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A multi-objective model of the edible fungus circular producing under fuzzy environment *

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Abstract. This paper develops a fuzzy multi-objective linear programming (FMOLP) model for solving the multi-lever and multi-species production of edible fungus circular economy system decision problem in a fuzzy environment. The proposed model attempts to make both economic and ecological maximize. A numerical example demonstrates the feasibility of applying the proposed model to edible fungus circular economy system. In particular, this paper is a combination of the fuzzy multi-objective programming and genetic algorithm.

Keywords: edible fungus, fuzzy multi-objective programming, circular production, genetic algorithm

1 Introduction

In the past few decades, circular economy has been put on the agenda not only in industry but also in agriculture. Edible fungus industry is one of the aspects. Literature [9] expounds the circular utilization of farm wastes in edible fungus culture and and analyzes the mutual promotion and supplementary effect between mushroom and crops in sunlight, gas and nutrition. In addition, the author puts forward four models of high efficient utilization of agricultural waste resources (including crop stalk). Literature [12] introduces the recycling methods of edible fungus chaff from soilless cultivation substrate, fungus chaff feed, biological fertilizer, fuel and hormones and pesticide chemicals. J. Chen analyzes different fungus chaff nutrient content. The result is fungus chaff can replace wood, cotton seed shell and wheat bran as the component elements of the culture medium to produce pleurotus geesteranus, tricholoma lobayense, and pleurotus abalonus in literature [2]. Literatures [8, 21] make comprehensive statement about the utilization of edible fungus chaff. With the realization of recycling the fungus chaff in the production, the necessity of programming for the circular production appears.

Mathematical model has been used to optimize producing edible. Literatures [5, 20] optimize culture medium formula of some kinds of edible fungus by regression model; literatures [6, 13] 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. But it is unusual to see utilizing the mathematical programming model to optimize the production.

Fuzzy multi-objective programming model has been used in many fields. Literature [17] proposes a general fuzzy goal programming (FGP) involving pre-emptive priorities and fuzzy goals which can be applied to tackle multi-criteria decision systems (MCDS) with imprecise parameters as a case study in agricultural

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planning. Literature [1] introduces an interactive approach to deal with fuzzy multiple objective linear programming problems, which is based on the analysis of the decomposition of the parametric diagram into indifference regions corresponding to basic efficient solutions. Based on analysis of the relationship of agricultural water resources and its sustainable development, literature [3] presents a multi-objective fuzzy optimization model for planting structure, which has a close relationship with the optimal allocation of agricultural water resources, and a new method named fuzzy decision weight is applied to the decision of the objective weight. Literature [14] presents a multi-objective fuzzy optimization model for cropping structure and water allocation, which overcomes the shortcoming of current models that only considering the economic objective. According to fuzzy optimization theory and the character if edible fungus culture medium production line, six evaluation items of the program design were ascertained in literature [18]. And using principles of maximum subordinated degree, sequencing principle forced decision method (FD method), and universal fuzzy plan method to obtain a design of a reasonable edible fungus culture medium production line and the general layout diagram of advanced production lines. Literature [19] develops a fuzzy multi-objective linear programming model for solving the multi-product aggregate production planning (APP) decision problem in a fuzzy environment. The proposed model attempts to minimize total production costs, carrying and backordering costs and rates of changes in labor levels considering inventory level, labor levels, capacity, warehouse space and the time value of money. But none of them considered the multi-lever and multi-species edible fungus in the circular production by using the fungus chaff. Multi-lever means recycling the fungus chaff several times, and multi-species means there are 3 to 4 kinds of edible fungus or more species in the circular production process.

According to these literatures, this paper attempts to develop a fuzzy multi-objective linear programming (FMOLP) model for solving the multi-level and multi-species edible fungus in the circular production by using the fungus chaff. First, a MOLP model of the problem is constructed in our early study. That model attempts to maximize the production and utilize the agricultural wastes as much as possible. Furthermore, it is necessary to think the prices of the edible fungus are fuzzy variables in the real life.

Based on the above discussion, the paper is organized as follows. Section 2 describes the problem, states the assumptions and develops the MOLP and FMOLP mathematical models of the problem. Section 3 presents a numerical example by genetic algorithm. Section 4 draws the conclusion.

2 Modelling

Agricultural wastes, fungus chaff and fermentation residue which are used to cultivate edible fungus[16] constitute the edible fungus circular production model. It is based on agricultural wastes, fungus chaff and fermentation residue to produce edible fungus which is often seen in actual production. This method can realize the maximization of resource recycling.

