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A multi-objective system dynamics model on the multi-levers and multi-species production in edible fungus circular system *

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Abstract. The edible fungus circular system is a process of comprehensive utilization of edible fungus wastes in their production activities. It requires economic activities which are associated with the edible fungus make up a feedback system like “resources-products-renewable resources”. In order to maximize both economic and ecological benefit, according to the process of multi-levers and multi-species circular production of edible fungus, this paper simulates the results of various production programs by system dynamics, and presents a satisfied production scheme of edible fungus circular through analyzing the simulation results.

Keywords: edible fungus, system dynamics, circular production, multi-levers, multi-species

1 Introduction

Edible fungi, are widely utilized as human foods. Traditionally, production studies on edible mushrooms were focused on a single strain[4]. However, economics and ecology are increasingly significant in agricultural production, so do in edible fungus industry. In the literature [7], the author introduces how to recycle the edible fungus chaff to make culture medium of edible fungus and the technical of reusing edible fungus chaff[3]. The edible fungi chaffs can replace wood, cotton seed shell and wheat chaff as the component elements of the culture medium to cultivate pleurotus geesteranus, coprinus comatus, and needle mushroom, which make comprehensive statement about the utilization of edible fungus chaff[7, 15]. In these papers, the researches introduces how to reuse the mushroom chaff very well, however, it is direct at a single strain but not make up a circular system.

System dynamics is a quantitative methods for studying the complexity of the socio-economic system. It is a method which is based on the feedback control theory, and use computer technology to simulate the actual situation. The system dynamics method is used in the the design of highway problem[1]. And in the literature [5], the author discusses how to use the system dynamics method on the agriculture problem. From these papers, we can find that a majority of the researches aim to resolve single objective problem. But the growth of edible fungus is a lengthy and complex process involving the use of composts or lignocellulosic wastes such as straws followed by a long cultivation period[5]. It will lead to waste numerous time and money if we research the production scheme by the traditional methods. In practice, the production of edible fungi need consider the economic and ecology benefit, so it is a multi-objective decision-making problem. Thus, in this paper, we will combine system dynamics methods with multi-objectives method in order to find a circular production scheme of edible fungus which is multi-levers and multi-species. Multi-levers means recycling the fungus chaff several times, and multi- species means including several edible fungi. So the paper is organized

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as follows: Section 2 is a brief introduction to purpose of the paper, and depict the system dynamics model of the problem. Section 3, we will analyze the results and gives a satisfying circular production scheme of edible fungus relatively after analyzing the model. Section 4 comes to conclusion, and presents the future research on the problem.

2 The model

How to make use of the concept of circular economy to guide enterprisers in the recycling of resources is very important, and has a strong operational practice. Edible fungus circular production model is the integration of agricultural wastes, fungus chaff and fermentation residue cultivating edible fungus[9]. It is often seen in the firms or parks, and will realize the maximization of resource recycling.

2.1 Description of the problem

Different edible fungus needs different culture medium. So we can divide the edible fungus circular production pattern into three groups shown in the Fig. 1.

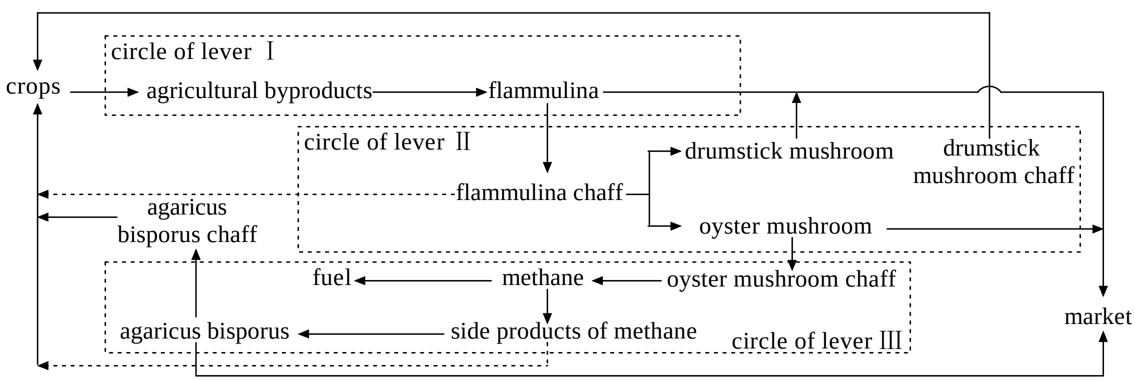

Fig. 1. Framework graph of circular production

From the figure, the edible fungus circular production can be depicted as follows:

