

An optimal model of a agriculture circular system for paddy & edible fungus & dry land*

Yong Zhao¹, Dong Zhang¹, Yonglu Tang², Jiao Wang¹, Lingyong Zheng^{2†}

¹ Uncertainty Decision-Making Laboratory, Sichuan University, Chengdu 610064, P. R. China

² Sichuan Academy of Agricultural Sciences, Chengdu 610066, P. R. China

(Received January 18 2009, Revised July 1 2009, Accepted August 26 2009)

Abstract. Paddy circular economic system, edible fungus economic system and dry land economic system constitute of the typical circular agricultural system. In the process of developing the circular economy, it is necessary to build a mathematical model to optimize the circular production of the system both on economic and ecological benefits. Based on building a multi-objective linear programming model of the typical circular agricultural system, this paper get some significant results and conclusion combining with genetic algorithm. The conclusions show that comprehensive utilization the agricultural wastes can bring huge economic and ecological benefits.

Keywords: optimal model, multi-objective linear programming, typical circular agricultural system, genetic algorithm

1 Introduction

There is increasing need to treat wastes from the world's farms and factories from reducing pollution to using the wastes as sources of feeds, foods, fertilizers and chemicals and energy and so to reduce the use of fresh raw materials in the preparation of these commodities. And agricultural wastes from paddy circular system and dry land circular system connect the edible fungus circular production system with the two systems mentioned above. These three systems constitute the typical circular agricultural system. The serious environmental situation in the agriculture is a consequence of agricultural specialization, pollution from industries, incorrect wastes management and the unsustainable lifestyle prevailing in the countries all over the world. Increased recycling of agricultural wastes within the agricultural systems will increase environmental and socio-economic benefits.

Agriculture is both close to real life and circular economy, and in order to achieve the delicate planting, it is necessary to study the agriculture by mathematical model to optimize the agricultural production from different aspects. [18] presents a mathematical formulation of the physicochemical and biological principles that govern the composting process. The model may be a useful tool for the prediction of the co-composting process performance in the future and could be used to assist in the operation of co-composting plants. The region optimal planning mathematical model of water saving irrigation was established based on considering the available quantity of irrigation water, types of water resource, areas of crop, project present situation of water saving irrigation and applicability of water saving irrigation technique in [2].

[3] focuses on mathematic model of agricultural eco-engineering at meso-lever. Based on the analysis, a

* This research was supported by the National Science Foundation for Distinguished Young Scholars (Grant No. 70425005), the Key Program of NSFC (Grant No. 70831005), the Key Program of Ministry of Education for Philosophy and Social Sciences research (Grant No. 08JHQ0002), P. R. China.

† Corresponding author. Tel.: +86-28-84504005, fax: +86-28-84504005; E-mail address: zly6559@126.com.

mathematical model of medium-sized agro-ecological engineering—Liuminying ecological agricultural systems established. The mathematical model has been applied to guiding the practical production in Liuminying Village and satisfactory results are achieved. Based on analysis of the relationship of agriculture water resources and its sustainable development, [6] presents a multi-objective fuzzy optimization model for planting structure, which has a close relationship with the optimal allocation of agriculture water resources, and a new method named fuzzy decision weight is applied to the decision of the objective weight in this paper.

Being different from literatures focusing on environment and management factors influencing the yield, some literatures focus on cropping decisions about land use and choosing the crops to grow. Cropping decisions in farm and regional level mainly involve determining the crops to be grown and the area to be used for each kind of crop. [13, 20] suggest the methods of multi-objective programming for land use in regional level planning. [4, 9] present how fuzzy goal programming can be efficiently used for modelling and solving land-use planning problems in agricultural systems for optimal production. [10] builds a model including multiple crops, market and nonmarket crops uses, and seasonality in production, consumption, and labor supply. Mathematical model has been used to optimize producing edible fungus. [7, 19] optimize culture medium formula of some kinds of edible fungus by regression model; [8, 11] research on the influence of the environmental factors during the production process for the optimization and a quadratic orthogonal regressive rotational combination test was used to screen the optimum submerged culture medium.

