	3.05E+15	2.90E+15	3.22E+15	3.21E+15	
Farming tools (yuan)	2.00E+02	1.13E+02	5.50E+01	1.13E+02	1.06E+02	6.00E+01	1.67E+02	4.37E+11 [*]	8.74E+13	4.92E+13	2.40E+13	4.92E+13	4.63E+13	2.62E+13	7.29E+13	5.07E+13	
Construction of reservoirs (yuan)	2.08E+02	1.56E+02	8.33E+01	1.56E+02	7.35E+01	5.00E+01	2.78E+02	4.37E+11 [*]	9.11E+13	6.83E+13	3.64E+13	6.83E+13	3.21E+13	2.19E+13	1.21E+14	6.28E+13	
Compound fertilizer (kg)	2.50E+02	0.00E+00	5.00E+02	1.03E+03	0.00E+00	7.50E+01	0.00E+00	3.56E+12 ^g	8.91E+14	0.00E+00	1.78E+15	3.68E+15	0.00E+00	2.67E+14	0.00E+00	9.45E+14	
Nitrogenous fertilizer (kg)	0.00E+00	6.00E+02	0.00E+00	0.00E+00	3.53E+02	4.80E+01	0.00E+00	4.83E+12 ^g	0.00E+00	2.90E+15	0.00E+00	0.00E+00	1.71E+15	2.32E+14	0.00E+00	6.91E+14	
Manure (32%) ^{##} (J)	3.86E+10	2.66E+10	1.75E+10	1.19E+09	1.51E+09	3.55E+08	3.94E+09	3.50E+04 ^f	1.35E+15	9.31E+14	6.11E+14	4.16E+13	5.30E+13	1.24E+13	1.38E+14	4.48E+14	

Pesticide (yuan)	5.50E+02	0.00E+00	7.50E+02	3.75E+03	1.06E+02	4.50E+01	1.00E+03	4.37E+11*	2.40E+14	0.00E+00	3.28E+14	1.64E+15	4.63E+13	1.97E+13	4.37E+14	3.87E+14
Subtotal									5.82E+15	7.11E+15	6.01E+15	9.40E+15	5.73E+15	3.53E+15	4.04E+15	5.95E+15
Purchased resource (F), F=F _R + F _N									9.03E+15	9.43E+15	7.67E+15	9.92E+15	6.18E+15	3.88E+15	4.69E+15	7.26E+15
Total input (U), U = I + F									1.02E+16	1.06E+16	8.88E+15	1.11E+16	7.39E+15	5.08E+15	5.89E+15	8.46E+15
Yield (Y₁), Y₁ = U									1.02E+16	1.06E+16	8.88E+15	1.11E+16	7.39E+15	5.08E+15	5.89E+15	8.46E+15
Honeysuckle, Plum, Corn																
Ecological benefits (Y ₂)																
Water conservation (W _C) ³	4.50E+11	2.35E+04 ^a	1.08E+15	1.08E+15	1.08E+15	1.08E+15	1.08E+15	1.08E+15	1.08E+15	1.08E+15						
Soil reinforcement (S _R) ⁴																
Total N (g)	1.82E+02	4.64E+08 ^b	8.42E+10	8.42E+10	8.42E+10	8.42E+10	8.42E+10	8.42E+10	8.42E+10	8.42E+10						
Total P (g)	1.76E+03	5.07E+09 ^b	8.93E+12	8.93E+12	8.93E+12	8.93E+12	8.93E+12	8.93E+12	8.93E+12	8.93E+12						
Total K (g)	1.43E+04	1.31E+09 ^c	1.87E+13	1.87E+13	1.87E+13	1.87E+13	1.87E+13	1.87E+13	1.87E+13	1.87E+13						
Organic (J)	7.12E+08	9.41E+04 ^d	6.69E+13	6.69E+13	6.69E+13	6.69E+13	6.69E+13	6.69E+13	6.69E+13	6.69E+13						
subtotal									9.47E+13	9.47E+13	9.47E+13	9.47E+13	9.47E+13	9.47E+13	9.47E+13	9.47E+13
Fertility (F _E) ⁵																
Total N (g)	-2.12E+06	4.64E+08 ^b	-9.84E+14													
Total P (g)	8.15E+05	5.07E+09 ^b	4.13E+15													
Total K (g)	5.14E+06	1.31E+09 ^c	6.73E+15	6.73E+15	6.73E+15	6.73E+15	6.73E+15	6.73E+15	6.73E+15	6.73E+15						
Organic (J)	2.49E+11	9.41E+04 ^d	2.35E+16	2.35E+16	2.35E+16	2.35E+16	2.35E+16	2.35E+16	2.35E+16	2.35E+16						
subtotal									3.33E+16	3.33E+16	3.33E+16	3.33E+16	3.33E+16	3.33E+16	3.33E+16	3.33E+16
Carbon fixation (C _F) (g) ⁶	6.54E+07	6.19E+06 ^b	4.05E+14	4.05E+14	4.05E+14	4.05E+14	4.05E+14	4.05E+14	4.05E+14	4.05E+14						
Oxygen production (O _P) (g) ⁶	4.81E+07	1.22E+06 ^b	5.88E+13	5.88E+13	5.88E+13	5.88E+13	5.88E+13	5.88E+13	5.88E+13	5.88E+13						
Total Y ₂ = W _C + S _R + F _E + C _F + O _P									3.50E+16	3.50E+16	3.50E+16	3.50E+16	3.50E+16	3.50E+16	3.50E+16	3.50E+16
Indices																
Em-Power Density (EPD)									1.02E+12	1.06E+12	8.87E+11	1.11E+12	7.38E+11	5.08E+11	5.89E+11	8.46E+11
Emergency Self-sufficiency Ratio (ESR)									0.12	0.11	0.14	0.11	0.16	0.24	0.20	0.15
Emergency Exchange Ratio (EER)									1.21	0.12	1.50	3.71	0.31	0.23	1.26	1.19
Emergency Yield Ratio (EYR)									1.13	1.13	1.16	1.12	1.19	1.31	1.26	1.18
Environmental Loading Ratio (ELR)									1.37	2.10	2.17	6.22	3.77	2.52	2.37	2.92
Emergency Restoration Ratio (ERR)									3.87	3.71	4.56	3.52	5.66	9.03	7.46	5.40
Emergency Benefit Ratio (EBR)									5.01	4.83	5.68	4.68	6.85	10.34	8.71	6.58
Emergency Sustainability Index (ESI)									0.83	0.54	0.53	0.18	0.32	0.52	0.53	0.49
Emergency Index for Sustainable Development (EISD)									1.00	0.07	0.80	0.67	0.10	0.12	0.67	0.49

Appendix A.4

Emergy analysis table of the CP method in 2013 (/ha/yr).