- Circle of lever I — the pattern of agricultural byproducts being used to cultivate edible fungus. The agricultural byproducts are rich of nutrition when we use them as the culture medium of mushrooms.
- Circle of lever II — the pattern of reusing the mushroom chaff. which use the mushroom chaff to cultivate the edible fungus which need less nutrition than the mushroom in group one .
- Circle of lever III — the pattern of biogas residue being used to cultivate edible fungus. we deal with the chaff produced in the secondary circular by methane produced, and then use the biogas residue to cultivate the mushrooms which need the least nutrition.

Based on the growth of demand for various edible fungus, we select flammulina as a representative of the first level circular production; oyster mushroom as a representative of the secondary circular production, and agaricus biparous as a representative of the third circular. The Fig. 1 shows the producer how to choose multi-species edible fungus to produce. Although fungus chaff can be used to cultivate edible fungus again, not any agricultural byproducts or other wastes can be fully used. And the nutrition of the mushroom bran is different also. For example, the flammulina chaff is full of nutrition, so it almost need not add new material to cultivate the mushroom which needs less nutrition to cultivate. Furthermore, not all the edible fungus chaff can be utilized for the second time. It must be good and unpolluted. Otherwise, the poisonous and harmful substances in the pollution will affect the growth of the edible fungus.

2.2 Multi-objective system dynamics model

In order to reduce the production cost, we may utilize edible fungus chaff as more as possible. According to the production technology of cultivating edible fungus and the preparation technology of culture medium,we produce various edible fungus reasonably. But the randomizing and uncertainty factor of mushroom product lead to cost numerous time and money. So we build the the system dynamics model to simulate different production programme to find the best production scheme in order to reach the production target.

Assumptions

In the Fig. 1, there are three-levels circular and four kinds of fungi. Combined with the actual situation, there are some assumptions: Firstly, the available agricultural wastes are common which are cotton seed hulls, straw and bran[6]; Secondly, edible fungus are also common which are flammulina, oyster mushroom, agaricus bisporus, drumstick mushroom; Thirdly, the proportion between medium and edible fungus is $1:1$, that is to say, the biological conversion is 100%. Lastly, the market demand of each edible fungus is the same.

Variables

Based on the above analysis and the Fig. 1, we will know the variables which support the circular system as follows:

R_g :the gross income,
R_m: revenue of methane,
R_m: revenue of methane,
Q_m: quantity of methane,
Q_{fc}: quantity of flammulina chaff
Q_{abc}: quantity of agaricus bisporus chaff
Q_{ab}: output of agaricus bisporus
Q_c: quantity of crops,
R_{pdm}: income of unit drumstick mushroom
R_{pab}: income of unit agaricus bisporus
g_{fc}: generation rate of flammulina chaff,
g_{oyc}: generation rate of oyster mushroom chaff,
R_{pf}: income of unit flammulina,
Q_{oy}: output of oyster mushroom,
R_{oy}: revenue of oyster mushroom,
R_m: revenue of methane,
R_m: revenue of methane,
Q_f: output of flammulina,
Q_{sm}: quantity of side product of methane,
Q_{oyc}: quantity of oyster mushroom chaff,
Q_{as}quantity of agricultural byproducts,
Q_{oycv}: variable quantity of oyster mushroom chaff,
R_{pm}: income of unit methane,
R_{poy}: income of unit oyster mushroom,
Q_{fcv}: variable quantity of flammulina chaff,
Q_{smv}: variable quantity of biogas residues
g_{br}: generation rate of biogas residues,
Q_{dm}: output of drumstick mushroom,
R_{dm}: revenue of drumstick mushroom, revenue of flammulina,
R_{dm}: revenue of drumstick mushroom, revenue of flammulina,
R_{dm}: revenue of drumstick mushroom, revenue of flammulina,
R_{dm}:revenue of drumstick mushroom, revenue of flammulina,
Q_{dmc}: quantity of drumstick mushroom chaff, output of crops.