From above review, we can see the existing studies focus on single agricultural system. But combining the “paddy circular economy system”, “edible fungus circular economy system” and “dry land circular economy system” together is feasible and necessary. And the combination is the typical circular agricultural system. The relationship among the three systems can be described in subsection 2.1. According to these literatures, the aim of this paper is to build a multi-objective linear programming model to optimize the production of typical circular agricultural system.

Based on the above discussion, this paper is organized as follows. Section 2 describes the problem, states the assumptions and builds the multi-objective linear programming models of the problem in Sichuan province. Section 3 presents a numerical example by genetic algorithm. Section 4 draws the conclusion.

2 Modelling

Under the principles of the circular economy, the agricultural wastes come from paddy and dry land are used to cultivate edible fungus constituting the edible fungus circular production. Combining the circular utilization on three agricultural systems not only gets the most economic benefits from agricultural wastes, but also ecological benefits.

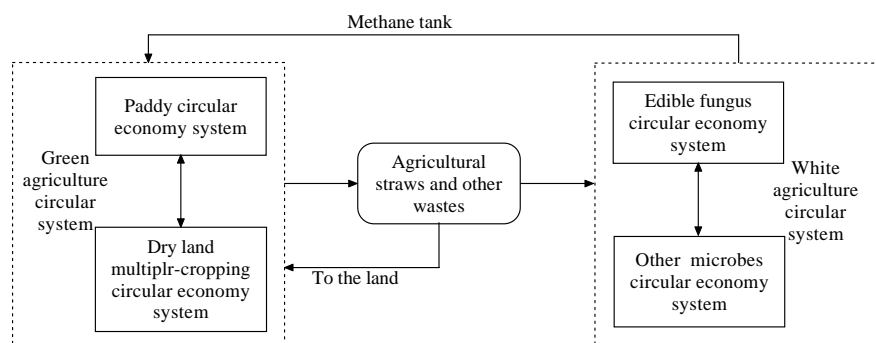


Fig. 1. The relationship of the three circular agriculture systems

2.1 Problem description

Crop farming is the main component of agriculture, and it is the largest proportion in agriculture. Crop farming is not only the source of food, but also the major source of textile industry, food industry. Crop farming

circular system includes the paddy circular system, dry land circular system and idiomatical planting circular system. And edible fungus is a representative of idiomatical planting industry. The relationship of the three circular agriculture systems are shown in Fig. 1.

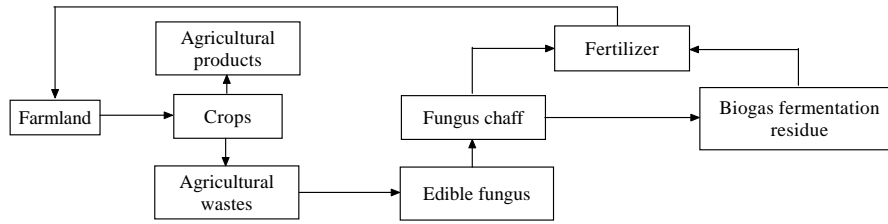


Fig. 2. The detailed circular relationship of the problem

In this figure, agricultural straws and other wastes are the source of producing edible fungus, while fungus chaff can be used marsh gas fermentation, and the biogas fermentation residue (dregs and slurry) is good materials to fertilize. So agricultural straws and biogas fermentation residue are the nucleus in the system. Green agriculture circular system refers to the green planting crops in the land. And white agriculture circular system is mainly referring to the microbial resources of new agricultural industrialization. The detailed circular relationship can be presented in Fig. 2. According to the actual production, the sowing (planting) and harvesting date of various crops paddy planting pattern and the number of crops combination selected for the three land types are respectively shown in Tab. 1 and Tab. 2.