Item	Raw amounts				EUVs (sej.unit ⁻¹)	Solar emergy (sej)				Average (sej)
	1	2	3	4		1	2	3	4	
Input										
Renewable resource (R)										
Solar radiation (J) ¹	2.92E+13	2.92E+13	2.92E+13	2.92E+13	1.00E+00 ^a	3.78E+13	3.78E+13	3.78E+13	3.78E+13	3.78E+13
Wind (J) ²	4.50E+11	4.50E+11	4.50E+11	4.50E+11	1.90E+03 ^a	8.56E+14	8.56E+14	8.56E+14	8.56E+14	8.56E+14
Rain (chemical) (J) ²	3.01E+10	3.01E+10	3.01E+10	3.01E+10	2.35E+04 ^a	7.06E+14	7.06E+14	7.06E+14	7.06E+14	7.06E+14
Subtotal, R = Wind						8.56E+14	8.56E+14	8.56E+14	8.56E+14	8.56E+14
Nonrenewable resource (N)										
Loss of topsoil ¹⁴										
Total N (g)	2.27E+02	2.27E+02	2.27E+02	2.27E+02	4.64E+08 ^b	1.05E+11	1.05E+11	1.05E+11	1.05E+11	1.05E+11
Total P (g)	1.99E+03	1.99E+03	1.99E+03	1.99E+03	5.07E+09 ^b	1.01E+13	1.01E+13	1.01E+13	1.01E+13	1.01E+13
Total K (g)	1.93E+04	1.93E+04	1.93E+04	1.93E+04	1.31E+09 ^c	2.52E+13	2.52E+13	2.52E+13	2.52E+13	2.52E+13
Organic (J)	9.74E+08	9.74E+08	9.74E+08	9.74E+08	9.41E+04 ^d	9.17E+13	9.17E+13	9.17E+13	9.17E+13	9.17E+13
Subtotal (Total N + Total P + Total K + Organic)						1.27E+14	1.27E+14	1.27E+14	1.27E+14	1.27E+14
Local resource (I), I = R + N						9.83E+14	9.83E+14	9.83E+14	9.83E+14	9.83E+14
Purchased renewable resource (Fr _R)										
Labor (10%) [#] (J)	1.74E+08	1.57E+08	1.04E+08	2.37E+08	2.20E+06 ^e	3.84E+14	3.45E+14	2.30E+14	5.22E+14	3.70E+14
Manure (68%) [#] (J)	1.85E+11	1.81E+11	5.61E+10	4.91E+10	3.50E+04 ^f	6.46E+15	6.35E+15	1.96E+15	1.72E+15	4.12E+15
Subtotal						6.84E+15	6.69E+15	2.19E+15	2.24E+15	4.49E+15
Purchased nonrenewable resource (Fr _N)										
Seeds of corn (kg)	7.50E+00	1.00E+01	0.00E+00	1.25E+01	1.21E+12 ^h	9.06E+12	1.21E+13	0.00E+00	1.51E+13	9.06E+12
Wheat seeds (kg)	1.13E+02	0.00E+00	1.13E+02	1.13E+02	4.29E+12 ^h	4.83E+14	0.00E+00	4.83E+14	4.83E+14	3.62E+14
Rap seeds (J)	9.86E+07	0.00E+00	9.86E+07	9.86E+07	8.94E+05 ⁱ	8.82E+13	0.00E+00	8.82E+13	8.82E+13	6.61E+13
Labor (90%) [#] (J)	1.57E+09	1.41E+09	9.40E+08	2.13E+09	2.20E+06 ^e	3.45E+15	3.11E+15	2.07E+15	4.70E+15	3.33E+15
Farming tools (yuan)	2.50E+02	3.00E+02	3.75E+02	3.00E+02	4.37E+11*	1.09E+14	1.31E+14	1.64E+14	1.31E+14	1.34E+14
Compound fertilizer (kg)	7.50E+02	8.00E+02	0.00E+00	0.00E+00	3.56E+12 ^g	2.67E+15	2.85E+15	0.00E+00	0.00E+00	1.38E+15
Nitrogenous fertilizer (kg)	1.20E+03	1.60E+03	9.00E+02	6.00E+02	4.83E+12 ^g	5.80E+15	7.73E+15	4.35E+15	2.90E+15	5.20E+15
Manure (32%) ^{##} (J)	8.68E+10	8.54E+10	2.64E+10	2.31E+10	3.50E+04 ^f	3.04E+15	2.99E+15	9.24E+14	8.08E+14	1.94E+15
Pesticide (yuan)	1.00E+03	0.00E+00	1.50E+03	1.00E+03	4.37E+11*	4.37E+14	0.00E+00	6.56E+14	4.37E+14	3.83E+14
Subtotal						1.61E+16	1.68E+16	8.74E+15	9.56E+15	1.28E+16
Purchased resource (F), F=Fr _R + Fr _N						2.29E+16	2.35E+16	1.09E+16	1.18E+16	1.73E+16
Total input (U), U = I + F						2.39E+16	2.45E+16	1.19E+16	1.28E+16	1.83E+16
Yield (Y₁), Y₁ = U						2.39E+16	2.45E+16	1.19E+16	1.28E+16	1.83E+16
Corn, Wheat, Rap										
Ecological benefits (Y ₂)										
Water conservation (W _C) ³	3.01E+10	3.01E+10	3.01E+10	3.01E+10	2.35E+04 ^a	7.06E+14	7.06E+14	7.06E+14	7.06E+14	7.06E+14
Soil reinforcement(S _R) ⁴										
Total N (g)	-2.48E+01	-2.48E+01	-2.48E+01	-2.48E+01	4.64E+08 ^b	-1.15E+10	-1.15E+10	-1.15E+10	-1.15E+10	-1.15E+10
Total P (g)	-2.17E+02	-2.17E+02	-2.17E+02	-2.17E+02	5.07E+09 ^b	-1.10E+12	-1.10E+12	-1.10E+12	-1.10E+12	-1.10E+12
Total K (g)	-2.10E+03	-2.10E+03	-2.10E+03	-2.10E+03	1.31E+09 ^c	-2.75E+12	-2.75E+12	-2.75E+12	-2.75E+12	-2.75E+12
Organic (J)	-1.06E+08	-1.06E+08	-1.06E+08	-1.06E+08	9.41E+04 ^d	-9.99E+12	-9.99E+12	-9.99E+12	-9.99E+12	-9.99E+12
subtotal						-1.39E+13	-1.39E+13	-1.39E+13	-1.39E+13	-1.39E+13
Fertility (F _E) ⁵										
Total N (g)	2.29E+04	2.29E+04	2.29E+04	2.29E+04	4.64E+08 ^b	1.06E+13	1.06E+13	1.06E+13	1.06E+13	1.06E+13
Total P (g)	2.06E+04	2.06E+04	2.06E+04	2.06E+04	5.07E+09 ^b	1.04E+14	1.04E+14	1.04E+14	1.04E+14	1.04E+14
Total K (g)	4.99E+04	4.99E+04	4.99E+04	4.99E+04	1.31E+09 ^c	6.52E+13	6.52E+13	6.52E+13	6.52E+13	6.52E+13
Organic (J)	7.86E+10	7.86E+10	7.86E+10	7.86E+10	9.41E+04 ^d	7.39E+15	7.39E+15	7.39E+15	7.39E+15	7.39E+15
subtotal						7.57E+15	7.57E+15	7.57E+15	7.57E+15	7.57E+15
Carbon fixation (C _F) (g) ⁶	6.42E+07	6.42E+07	6.42E+07	6.42E+07	6.19E+06 ^b	3.98E+14	3.98E+14	3.98E+14	3.98E+14	3.98E+14
Oxygen production (O _P) (g) ⁶	2.36E+07	2.36E+07	2.36E+07	2.36E+07	1.22E+06 ^b	2.89E+13	2.89E+13	2.89E+13	2.89E+13	2.89E+13
Total Y ₂ = W _C + S _R + F _E + C _F + O _P						8.69E+15	8.69E+15	8.69E+15	8.69E+15	8.69E+15
Indices										
Em-Power Density (EPD)						2.39E+12	2.45E+12	1.19E+12	1.28E+12	1.83E+12
Energy Self-sufficiency Ratio (ESR)						0.04	0.04	0.08	0.08	0.06
Energy Exchange Ratio (EER)						0.61	0.21	0.55	0.47	0.46
Energy Yield Ratio (EYR)						1.04	1.04	1.09	1.08	1.06
Environmental Loading Ratio (ELR)						2.11	2.25	2.91	3.13	2.60
Energy Restoration Ratio (ERR)						0.38	0.37	0.80	0.74	0.57
Energy Benefit Ratio (EBR)						1.42	1.41	1.89	1.82	1.64
Energy Sustainability Index (ESI)						0.49	0.46	0.38	0.35	0.42
Energy Index for Sustainable Development (EISD)						0.30	0.10	0.21	0.16	0.19