Therefore, the multi-lever and multi-species production in edible fungus circular system can be described as Fig. 2.

System structure

Because the circular production of edible fungus is mainly used in the production enterprise, many factors of the production scheme of edible fungi should be considered. Such as yield maximization, edible fungi profit maximization, or the ecological benefit maximization. According to the variables and the fundamental in-trees shown in the Fig. 2, we can build the system dynamics model of the multi-levers and multi-species production in edible fungus circular system shown in Fig. 3.

Parameters

Based on the system structure of edible fungus circular production in the Fig. 3 and the causal relationship of the circular system, we can get the parameters shown in Tab. 1.

3 The analysis

According to the above discussion, we can see that the multi-levers and multi-species production in edible fungus circular system is a multi-objective production problem. In the actual production process, enterprise

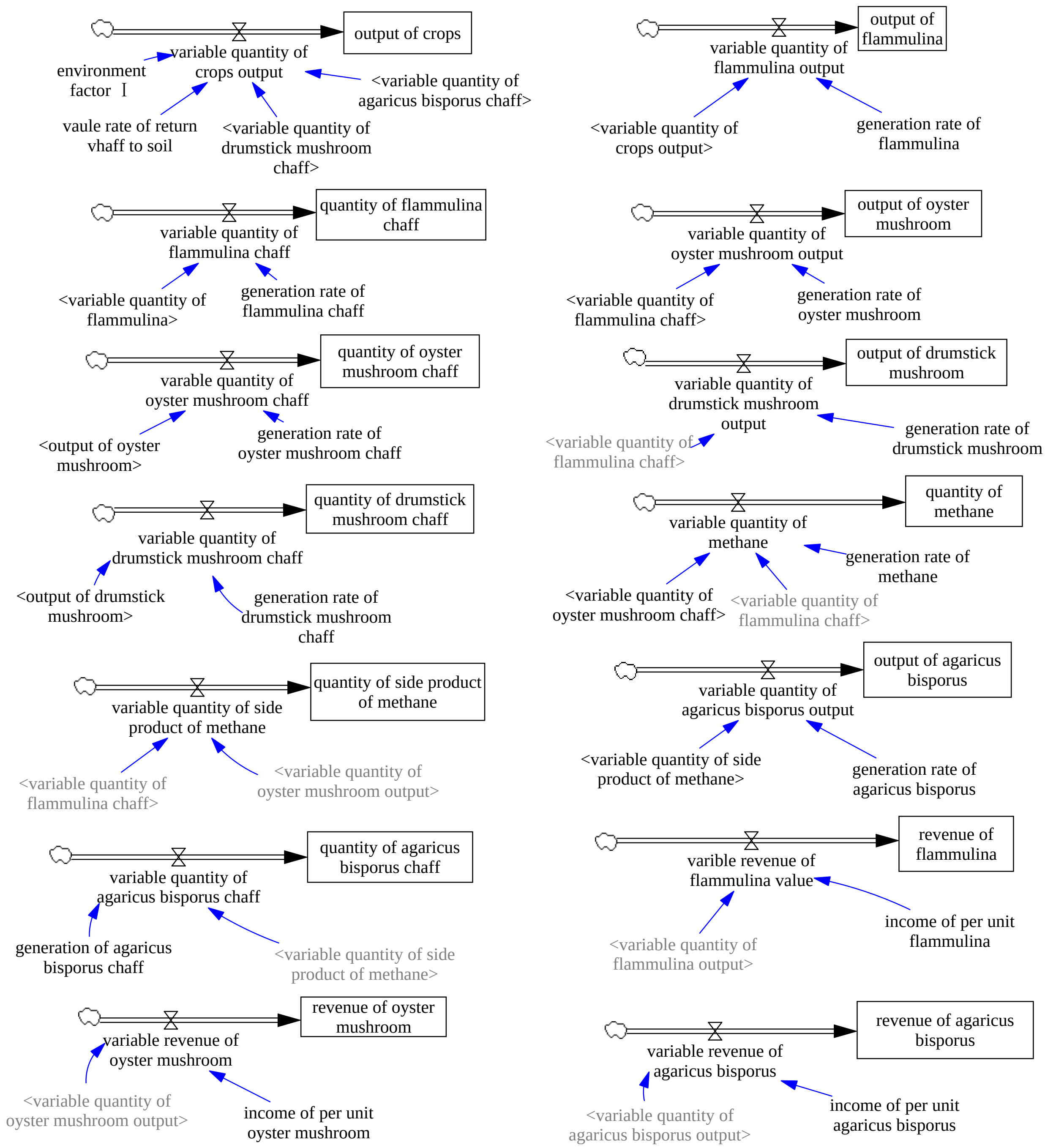

Fig. 2. Fundamental in-tree

Table 1. Parameters of circular product model

Variable	Unit	Variable	Unit	Variable	Unit	Variable	Unit
R_g	yuan	Q_{as}	kg	R_f	yuan	R_{dm}	yuan
R_m	yuan	R_{ab}	yuan	R_{oy}	yuan	Q_{oy}	kg
Q_f	kg	Q_{dm}	kg	Q_{ab}	kg	Q_{dm}	kg
R_{pf}	yuan/kg	R_{pdm}	yuan/kg	Q_m	m^3	R_{pm}	yuan/m^3
R_{pab}	yuan/kg	R_{poy}	yuan/kg	Q_{fc}	kg	g_{fc}	%
g_{oyc}	% Q_{sm}	kg	g_{br}	%			