Table 1. sowing (planting) and harvesting date of various crops in each planting patterns

Planting patterns	Rice	Wheat	Rape	Potato (s)	Potato (a)	Vegetable (s)	Vegetable (a)
wheat-rice	5.20-8.30	11.5-5.15					
rape-rice	5.20-8.30		10.15-5.5				
wheat-rice-vegetable	5.25-8.25	11.5-5.15					9.5-11.3
vegetable-rice-vegetable	5.30-8.30					1.20-5.25	9.5-20.30
rape/potato-rice	5.20-8.30		10.20-5.5		9.5-12.20		
potato-rice-potato	4.25-8.25			12.10-4.20	9.1-11.30		

Table 2. The number of crop combinations selected for these three land types

NO	single-cropped land	double-cropped land	triple-cropped land
I	wheat	wheat-wheat	wheat-maize-potato
II	maize	wheat-maize	wheat-maize-soybean
III	potato	wheat-potato	-
IV	soybean	wheat-soybean	-

2.2 Mathematical model

As mentioned in the subsection 2.1, this section can build the optimal model of paddy planting and dry land multiple-planting circular economy system. The objective functions and constraints can be designed as follows:

Assumptions

In order to discuss the production problem better, we ignore the human resource constraints in the production. Based on the above characteristics of the discussed problem, the mathematical model herein is developed on the following assumptions.

- (1) The available agricultural wastes are common in the production which are from the paddy and dry land.

(2) Edible mushrooms are also common in the market which are asparagus, oyster mushroom, *agricus bisporus*, *coprinus comatua*.

(3) The proportion between medium and edible fungus is 1:1, i.e. the biological conversion is 100%.

(4) All the materials cannot exceed their respective maximum levels.

(5) The cost of controlling the agricultural wastes is can't be ignored.

(6) The waste quantity of each crop is 1.2 times of this crop yield.

Assumptions (1) ~ (3) intend to simplify the question. Assumption (4) represents the limits on the maximum available materials in a general case.

Notations

- i the index of the land type ($i = 1, 2$)
- j the index of planting pattern ($j = 1, 2, \dots, 16$)
- x_{1j} the planting area of the j th planting pattern
- x_{2k} the yield of the k th edible fungus ($k = 1, 2, 3, 4$)
- g_j the pollution treatment cost of the per unit j th agricultural wastes
- e_{ks} the amount of the s th raw material when produce the k th edible fungus
- r_k generation rate of the k th edible fungus
- r_{kz} generation rate of the k th edible fungus chaff
- r_{zq} the generation rate of methane
- r_{zz} the generation rate of biogas residues
- r_{jl} the generation rate of the l th waste in the j th planting pattern ($l = 1, 2, \dots, 7$)
- Q_{1jt} a unit area yield of the t th crop in the j th planting pattern
- B_{jl} the yield of the l th waste in j th planting pattern
- C_j the cost per unit of the j th crop under the i th planting pattern
- P_{zq} the price of methane
- I_k the cost of cultivating a kilogram the k th edible fungus
- H_{jl} the returning proportion of the j th agricultural wastes in the i th planting pattern
- R_{jl} the increase production scale of the l th agricultural wastes under the j th planting pattern
- S the area of the paddy and dry land
- P_t the price of the t th crop ($t = 1, 2, \dots, 12$)

where the detailed means of the subscript is shown in Tab. 3

Table 3. The detailed means of the subscript

$i = 1$	plant grain crops	$i = 2$	cultivate edible fungus	$j = 1$	wheat
$j = 2$	maize	$j = 3$	sweet potato	$j = 4$	soybean
$j = 5$	wheat-rice	$j = 6$	rape-rice	$j = 7$	potato-rice
$j = 8$	wheat-wheat	$j = 9$	wheat-maize	$j = 10$	wheat-sweet potato
$j = 11$	wheat-soybean	$j = 12$	wheat-rice-vegetable	$j = 13$	vegetable-rice-vegetable
$j = 14$	sweet potato-rice-sweet potato	$j = 15$	wheat-maize-sweet potato	$j = 16$	wheat-maize-soybean
$t = 1$	rice	$t = 2$	wheat	$t = 3$	maize
$t = 4$	rape	$t = 5$	vegetable	$t = 6$	potato
$t = 7$	soybean	$t = 8$	sweet potato	$t = 9$	flammulina
$t = 10$	oyster mushroom	$t = 11$	drumstick mushroom	$t = 12$	<i>agricus bisporus</i>

Objective functions

For maximizing the economic and ecological benefits in the mathematical model, the economic benefits is expressed by the agricultural products net revenue and the ecological benefits is measured by the agricultural wastes returning benefits.