Appendix A.5

Energy analysis table of the PPL method in 2013 (/ha/yr).

Item	Raw amounts				EUVs (sej.unit ⁻¹)	Solar energy (sej)				Average (sej)
	1	2	3	4		1	2	3	4	
Input										
Renewable resource (R)										
Solar radiation (J) ¹	2.92E+13	2.92E+13	2.92E+13	2.92E+13	1.00E+00 ^a	2.92E+13	2.92E+13	2.92E+13	2.92E+13	2.92E+13
Wind (J) ²	4.50E+11	4.50E+11	4.50E+11	4.50E+11	1.90E+03 ^a	8.56E+14	8.56E+14	8.56E+14	8.56E+14	8.56E+14
Rain (chemical) (J) ³	3.93E+10	3.93E+10	3.93E+10	3.93E+10	2.35E+04 ^a	9.21E+14	9.21E+14	9.21E+14	9.21E+14	9.21E+14
Water (for irrigation) (J)	1.33E+08	1.13E+08	1.25E+08	9.32E+07	2.35E+04 ^a	3.11E+12	2.65E+12	2.94E+12	2.19E+12	2.72E+12
Water (for livestock) (J)	2.97E+08	1.42E+08	2.19E+08	7.42E+07	2.35E+04 ^a	6.96E+12	3.32E+12	5.13E+12	1.74E+12	4.29E+12
Subtotal, R = Rain + Water						9.31E+14	9.27E+14	9.29E+14	9.25E+14	9.28E+14
Nonrenewable resource (N)										
Loss of topsoil (Total N + Total P + Total K + Organic)										
Total N (g)	4.26E+03	4.26E+03	4.26E+03	4.26E+03	4.64E+08 ^b	1.98E+12	1.98E+12	1.98E+12	1.98E+12	1.98E+12
Total P (g)	1.42E+03	1.42E+03	1.42E+03	1.42E+03	5.07E+09 ^b	7.20E+12	7.20E+12	7.20E+12	7.20E+12	7.20E+12
Total K (g)	7.93E+03	7.93E+03	7.93E+03	7.93E+03	1.31E+09 ^c	1.04E+13	1.04E+13	1.04E+13	1.04E+13	1.04E+13
Organic (J)	1.50E+09	1.50E+09	1.50E+09	1.50E+09	9.41E+04 ^d	1.41E+14	1.41E+14	1.41E+14	1.41E+14	1.41E+14
Subtotal						1.60E+14	1.60E+14	1.60E+14	1.60E+14	1.60E+14
Local resource (I), I = R + N						1.09E+15	1.09E+15	1.09E+15	1.09E+15	1.09E+15
Purchased renewable resource (F _R)										
Labor (10%) [#] (J)	9.66E+07	2.21E+08	2.21E+08	1.28E+08	2.20E+06 ^e	2.13E+14	4.88E+14	4.86E+14	2.82E+14	3.67E+14
Manure (68%) ^{##} (J)	6.73E+08	1.89E+09	1.57E+09	1.08E+09	3.50E+04 ^f	2.36E+13	6.60E+13	5.50E+13	3.77E+13	4.56E+13
Subtotal						2.36E+14	5.54E+14	5.41E+14	3.19E+14	4.13E+14
Purchased nonrenewable resource (F _N)										
Pepper seedling (yuan)	2.78E+01	2.63E+01	2.63E+01	2.44E+01	4.37E+11 [*]	1.21E+13	1.15E+13	1.15E+13	1.07E+13	1.14E+13
Chili seedlings (yuan)	1.43E+02	0.00E+00	0.00E+00	0.00E+00	4.37E+11 [*]	6.24E+13	0.00E+00	0.00E+00	0.00E+00	1.56E+13
Seeds of peanut (kg)	1.36E+01	0.00E+00	0.00E+00	0.00E+00	2.25E+13 ^c	3.06E+14	0.00E+00	0.00E+00	0.00E+00	7.65E+13
Labor (90%) [#] (J)	8.69E+08	1.99E+09	1.99E+09	1.15E+09	2.20E+06 ^e	1.92E+15	4.39E+15	4.37E+15	2.53E+15	3.30E+15
Farming tools (yuan)	6.43E+01	1.50E+02	1.88E+02	8.57E+01	4.37E+11 [*]	2.81E+13	6.56E+13	8.20E+13	3.75E+13	5.33E+13
Construction of reservoirs (yuan)	5.95E+01	8.33E+01	1.04E+02	7.14E+01	4.37E+11 [*]	2.60E+13	3.64E+13	4.55E+13	3.12E+13	3.48E+13
Compound fertilizer (kg)	0.00E+00	1.00E+03	9.38E+02	0.00E+00	3.56E+12 ^g	0.00E+00	3.56E+15	3.34E+15	0.00E+00	1.73E+15
Manure (32%) ^{##} (J)	3.17E+08	8.87E+08	7.39E+08	5.07E+08	3.50E+04 ^f	1.11E+13	3.10E+13	2.59E+13	1.77E+13	2.14E+13
Chicks (yuan)	1.07E+04	1.95E+02	5.69E+02	1.67E+02	4.37E+11 [*]	4.67E+15	8.52E+13	2.49E+14	7.31E+13	1.27E+15
Piglets (kg)	1.07E+01	3.00E+01	7.50E+01	2.57E+01	9.15E+12 ^h	9.80E+13	2.74E+14	6.86E+14	2.35E+14	3.23E+14
Cow cubs (kg)	0.00E+00	2.00E+02	2.50E+02	8.57E+01	6.35E+12 ^a	0.00E+00	1.27E+15	1.59E+15	5.44E+14	8.50E+14