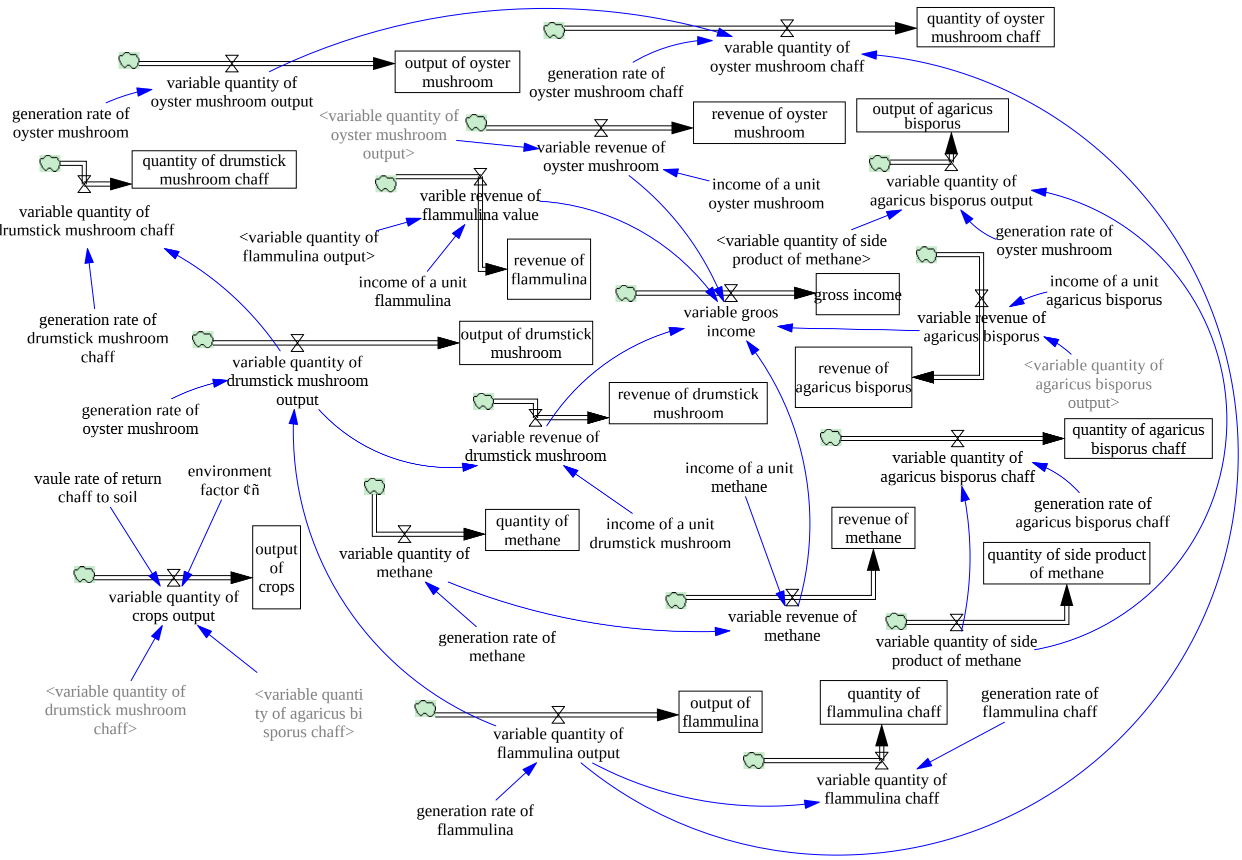

Fig. 3. Circular system structure

should not only consider the economic benefit but also take care of ecological benefit. So the production scheme is not the same while the aim is different. Considering the actual situation, this paper intends to build the system dynamics model which is based on preference to economic benefit and comprehensive consideration on the economic and ecological benefit to simulate the production in edible fungus circular system.

Preference to economic benefit

Combined with the actual production of edible fungi and the material consumption of the edible production shown in the Tab. 2, we can build the system dynamics model of the edible fungus circular production shown in the Fig. 3. By analysing the the system dynamics model shown in Fig. 3, we can initialize some parameters as Tab. 3 and give the main mathematical equations as Eq. (1).