(1) Production value maximization . The objective function is to maximize the total annual net revenue that can be obtained from cropping in a year. So we have:

$$\max \pi_1 = \sum_{j=1}^{16} \sum_{t=1}^8 (p_t - C_{1j})x_{1j}Q_{1jt} + \sum_{k=1}^4 \sum_{t=9}^{12} x_{2k}(P_t - I_k) + x_{22}r_{zq}(P_{zq} - I_{zq}) \tag{1}$$

(2) The total crop yields maximization. This objective function is to maximize the sum of production of crop in a year. So we have: $\max \pi_2 = \sum_{j=1}^{16} \sum_{t=1}^5 x_{1j}Q_{1jt} + \sum_{k=1}^4 \sum_{t=9}^{12} x_{2k}$.

(3) The ecological benefit maximization. This objective function is to maximize the ecological benefit by reusing the waste. $\max \pi_3 = \sum_{i=1}^3 \sum_{k=1}^4 \sum_{j=1}^{16} \sum_{l=1}^7 H_{jl}r_{jl}R_{jl}x_{1j}$.

Constraints

According to the relationship of the three circular agriculture systems and actual production, we can divide the constraints into two classes. They are mainly raw material supply constraints and material balance constraints.

(1) material balance constraints: In the circular production process, we should consider the supply of material balance, such as using the straw or wheat bran waste to cultivate mushroom. So according to the formula of culture medium we can the establish the constraints as follows:

$$\begin{aligned} \sum_{k=1}^4 x_{2k}e_{kf} &\leq w_f; & \sum_{k=2}^4 x_{2k}e_{k8} &\leq x_{21}r_{kz}; \\ \sum_{k=1}^4 x_{2k}e_{k1} &\leq \sum_{j=1}^{16} (r_{j1} - H_{j1})x_{1j}; & \sum_{k=1}^4 x_{2k}e_{k2} &\leq \sum_{j=1}^{16} (r_{j2} - H_{j2})x_{1j} \end{aligned}$$

(3) area constraints: The area constraint means the crop planting should consider the actual land area.

$$\sum_{j=1}^{16} x_{ij} \leq S \tag{2}$$

(4) Non-negativity constraint. The areas used for any crop and the yield of the each crop or mushroom under a planting pattern must exceed 0.

Based on the notations, objective functions, and constraints above, we can get the mathematical model about the problem expressed as Eq. (3).

$$\left\{ \begin{aligned} \max \pi_1 &= \sum_{j=1}^{16} \sum_{t=1}^8 (p_t - C_{1j})x_{1j}Q_{1jt} + \sum_{k=1}^4 \sum_{t=9}^{12} x_{2k}(P_t - I_k) + x_{22}r_{zq}(P_{zq} - I_{zq}) \\ \max \pi_2 &= \sum_{j=1}^{16} \sum_{t=1}^5 x_{1j}Q_{1jt} + \sum_{k=1}^4 \sum_{t=9}^{12} x_{2k} \\ \max \pi_3 &= \sum_{i=1}^3 \sum_{k=1}^4 \sum_{j=1}^{16} \sum_{l=1}^7 H_{jl}r_{jl}R_{jl}x_{1j} \\ \text{s.t.} &\left\{ \begin{aligned} \sum_{j=1}^{16} x_{ij} &\leq S \\ \sum_{k=1}^4 x_{2k}e_{kf} &\leq w_f \\ \sum_{k=2}^4 x_{2k}e_{k8} &\leq x_{21}r_{kz} \\ \sum_{k=1}^4 x_{2k}e_{k1} &\leq \sum_{j=1}^{16} (r_{j1} - H_{j1})x_{1j} \\ \sum_{k=1}^4 x_{2k}e_{k2} &\leq \sum_{j=1}^{16} (r_{j2} - H_{j2})x_{1j} \\ x_{1j} &\geq 0, x_{2k} \geq 0 \end{aligned} \right. \end{aligned} \right. \tag{3}$$

3 Analysis

This section mainly focuses on the algorithm to solve the problem and analyzing the results of the model. In this paper, we utilize the genetic algorithm to optimize the multi-objective linear programming.