Corn (kg)	1.50E+04	2.00E+03	2.19E+03	7.50E+02	1.21E+12 ^h	1.81E+16	2.42E+15	2.64E+15	9.06E+14	6.02E+15
Forage (kg)	0.00E+00	4.00E+02	1.00E+03	3.43E+02	1.81E+12 ^j	0.00E+00	7.26E+14	1.81E+15	6.22E+14	7.90E+14
Rice bran (yuan)	0.00E+00	6.50E+02	0.00E+00	0.00E+00	4.37E+11 [*]	0.00E+00	2.84E+14	0.00E+00	0.00E+00	7.10E+13
Animal drugs (yuan)	2.14E+03	0.00E+00	1.25E+02	0.00E+00	4.37E+11 [*]	9.37E+14	0.00E+00	5.46E+13	0.00E+00	2.48E+14
Electricity (J)	1.03E+07	3.60E+07	4.50E+07	1.85E+07	2.21E+05 ^k	2.27E+12	7.95E+12	9.94E+12	4.09E+12	6.06E+12
Building Chicken house, barn, pigsty (yuan)	5.75E+02	1.83E+03	2.15E+03	7.93E+02	4.37E+11 [*]	2.51E+14	8.00E+14	9.40E+14	3.47E+14	5.84E+14
Subtotal						2.64E+16	1.40E+16	1.59E+16	5.36E+15	1.54E+16
Purchased resource (F), F=F _R + F _N						2.67E+16	1.45E+16	1.64E+16	5.68E+15	1.58E+16
Total input (U), U = I + F						2.78E+16	1.56E+16	1.75E+16	6.77E+15	1.69E+16
Yield (Y₁), Y₁ = U						2.78E+16	1.56E+16	1.75E+16	6.77E+15	1.69E+16
Ecological benefits (Y ₂)										
Water conservation (W _C) ³	3.93E+10	3.93E+10	3.93E+10	3.93E+10	2.35E+04 ^a	9.21E+14	9.21E+14	9.21E+14	9.21E+14	9.21E+14
Soil reinforcement (S _R) ⁴										
Total N (g)	5.90E+02	5.90E+02	5.90E+02	5.90E+02	4.64E+08 ^b	1.19E+12	1.19E+12	1.19E+12	1.19E+12	1.19E+12
Total P (g)	1.97E+02	1.97E+02	1.97E+02	1.97E+02	5.07E+09 ^b	4.32E+12	4.32E+12	4.32E+12	4.32E+12	4.32E+12
Total K (g)	1.10E+03	1.10E+03	1.10E+03	1.10E+03	1.31E+09 ^c	6.23E+12	6.23E+12	6.23E+12	6.23E+12	6.23E+12
Organic (J)	2.07E+08	2.07E+08	2.07E+08	2.07E+08	9.41E+04 ^d	8.45E+13	8.45E+13	8.45E+13	8.45E+13	8.45E+13
subtotal						9.62E+13	9.62E+13	9.62E+13	9.62E+13	9.62E+13
Fertility (F _E) ⁵										
Total N (g)	1.03E+03	1.03E+03	1.03E+03	1.03E+03	4.64E+08 ^b	2.07E+12	2.07E+12	2.07E+12	2.07E+12	2.07E+12
Total P (g)	3.46E+03	3.46E+03	3.46E+03	3.46E+03	5.07E+09 ^b	7.60E+13	7.60E+13	7.60E+13	7.60E+13	7.60E+13
Total K (g)	-3.37E+03	-3.37E+03	-3.37E+03	-3.37E+03	-3.37E+03	-1.91E+13	-1.91E+13	-1.91E+13	-1.91E+13	-1.91E+13
Organic (J)	8.82E+09	8.82E+09	8.82E+09	8.82E+09	9.41E+04 ^d	3.60E+15	3.60E+15	3.60E+15	3.60E+15	3.60E+15
subtotal						3.65E+15	3.65E+15	3.65E+15	3.65E+15	3.65E+15
Carbon fixation (C _F) (g) ⁶	3.93E+06	3.93E+06	3.93E+06	3.93E+06	6.19E+06 ^b	1.05E+14	1.05E+14	1.05E+14	1.05E+14	1.05E+14
Oxygen production (O _P) (g) ⁶	2.89E+06	2.89E+06	2.89E+06	2.89E+06	1.22E+06 ^b	1.53E+13	1.53E+13	1.53E+13	1.53E+13	1.53E+13
Total Y ₂ = W _C + S _R + F _E + C _F + O _P						4.79E+15	4.79E+15	4.79E+15	4.79E+15	4.79E+15
Indices										
Em-Power Density (EPD)						2.77E+12	1.56E+12	1.75E+12	6.76E+11	1.69E+12
Emergency Self-sufficiency Ratio (ESR)						0.04	0.07	0.06	0.16	0.08
Emergency Exchange Ratio (EER)						3.23	2.44	2.73	4.11	3.13
Emergency Yield Ratio (EYR)						1.04	1.07	1.07	1.19	1.09
Environmental Loading Ratio (ELR)						22.77	9.54	10.90	4.44	11.91
Emergency Restoration Ratio (ERR)						0.18	0.33	0.29	0.84	0.41
Emergency Benefit Ratio (EBR)						1.22	1.41	1.36	2.03	1.50
Emergency Sustainability Index (ESI)						0.05	0.11	0.10	0.27	0.13
Emergency Index for Sustainable Development (EISD)						0.15	0.28	0.27	1.10	0.45

Appendix A.6

Appendix A.5 Energy analysis table of the PPLB method in 2013 (/ha/yr).