$$\begin{cases} Q_{as} = Q_c \times g_{as}; \\ R_g = Rf + R_{dm} + R_m + R_{ab} + R_{oy}; \\ Rf = Q_f \times R_{pf}; \\ R_{dm} = Q_{dm} \times R_{pdm}; \\ R_m = Q_m \times R_{pm}; \\ R_{ab} = Q_{ab} \times R_{pab}; \\ R_{oy} = Q_{oy} \times R_{poy}; \\ Q_{fc}(t + \Delta t) = Q_{fc}(t) + Q_{fcv}(\Delta t); \\ Q_{oyc}(t + \Delta t) = Q_{oyc}(t) + Q_{oyc}(\Delta t); \\ Q_{sm}(t + \Delta t) = Q_{sm}(t) + Q_{smv}(\Delta t). \end{cases} \quad (1)$$

According to the system dynamics model and the equations we can get the output value of each edible fungus in the circular production shown in Fig. 4 $\sim$ Fig. 8.

As shown in the figures, the revenue of the flammulina is the highest of all when the external environment is in the same situation. But we can see when the supply of the each edible fungus is outstripping the require-

Table 2. 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%	–

Table 3. Parameter initialization I

Variable	Value	Variable	Value
price of flammulina	8 yuan/kg	price of drumstick mushroom	5 yuan/kg
price of methane	2 yuan/m^3	price of agaricus bisporus	6 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 each edible fungus	2000 kg