3.1 The algorithm

The general implementation structure of genetic algorithm for the proposed model is shown in Fig. 3. Let P_t and C_t be parents and offspring in current generation t . In the given genetic algorithm, the crossover

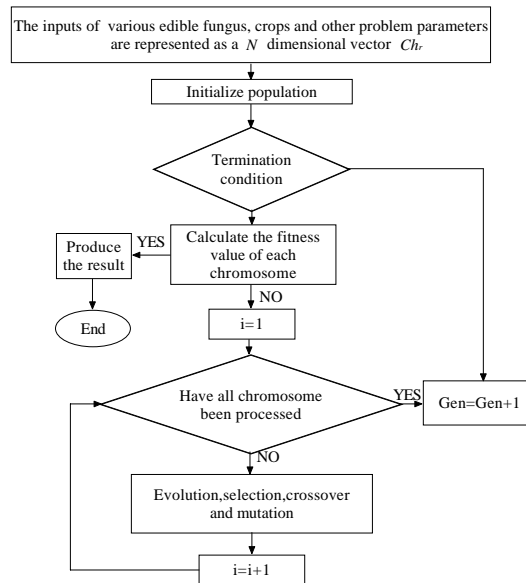


Fig. 3. The step of GA for the mathematical model

rate deciding pairs of individuals among all the individuals in the population is 0.3 in the GA and the mutation rate is 0.2. According to the variables and the problem, the Gen_{max} is 400 and the $Pop-Size$ is 30.

Table 4. Crops yield, production value of each planting pattern in paddy

Planting patterns	Rice (kg)	Wheat (kg)	Potato (kg)	Production value (yuan)
“wheat–rice”	550	350	–	1495
“rape–rice”	550	–	–	1735
“wheat–rice–vegetable”	500	320	–	2862
“vegetable–rice–vegetable”	500	–	–	5850
“rape/potato–rice”	500	–	800	2400
“potato–rice–potato”	650	–	3300	3702.4

Table 5. The yield, cost of production, net revenue of Sichuan’s crops

Crop	yield (kg/a unit of area)	cost (yuan/a unit of area)	revenue (yuan/a unit of area)
wheat	487	270	233
maize	580	264	362.59
sweet potato	1446	290.2	462
soybean	400	340	346

Note: for simplicity, we set the yield, cost of production, net revenue of the crops for different crop combinations in different land types as the same.

3.2 Results analysis

Based on the actual situation in Sichuan province, the yield of the main grain crops in the different cropping patterns and the price of each price are shown in Tabs. 4 ~ 5.

Table 6. Price of each edible fungus

Variable	Value	Variable	Value
price of flammulina	8 yuan/kg	price of drumstick mushroom	6 yuan/kg
price of methane	2 yuan/m ³	price of agaricus bisporus	8 yuan/kg
price of oyster mushroom	3 yuan/kg	quantity of agricultural byproducts	200000 kg
generation rate of flammulina chaff	40%	generation rate of oyster mushroom chaff	50%
generation rate of biogas residues	40%	market demand of every edible fungus	2000 kg
the maximum quantity of the flammulina chaff	2000 kg	the maximum quantity of the oyster mushroom chaff	1500 kg
the maximum quantity of the biogas residues	1000 kg		

Table 7. The material consumption of the edible production

Element of culture medium	Flammulina	Oyster mushroom	Agaricus bisporus	Drumstick mushroom
cottonseed hull	87.5%	50%	–	–
wheat chaff	8%	–	47%	38%
corn meal	3%	–	1%	3%
gesso	1.5%	1%	1%	–
calcium superphosphate	–	1%	2%	1%
urea	–	–	1%	1%
lime	–	1%	1%	–
flammulina chaff	–	47%	–	57%
biogas residues	–	–	47%	–

In this model, the multi-objective model can transform into the single objective model by using lexicographic method. According to the situation of practical situation, we can support the importance degree of the three objectives. For example, there suppose the importance degree of the three objectives as following: production value maximization > crops yield maximization > ecological benefit of straw maximization. So in the first step, we only calculate the first objective as Eq. (1).