Water conservation (W_C) ³	3.93E+10	3.93E+10	3.93E+10	3.93E+10	3.93E+10	3.93E+10	2.35E+04 ^a	9.21E+14	9.21E+14	9.21E+14	9.21E+14	9.21E+14	9.21E+14	9.21E+14
Soil reinforcement (S_R) ⁴														
Total N (g)	2.56E+03	2.56E+03	2.56E+03	2.56E+03	2.56E+03	2.56E+03	4.64E+08 ^b	1.19E+12	1.19E+12	1.19E+12	1.19E+12	1.19E+12	1.19E+12	1.19E+12
Total P (g)	8.52E+02	8.52E+02	8.52E+02	8.52E+02	8.52E+02	8.52E+02	5.07E+09 ^b	4.32E+12	4.32E+12	4.32E+12	4.32E+12	4.32E+12	4.32E+12	4.32E+12
Total K (g)	4.76E+03	4.76E+03	4.76E+03	4.76E+03	4.76E+03	4.76E+03	1.31E+09 ^c	6.23E+12	6.23E+12	6.23E+12	6.23E+12	6.23E+12	6.23E+12	6.23E+12
Organic (J)								8.45E+13	8.45E+13	8.45E+13	8.45E+13	8.45E+13	8.45E+13	8.45E+13
subtotal	8.98E+08	8.98E+08	8.98E+08	8.98E+08	8.98E+08	8.98E+08	9.41E+04 ^d	9.62E+13	9.62E+13	9.62E+13	9.62E+13	9.62E+13	9.62E+13	9.62E+13
Fertility (F_E) ⁵														
Total N (g)	4.46E+03	4.46E+03	4.46E+03	4.46E+03	4.46E+03	4.46E+03	4.64E+08 ^b	2.07E+12	2.07E+12	2.07E+12	2.07E+12	2.07E+12	2.07E+12	2.07E+12
Total P (g)	1.50E+04	1.50E+04	1.50E+04	1.50E+04	1.50E+04	1.50E+04	5.07E+09 ^b	7.60E+13	7.60E+13	7.60E+13	7.60E+13	7.60E+13	7.60E+13	7.60E+13
Total K (g)	-1.46E+04	-1.46E+04	-1.46E+04	-1.46E+04	-1.46E+04	-1.46E+04	1.31E+09 ^c	-1.91E+13	-1.91E+13	-1.91E+13	-1.91E+13	-1.91E+13	-1.91E+13	-1.91E+13
Organic (J)								3.82E+10	3.82E+10	3.82E+10	3.82E+10	9.41E+04 ^d	3.60E+15	3.60E+15
subtotal	3.82E+10	3.82E+10	3.82E+10	3.82E+10	3.82E+10	3.82E+10							3.65E+15	3.65E+15
Carbon fixation (C_F) (g) ⁶	1.70E+07	1.70E+07	1.70E+07	1.70E+07	1.70E+07	1.70E+07	6.19E+06 ^b	1.05E+14	1.05E+14	1.05E+14	1.05E+14	1.05E+14	1.05E+14	1.05E+14
Oxygen production (O_P) (g) ⁶	1.25E+07	1.25E+07	1.25E+07	1.25E+07	1.25E+07	1.25E+07	1.22E+06 ^b	1.53E+13	1.53E+13	1.53E+13	1.53E+13	1.53E+13	1.53E+13	1.53E+13
Total $Y_2 = W_C + S_R + F_E + C_F + O_P$								4.79E+15	4.79E+15	4.79E+15	4.79E+15	4.79E+15	4.79E+15	4.79E+15
Indices														
Em-Power Density (EPD)								7.81E+11	1.89E+12	4.78E+11	2.49E+12	9.98E+11	2.68E+11	1.15E+12
Emergency Self-sufficiency Ratio (ESR)								0.14	0.06	0.23	0.04	0.11	0.40	0.16
Emergency Exchange Ratio (EER)								2.87	1.55	8.77	1.46	1.76	3.53	3.33
Emergency Yield Ratio (EYR)								1.16	1.06	1.29	1.05	1.12	1.68	1.23
Environmental Loading Ratio (ELR)								5.74	13.97	2.77	19.42	7.36	1.59	8.47
Emergency Restoration Ratio (ERR)								0.71	0.27	1.30	0.20	0.54	3.00	1.00
Emergency Benefit Ratio (EBR)								2.33	1.50	3.42	1.38	2.01	6.59	2.87
Emergency Sustainability Index (ESI)								0.20	0.08	0.47	0.05	0.15	1.06	0.33
Emergency Index for Sustainable Development (EISD)								0.58	0.12	4.09	0.08	0.27	3.73	1.48

¹ Chen et al., 2007a,b; ² Zhenfeng Meteorological Bureau; ³ Peng et al., 2008; ⁴ Wang, 2009; ⁵ Zhou et al., 2009; ⁶ Zhang and Ren, 2006; ⁷ Peng, 2006; ⁸ Hu, 2008; ⁹ Liao et al., 2012; ¹⁰ Luo et al., 2011a,b; ¹¹ Gao and Xiong, 2015; ¹² Zhou, 2010; ¹³ Ren et al., 2015; ¹⁴ Liu, 2014; ¹⁵ Soil and Fertilizer Station of Agricultural Bureau of Zhenfeng Country.