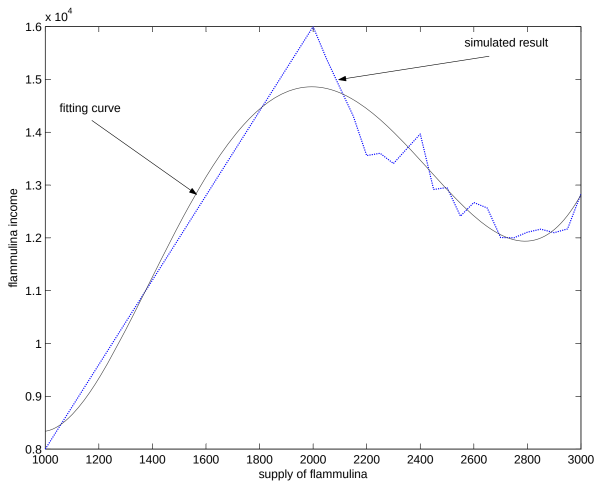

Fig. 4. Flammulina income

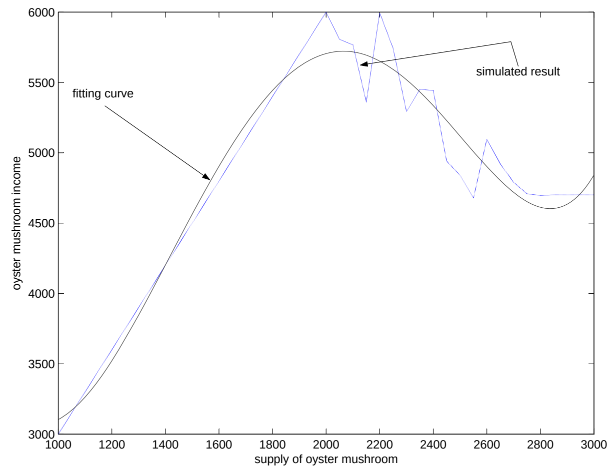

Fig. 5. Oyster mushroom income

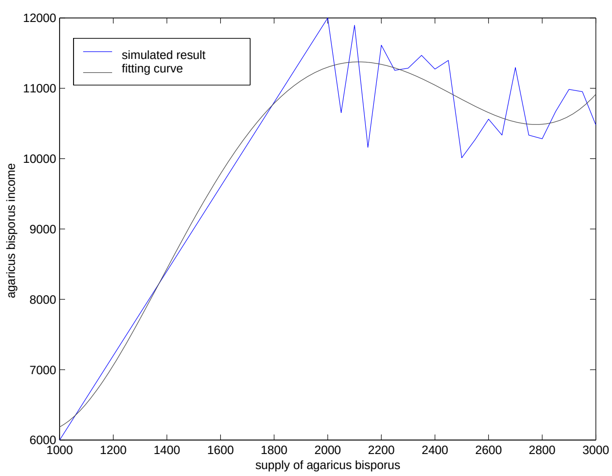

Fig. 6. Agaricus bisporus income

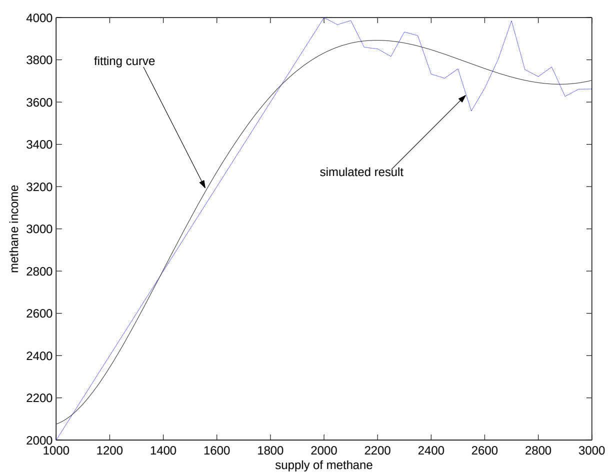

Fig. 7. Methane income

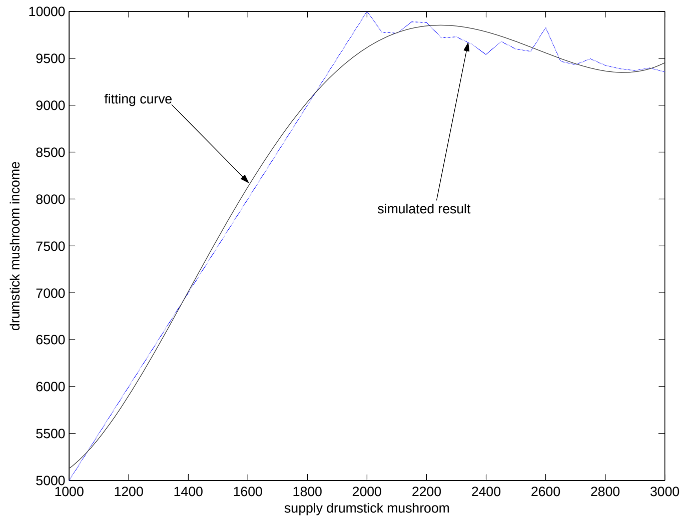

Fig. 8. Drumstick mushroom income

ment the revenue is decreased. So we do not produce the single species of edible fungi. when we consider the economic benefit preferably, we should make the production arrangement based on the market price of the edible fungus. We can get the production scheme shown in the Tab. 4 by initializing the parameters.

Table 4. The production programme of edible fungus

Production capacity (PC)	Flammulina	Oyster Mushroom	Agaricus bisporus	Drumstick mushroom
$PC \leq 2000$	PC	0	0	0
$2000 < PC \leq 4000$	2000	0	$PC - 2000$	0
$4000 < PC \leq 6000$	2000	0	2000	$PC - 4000$
$6000 < PC \leq 8000$	2000	$PC - 6000$	2000	2000
$8000 < PC$	2000	2000	2000	2000

Comprehensive coordination consideration

We have discussed the cases considered economic benefit preferably, but in reality, we should also consider economic and ecological benefit comprehensively to make a production arrangement. As the same as the situation of considering economic benefit preferably, the model is shown in Fig. 3 and the equations of the model is also the same. We can simulate the situation of considering economic and ecological benefit comprehensively by changing the initial value of some parameters. In this case, the Tab. 5 shows the initialized value of the parameters. The Tab. 5 shows that there are the upper limit of the quantity of the edible fungus chaff. When the quantity of any edible fungus chaff is beyond the upper limit, we must increase the yield of the downstream products which can consume the wastes. After initializing the parameters we can get the result shown in the Tab 6. From the table, we can see that the gross income is 44102 yuan when we do not consider the requirement of