Table 8. The results when considering the first objective

Planting patterns	area	Planting patterns	area
wheat	0	wheat–maize	0
maize	0	wheat–sweet potato	0
sweet potato	0	wheat–soybean	0
soybean	0	wheat–rice–vegetable	10
wheat–rice	10	vegetable–rice–vegetable	50
rape–rice	10	potato–rice–potato	10
potato–rice	10	wheat–maize–sweet potato	20
wheat–wheat	0	wheat–maize–soybean	30
Types of mushroom	yield (kg)	Types of mushroom	yield (kg)
flammulina	2000	drumstick mushroom	1200
oyster mushroom	2000	agaricus bisporus	1500

From the single objective model, it can get the the best solution of the first objective is 23824 yuan when the value of decision variable shown in Tab. 8. Then we will find the best solution of the second objective based on the above result. So the first objective turn into a new constraint. There support the transform index of the first objective is $\alpha = 0.9$, and then add a new constraint to the model as follows:

Table 9. The results when considering double pumps objectives

Planting patterns	area (a unit of area)	Planting patterns	area (a unit of area)
wheat	0	wheat-maize	0
maize	0	wheat-sweet potato	0
sweet potato	0	wheat-soybean	0
soybean	0	wheat-rice-vegetable	20
wheat-rice	10	vegetable-rice-vegetable	28
rape-rice	10	potato-rice-potato	10
potato-rice	10	wheat-maize-sweet potato	18
wheat-wheat	0	wheat-maize-soybean	32
Types of mushroom	yield (kg)	Types of mushroom	yield (kg)
flammulina	2200	drumstick mushroom	2000
oyster mushroom	2100	agaricus bisporus	1800

Table 10. The results when considering all the objectives

Planting patterns	area (a unit of area)	Planting patterns	area (a unit of area)
wheat	0	wheat-maize	0
maize	0	wheat-sweet potato	0
sweet potato	0	wheat-soybean	0
soybean	0	wheat-rice-vegetable	26
wheat-rice	10	vegetable-rice-vegetable	40
rape-rice	10	potato-rice-potato	10
potato-rice	10	wheat-maize-sweet potato	25
wheat-wheat	0	wheat-maize-soybean	32
Types of mushroom	yield (kg)	Types of mushroom	yield (kg)
flammulina	2400	drumstick mushroom	120
oyster mushroom	2600	agaricus bisporus	1600

$$\sum_{j=1}^{16} \sum_{t=1}^8 (p_t - C_{1j})x_{1j}Q_{1jt} + \sum_{k=1}^4 \sum_{t=9}^{12} x_{2k}(P_t - I_k) + x_{22}r_{zq}(P_{zq} - I_{zq}) \geq 23824 \times 0.9 \tag{4}$$

Based on above model, we can get the the best solution of the second objective is 136043.1 kilogram when the value of decision variable shown in Tab. 9. Then the transform index of the second objective is $\beta = 0.9$, and then the best solution of the third objective is 1640.129 yuan when the the value of decision variable shown in Tab. 10. we can get the final results: $\pi_1 = 896538.56$ yuan, $\pi_2 = 89765.37$ kg, $\pi_3 = 3578.21$ yuan.

As can be seen from the result, the area of single-cropped pattern is all zero, the area of double-cropped pattern is also a relatively small acreage, most of the land should be planted triple-cropped. In addition, the production of mushroom has been greatly improved, In the circular production, we have taken into account the reuse of waste, in this way, can not only increasing the production of edible fungi, but also reducing the emissions waste and improving resource utilization.

4 Conclusion

In this paper, we build a multi-objective linear programming of the typical circular agriculture system. From the above results,we can get two useful conclusions as follows: At first, the typical agriculture circular system is very important in the reality life, because we do not only get comparatively large economic benefit, but also reduce the discharge amount of wastes. Secondly, in the practical situation, we should expand the triple-cropped pattern in paddy or dry land. Furthermore, we should expand multi-levers and multi-species production in cultivating edible fungus. So we should make use of the agricultural wastes to produce other agricultural products in next level of production. Moreover, the comprehensive utilization of the agricultural wastes should correspond with local conditions such as various planting patterns, various vegetables, and

various edible fungus. In the further research, because of some parameters uncertain, we will consider develop the model into a fuzzy linear programming and combine the proposed mathematical model with computer simulation. In addition, we also think over solving the model by other algorithms such as PSO to obtain the optimal solution.