^a Campbell et al., 2005 (converted to 12.0E24 sej.yr⁻¹ baseline from 9.26E24 sej.yr⁻¹ baseline); ^b Campbell et al., 2014 (converted to 12.0E24 sej.yr⁻¹ baseline from 9.26E24 sej.yr⁻¹ baseline); ^c Brandt-Williams, 2002 (converted to 12.0E24 sej.yr⁻¹ baseline from 15.83 E24 sej.yr⁻¹ baseline); ^d Lu et al., 2006 (converted to 12.0E24 sej.yr⁻¹ baseline from 9.26E24 sej.yr⁻¹ baseline); ^e Lan et al., 1998 (converted to 12.0E24 sej.yr⁻¹ baseline from 9.44E+24 sej.yr⁻¹ baseline); ^f Lan et al., 2002 (converted to 12.0E24 sej.yr⁻¹ baseline from 9.26E24 sej.yr⁻¹ baseline); ^g Odum, 1996 (converted to 12.0E24 sej.yr⁻¹ baseline from 9.44 E24 sej.yr⁻¹ baseline); ^h Odum et al., 1998, (converted to 12.0E24 sej.yr⁻¹ baseline from 9.44 E24 sej.yr⁻¹ baseline); ⁱ The Energy Database: <http://energydatabase.org/>(accessed 05.31.16); ^j Hu et al., 2011 (converted to 12.0E24 sej.yr⁻¹ baseline from 9.26E24 sej.yr⁻¹ baseline); ^k Mitchell, 1979 (converted to 12.0E24 sej.yr⁻¹ baseline from 9.44 E24 sej.yr⁻¹ baseline).

* EMR (Energy Money Ratio) was deduced by the linear correlation between the energy/money ratio and GDP found by Campbell and Lu (2007) as the Chinese GDP smoothing index of year 2005–2013 is 2.155 (GDP₂₀₁₃/GDP₂₀₀₅ = 2608.6/1210.4 = 2.155, GDP is calculated at constant prices in GDP₁₉₇₈ = 100), and converted to 12.0E24 sej.yr⁻¹ baseline from 9.26 E24 sej.yr⁻¹.

90% of the energy input required for lobar was assumed to be F_N , which left 10% to be classified as F_R (Lu et al., 2014).

68% of the energy input required for manure was assumed to be F_R , which left 32% to be classified as F_N (Yang and Chen, 2014).

Appendix B.1

Economical raw amounts of the PP method in 2013 (/ha/yr).

Item	Money (yuan)					Average (yuan)	
	1	2	3	4	5		
Input (I)							
Input for actual (I_a)							
Pepper seeding	27.75	26.25	25.50	27.75	26.25	26.70	
Labor of purchased	6923.08	3500.00	0.00	2400.00	6136.36	3791.89	
Farming tools	46.15	108.33	90.00	107.14	88.64	88.05	
Construction of reservoirs	38.46	69.44	50.00	59.52	56.82	54.85	
Fertilizer	0.00	1066.67	1056.00	1714.29	736.36	914.66	
Subtotal I_a	7035.44	4770.69	1221.50	4308.70	7044.43	4876.15	
Input for free (I_f)							
Labor of farmers	5815.38	5760.00	5760.00	5828.57	5890.91	5810.97	
Manure	140.45	914.61	782.28	773.21	494.91	621.09	
Subtotal I_f	5955.84	6674.61	6542.28	6601.79	6385.82	6432.07	
Total input $I = I_a + I_f$	12991.28	11445.31	7763.78	10910.49	13430.26	11308.22	
Output (O)							
Pepper	55384.61538	23333.33	17280.00	22857.14	43636.36	32498.29	
Total output	55384.62	23333.33	17280.00	22857.14	43636.36	32498.29	
Indices							
Input with I_f	12991.28	11445.31	7763.78	10910.49	13430.26	11308.22	
Input without I_f	7035.44	4770.69	1221.50	4308.70	7044.43	4876.15	
Output	55384.62	23333.33	17280.00	22857.14	43636.36	32498.29	
Economic Output/Input with I_f (O/I)	4.26	2.04	2.23	2.09	3.25	2.77	
Economic Output/Input without I_f (O/I_a)	7.87	4.89	14.15	5.30	6.19	7.68	
Economic benefit per unit (EBU, O-I)	42393.33	11888.02	9516.22	11946.65	30206.11	21190.07	
Economic pure benefit per unit (EPBU, O-I_a)	48349.17	18562.64	16058.50	18548.44	36591.93	27622.14	

Appendix B.2

Economical raw amounts of the PC method in 2013 (/ha/yr).

Item	Money (yuan)					Average (yuan)	
	1	2	3	4	5		
Input (I)							
Input for actual (I_a)							
Planting pitaya	2076.92	2250.00	2250.00	2250.00	2625.00	2290.38	
Labor of purchased	15000.00	0.00	18750.00	0.00	28000.00	12350.00	
water	0.00	0.00	225.00	0.00	0.00	45.00	
Pepper seeding	30.00	30.00	0.00	0.00	0.00	12.00	
Farming tools	138.46	100.00	93.75	100.00	75.00	101.44	
Construction of reservoirs	192.31	208.33	31.25	138.89	0.00	114.16	
Compound fertilizer	0.00	0.00	3562.50	750.00	6600.00	2182.50	
Nitrogenous fertilizer	0.00	456.25	0.00	0.00	0.00	91.25	
Potassium fertilizer	0.00	0.00	3112.50	0.00	0.00	622.50	
Organic fertilizer	2307.69	0.00	7312.50	1250.00	5250.00	3224.04	
Potassium phosphate fertilizer	0.00	1800.00	0.00	0.00	2550.00	870.00	
Cured tobacco fertilizer	0.00	0.00	0.00	5666.67	0.00	1133.33	
Rents	0.00	0.00	7500.00	0.00	0.00	1500.00	
Pesticide	0.00	187.50	0.00	0.00	0.00	37.50	
Subtotal I_a	19745.38	5032.08	42837.50	10155.56	45100.00	24574.10	
Input for free (I_f)							
Labor of farmers	28800.00	28800.00	28800.00	28800.00	28800.00	28800.00	
Manure	3640.88	9794.83	0.00	1444.33	119.09	2999.82	
Subtotal I_f	32440.88	38594.83	28800.00	30244.33	28919.09	31799.82	
Total input $I = I_a + I_f$	52186.26	43626.91	71637.50	40399.88	74019.09	56373.93	
Output (O)							
Pitaya	0.00	12500.00	60000.00	35000.00	135000.00	48500.00	
Pepper	5769.23	4375.00	0.00	0.00	0.00	2028.85	
Total output	5769.23	16875.00	60000.00	35000.00	135000.00	50528.85	
Indices							
Input with I_f	52186.26	43626.91	71637.50	40399.88	74019.09	56373.93	
Input without I_f	19745.38	5032.08	42837.50	10155.56	45100.00	24574.10	
Output	5769.23	16875.00	60000.00	35000.00	135000.00	50528.85	
Economic Output/Input with I_f (O/I)	0.11	0.39	0.84	0.87	1.82	0.81	
Economic Output/Input without I_f (O/I_a)	0.29	3.35	1.40	3.45	2.99	2.30	
Economic benefit per unit (EBU, O-I)	-46417.03	-26751.91	-11637.50	-5399.88	60980.91	-5845.08	
Economic pure benefit per unit (EPBU, O-I_a)	-13976.15	11842.92	17162.50	24844.44	89900.00	25954.74	

Appendix B.3

Economical raw amounts of the HPIP method in 2013 (/ha/yr).