the market. In the same cases, the income is 50000 yuan when we consider the economic benefit preferably. However, it will produce 1800kg wastes while get economic benefit. Considered with economic benefit and ecological benefit, we would approximately get zero draining and decrease the utilization of resources.

4 Conclusion

In this paper, we present a multi-levers and multi-species circular system of edible fungus production by dividing the edible fungus circular production pattern into three groups, and build a system dynamics model to simulate the the circular production of edible fungus. we can get some useful conclusions though analyzing the results. Firstly, using the edible fungus chaff reproduction can bring great economic benefit. Secondly,

Table 5. Parameter initialization II

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 6. Simulation results

Variable	Value
yield of flammulina	2148.2350 kg/month
yield of oyster mushroom	1998.3524 kg/month
yield of agaricus bisporus	2018.0976 kg/month
yield of Goprinus comatus	0.000000 kg/month
gross of income	34102 yuan

edible fungus chaff comprehensive utilization can reduce the emission of the wastes. So it is beneficial for ecological environment. Furthermore, we can see that the system dynamics is a useful and effective method for the simulation of the multi-levers and multi-species production in edible fungus circular system. We can simulation the various situation by changing the initial value of the related parameters. The edible fungus enterprise may arrange the production scheme more reasonable. However, the simulation data is not accurate enough since the prices of the edible fungus are not changed with the market, and the influencing factors of the edible fungus production such as prices and the time of the edible fungus cultivated are random or fuzzy. So in the future research, we can consider the situation of market change and the dynamic price , and consider uncertainty factors.

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