References

- [1] I. Amini. Determination of the best management for soybean cropping following barley. *Soil & Tillage Research*, 2005, **84**: 168–174.
- [2] D. Bai, S. Zhang, et al. The optimal planning mathematical model and application of water saving irrigation in xinjiang. *Journal of Hydraulic Engineering*, 2005, 306–309, 314. (In Chineses)
- [3] Y. Bian, L. Liu, R. Xu. The mathematic model of medium sized agro-ecological engineering. *Engineering Science*, 2001, **3**(11): 39–44. (In Chineses)
- [4] A. Biswas, B. Pal. Application of fuzzy goal programming technique to land use planning in agricultural system. *Omega*, 2005, **33**: 391–398.
- [5] T. Bontkes, H. Keulen. Modelling the dynamics of agricultural development at farm and regional level. *Agricultural Systems*, 2003, **76**: 379–396.
- [6] S. Chen, J. Ma, et al. A multi-objective fuzzy optimization model for planting structure and its method. *Journal of Dalian University of Technology*, 2003, **43**(1): 12–15. In Chinese.
- [7] W. Cui, P. Yan, J. Zhang. The mathematical model and optimal research agaric high-yielding formula. *Statistics and Management*, 1997, **16**: 8–11. (In Chinese)
- [8] S. Furlan, L. Virmond, et al. Mushroom strains able to grow at high temperatures and low PH values. *World Journal of Microbiology and Biotechnology*, 1997, **13**: 689–692.
- [9] A. Gupta, R. Harboe, M. Tabucanon. Fuzzy multiple-criteria decision making for crop area planning in narmada river basin. *Agricultural Systems*, 2000, **63**: 1–18.
- [10] D. Lee, T. Tipton, P. Lang. Modelling cropping decisions in a rural developing country:a multiple-objective programming approach. *Agricultural Systems*, 1995, **49**: 101–111.
- [11] S. Li, S. Ma, et al. Regression model to optimize the fermentation process of lark mushroom. *Preservation and processing*, 2006, **15**: 40–42. (In Chinese)
- [12] H. Lu, D. Campbell. Ecological and economic dynamics of the shunde agricultural system under china’s small city development strategy. *Journal of Environmental Management*, 2009, **90**: 2589–2600.
- [13] C. Miao, B. He, X. Chen. Study on the multiple objective linear planning applied in comprehensive control of small watershed—a case study from mimagou small watershed in shizhu county,sichuan province. *Chinese Journal of Eco-Agriculture*, 2006, **14**(3): 223–227.
- [14] T. Ponsioen, H. Hengsdijk, et al. Technogin, a tool for exploring and evaluating resource use efficiency of cropping systems in east and southeast asia. *Agricultural Systems*, 2006, **87**: 80–100.
- [15] A. Saysel, Y. Barlas. A dynamic model of salinization on irrigated lands. *Ecological Modelling*, 2001, **139**: 177–199.
- [16] T. Shi, R. Gill. Developing effective policies for the sustainable development of ecological agriculture in china: the case study of jinshan county with a systems dynamics model. *Ecological Economics*, 2005, **53**: 223–246.
- [17] C. Stockle, M. Donatelli, R. Nelson. Cropsyst, a cropping systems simulation model. *European Journal of Agronomy*, 2003, **18**: 289–307.
- [18] A. Vlyssides, S. Mai, E. Barampouti. An integrated mathematical model for co-composting of agricultural solid wastes with industrial wastewater. *Bioresource Technology*, 2009, **100**: 4797–4806.
- [19] X. Wang, H. Cui, Y. Yan. The mathematical model and optimized formula of spring oyster mushroom cultivated by wheat straw hood. *Acta Edulis Fungi*, 1995, **16**: 16–18. (In Chinese)
- [20] S. Yu, J. Zhang. Multi-objective programming method for land use based on genetic algorithm. *China Population, reources and enviornment*, 2006, **16**(5): 62–66.