Item	Money (yuan)							Average (yuan)	
	1	2	3	4	5	6	7		
Input (I)									
Input for actual (I_a)									
Labor of purchased honeysuckle seedlings	0.00	0.00	1000.00	1875.00	0.00	0.00	0.00	410.71	
Plum seedlings	37.50	42.19	37.50	42.19	41.91	42.00	41.67	40.71	
Seeds of peanut	68.75	65.63	7.50	65.63	1323.53	67.50	66.67	237.89	
Seeds of corn	0.00	0.00	0.00	0.00	132.35	0.00	0.00	18.91	
Farming tools	200.00	22.50	0.00	0.00	750.00	0.00	0.00	110.36	
Construction of reservoirs	208.33	156.25	83.33	156.25	73.53	50.00	277.78	143.64	
Compound fertilizer	950.00	0.00	1900.00	3918.75	0.00	225.00	0.00	999.11	
Nitrogenous fertilizer	0.00	1200.00	0.00	0.00	661.76	48.00	0.00	272.82	
Pesticide	550.00	0.00	750.00	3750.00	105.88	45.00	1000.00	885.84	
Subtotal I_a	2014.58	1599.06	3833.33	9920.31	3194.85	537.50	1552.78	3236.06	
Input for free (I_f)									
Labor of farmers	21600.00	21600.00	21120.00	21600.00	21176.47	20160.00	22400.00	21379.50	
Manure	9667.08	6652.12	4369.56	297.16	378.88	88.77	986.38	3205.71	
Subtotal I_f	31267.08	28252.12	25489.56	21897.16	21555.35	20248.77	23386.38	24585.20	
Total input $I = I_a + I_f$	33281.66	29851.18	29322.90	31817.47	24750.20	20786.27	24939.16	27821.26	
Output (O)									
Honeysuckle + peanut + corn	12500.00	3000.00	4750.00	56250.00	0.00	900.00	6000.00	11914.29	
Plum	15750.00	0.00	26000.00	37500.00	5294.12	1800.00	11000.00	13906.30	
Total output	28250.00	3000.00	30750.00	93750.00	5294.12	2700.00	17000.00	25820.59	
Indices									
Input with I_f	33281.66	29851.18	29322.90	31817.47	24750.20	20786.27	24939.16	27821.26	
Input without I_f	2014.58	1599.06	3833.33	9920.31	3194.85	537.50	1552.78	3236.06	
Output	28250.00	3000.00	30750.00	93750.00	5294.12	2700.00	17000.00	25820.59	
Economic Output/Input with I_f (O/I_f)	0.85	0.10	1.05	2.95	0.21	0.13	0.68	0.85	
Economic Output/Input without I_f (O/I_a)	14.02	1.88	8.02	9.45	1.66	5.02	10.95	7.29	
Economic benefit per unit (EBU, O-I_f)	-5031.66	-26851.18	1427.10	61932.53	-19456.09	-18086.27	-7939.16	-2000.68	
Economic pure benefit per unit (EPBU, O-I_a)	26235.42	1400.94	26916.67	83829.69	2099.26	2162.50	15447.22	22584.53	

Appendix B.4

Economical raw amounts of the CP method in 2013 (/ha/yr).

Item	Money (yuan)				Average (yuan)	
	1	2	3	4		
Input (I)						
Input for actual (I_a)						
Labor of purchased seeds of corn	0.00	0.00	0.00	5000.00	1250.00	
Wheat seeds	750.00	1000.00	0.00	1250.00	750.00	
Rap seeds	337.50	0.00	337.50	337.50	253.13	
Farming tools	18.75	0.00	37.50	18.75	18.75	
Compound fertilizer	250.00	300.00	375.00	300.00	306.25	
Nitrogenous fertilizer	3000.00	1000.00	0.00	0.00	1000.00	
Pesticide	1200.00	1600.00	1800.00	1200.00	1450.00	
Subtotal I_a	6556.25	3900.00	4050.00	9106.25	5903.13	
Input for free (I_f)						
Labor of farmers	24000.00	21600.00	14400.00	24000.00	21000.00	
Manure	21720.23	21350.34	6603.80	5776.36	13862.68	
Subtotal I_f	45720.23	42950.34	21003.80	29776.36	34862.68	
Total input $I = I_a + I_f$	52276.48	46850.34	25053.80	38882.61	40765.81	
Output (O)						
Corn	13500.00	11700.00	9750.00	9750.00	11175.00	
Wheat	1875.00	0.00	2250.00	1125.00	1312.50	
Rap	18000.00	0.00	3000.00	3000.00	6000.00	
Total output	33375.00	11700.00	15000.00	13875.00	18487.50	
Indices						
Input with I_f	52276.48	46850.34	25053.80	38882.61	40765.81	
Input without I_f	6556.25	3900.00	4050.00	9106.25	5903.13	
Output	33375.00	11700.00	15000.00	13875.00	18487.50	
Economic Output/Input with I_f (O/I_f)	0.64	0.25	0.60	0.36	0.46	
Economic Output/Input without I_f (O/I_a)	5.09	3.00	3.70	1.52	3.33	
Economic benefit per unit (EBU, O-I_f)	-18901.48	-35150.34	-10053.80	-25007.61	-22278.31	
Economic pure benefit per unit (EPBU, O-I_a)	26818.75	7800.00	10950.00	4768.75	12584.38	

Appendix B.5

Economical raw amounts of the PPL method in 2013 (/ha/yr).

Item	Money (yuan)				Average (yuan)	
	1	2	3	4		
Input (I)						
Input for actual (I_a)						
Labor of purchased	1071.43	6000.00	0.00	3085.71	2539.29	
Pepper seeding	27.75	26.25	26.25	24.38	26.16	
Chili seedlings	142.86	0.00	0.00	0.00	35.71	
Seeds of peanut	67.86	0.00	0.00	0.00	16.96	
Farming tools	64.29	150.00	187.50	85.71	121.88	
Construction of reservoirs	59.52	83.33	104.17	71.43	79.61	
Compound fertilizer	0.00	1600.00	3000.00	0.00	1150.00	
Chicks	10678.57	195.00	568.75	167.14	2902.37	
Piglets	214.29	600.00	1500.00	514.29	707.14	
Cow cubs	0.00	33600.00	42000.00	14400.00	22500.00	
Corn	38976.79	4400.00	5250.00	1800.00	12606.70	
Forage	0.00	2560.00	6400.00	2194.29	2788.57	
Rice bran	0.00	650.00	0.00	0.00	162.50	
Animal drugs	2142.86	0.00	125.00	0.00	566.96	
Electricity	1.36	4.75	5.94	2.44	3.62	
Building Chicken house, barn, pigsty	575.00	1830.00	2150.00	792.86	1336.96	
Subtotal I_a	54022.56	51699.33	61317.60	23138.25	47544.44	
Input for free (I_f)						
Labor of farmers	12799.29	25470.00	30397.50	15145.71	20953.13	
Subtotal I_f	12799.29	25470.00	30397.50	15145.71	20953.13	
Total input I = $I_a + I_f$	66821.85	77169.33	91715.10	38283.96	68497.56	
Output (O)						
Pepper	17857.14	16000.00	25000.00	24000.00	20714.29	
Chili	892.86	0.00	0.00	0.00	223.21	
Peanut	1428.57	0.00	0.00	0.00	357.14	
Chicken	184000.00	1800.00	5250.00	1851.43	48225.36	
Pig	785.71	2200.00	5500.00	1714.29	2550.00	
Cow	0.00	67200.00	73500.00	36000.00	44175.00	
Total output	204964.29	87200.00	109250.00	63565.71	116245.00	
Indices						
Input with I_f	66821.85	77169.33	91715.10	38283.96	68497.56	
Input without I_f	54022.56	51699.33	61317.60	23138.25	47544.44	
Output	204964.29	87200.00	109250.00	63565.71	116245.00	
Economic Output/Input with I_f (O/I_f)	3.07	1.13	1.19	1.66	1.76	
Economic Output/Input without I_f (O/I_a)	3.79	1.69	1.78	2.75	2.50	
Economic benefit per unit (EBU, O-I)	138142.44	10030.67	17534.90	25281.75	47747.44	
Economic pure benefit per unit (EPBU, O- I_a)	150941.73	35500.67	47932.40	40427.47	68700.56	

Appendix B.6

Economical raw amounts of the PPLB method in 2013 (/ha/yr).

Item	Money (yuan)					Average (yuan)	
	1	2	3	4	5		
Input (I)							
Input for actual (I_a)							
Labor of purchased	3090.91	3333.33	5454.55	0.00	0.00	1979.80	
Pepper seeding	24.38	24.38	27.75	26.25	24.38	25.25	
Seeds of peanut	0.00	0.00	0.00	55.00	16.30	16.11	
Farming tools	45.45	60.00	102.27	75.00	78.26	71.19	
Construction of reservoirs	37.88	55.56	56.82	41.67	54.35	47.17	
Compound fertilizer	0.00	0.00	0.00	800.00	0.00	133.33	
Pesticide	0.00	100.00	0.00	0.00	65.22	42.24	
Chicks	354.55	260.00	243.75	130.00	635.87	143.38	
Piglets	0.00	0.00	0.00	300.00	5478.26	0.00	
Cow cubs	5454.55	9146.67	0.00	37000.00	0.00	8600.20	
Corn	3272.73	1300.00	0.00	2750.00	0.00	286.76	
Forage grass + forage	2636.36	21770.00	0.00	1280.00	0.00	4281.06	
Rice bran	0.00	0.00	0.00	750.00	0.00	125.00	
Electricity	1.94	2.38	3.24	2.85	4.65	1.05	
Building Chicken house, barn, pigsty	477.27	941.67	262.50	1359.00	430.43	13.24	
Pig sowing	272.73	200.00	68.18	0.00	0.00	90.15	
Building digesters	98.48	72.22	147.73	108.33	282.61	95.59	
Manure (of purchased)	0.00	0.00	0.00	0.00	0.00	134.16	
Subtotal I_a	15767.23	37266.19	6366.78	44678.10	7070.33	957.41	

Appendix B.6 (continued)

Item	Money (yuan)						Average (yuan)
	1	2	3	4	5	6	
Input for free (I_f)							
Labor of farmers	12027.27	17560.00	15095.45	16890.00	14752.17	5876.47	13700.23
Subtotal I_f	12027.27	17560.00	15095.45	16890.00	14752.17	5876.47	13700.23
Total input $I = I_a + I_f$	27794.50	54826.19	21462.24	61568.10	21822.50	6833.88	32384.57
Output (O)							
Pepper	27272.73	30000.00	40909.09	12000.00	13043.48	21176.47	24066.96
Peanut	0.00	0.00	0.00	975.00	293.48	441.18	284.94
Chicken	3927.27	2880.00	2700.00	1200.00	5869.57	0.00	2762.81
Pig	0.00	733.33	4090.91	1100.00	20086.96	0.00	4335.20
Cow	9545.45	18480.00	0.00	67200.00	0.00	0.00	15870.91
biogas	417.65	1029.36	553.60	816.40	883.31	41.39	623.62
Piglets	10181.82	14000.00	47727.27	0.00	0.00	0.00	11984.85
Total output	51344.93	67122.69	95980.87	83291.40	40176.79	21659.04	59929.29
Indices							
Input with I_f	27794.50	54826.19	21462.24	61568.10	21822.50	6833.88	32384.57
Input without I_f	15767.23	37266.19	6366.78	44678.10	7070.33	957.41	18684.34
Output	51344.93	67122.69	95980.87	83291.40	40176.79	21659.04	59929.29
Economic Output/Input with I_f (O/I_f)	1.85	1.22	4.47	1.35	1.84	3.17	2.32
Economic Output/Input without I_f (O/I_a)	3.26	1.80	15.08	1.86	5.68	22.62	8.38
Economic benefit per unit (EBU, $O-I_f$)	23550.43	12296.50	74518.63	21723.30	18354.29	14825.16	27544.72
Economic pure benefit per unit (EPBU, $O-I_a$)	35577.70	29856.50	89614.09	38613.30	33106.46	20701.63	41244.95

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