2.1 Problem description

The multi-level and multi-species edible fungus in the circular production can be described as follows. According to different utilization by substrate components of different characteristics, we can arrange to cultivate the second type of edible fungus reasonably[12]. The first crop of edible fungus hypha will secrete kinds of enzymes, and the decomposition of fibrin from substrate can be utilized by the second crop of edible fungus. Fig. 1 represents the process of circular production. Producers should choose various, complementary edible fungus. For example, lignin can't be utilized by straw mushrooms, but the straw mushrooms chaff is suitable for cultivated oyster mushroom, not for agaricus bisporus.

Not all the edible fungus chaff can be utilized again. And the fungus chaff must be with high quality. Most important of all, the fungus chaff should be good and not polluted. Otherwise, the poisonous and harmful substances in the pollution will affect the growth of second crop of edible fungus. It is also an obstacle in the process of sterilization. Fungus chaff recycling involves a very important content is the determination of the nutrient content in the fungus chaff.

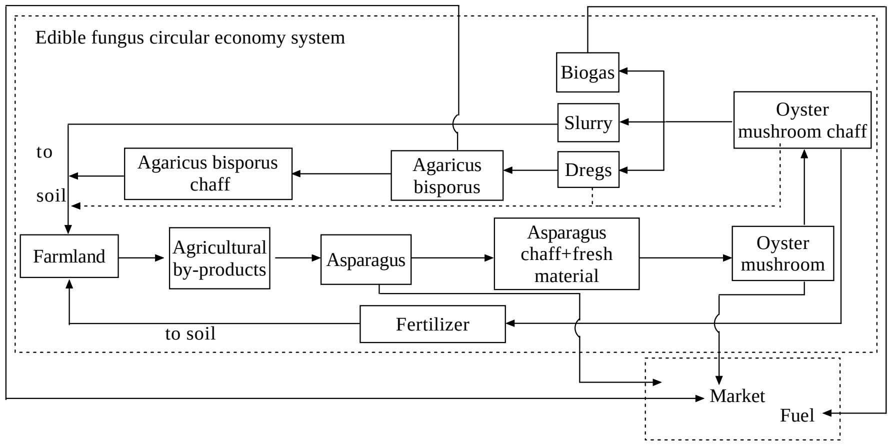

Fig. 1. Circular production reduced graph

2.2 Mathematical model

In order to decrease the production cost, we want to utilize edible fungus chaff as more as possible and reduce the discharge of edible fungus chaff. Therefore, it is necessary to optimize the edible circular production by reusing the wastes to reach the enterprise production target. According to the production technology of cultivating edible fungus and the preparation technology of medium, we plan to produce various edible fungus reasonably.

But in the real life, the prices of multifarious edible fungus is always a fuzzy variable. In addition, the chaff generation rate is also uncertain. So we establish the multi-objective optimization fuzzy mathematical model under the condition of using the goal programming of the problem to obtain a satisfactory solution which can reflect the decision makers' preference when the prices of the edible fungus are fuzzy. Based on above analysis, we can get the fuzzy mathematical model of edible fungus circular production systems as follows.

Assumptions

In order to discuss the production problem better, we ignore the human resource constraints of edible production mode. We consider the cultivation medium ingredients of edible fungus optimization only. Based on the above characteristics of the considered problem, the mathematical model herein is developed on the following assumptions.

(1) The membership function is specified for all fuzzy sets involved;

(2) The minimum operator is used to aggregate fuzzy sets;

(3) The available agricultural wastes are common in the production which are cotton seed hulls, straw and bran[10];

(4) Edible mushrooms are also common in the market which are asparagus, oyster mushroom, agricus bisporus, coprinus comatua;

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

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

Assumption (1) and (2) are made to convert the original fuzzy MOLP problem into a equivalent LP problem that can be solved efficiently by the standard simplex method[22]. Assumption (1) follows from that the fact the decision maker could specify the degree of membership on distinct values for each of the objective function, so the triangle membership function may be used to represent the fuzzy sets. Assumption (2) implies that the minimum operator suffices for aggregating the fuzzy sets. Assumption (3) to Assumption (5) intend to simplify the question. Assumption (6) represents the limits on the maximum available materials in a normal business operation.

Notations

x_i	:	output of the$i$th edible fungus;
t_{ij}	:	proportion of the$i$th raw material in the culture medium to produce the ith edible fungus per unit;
b_j	:	supply of the ith raw material;
$\tilde{r}_{zz}$	:	generation rate of the dregs when fungus chaff is converted to biogas;
r_i	:	generation rate of fungus chaff when cultivate the$i$th edible fungus;
$tildep_i$	:	price of the$i$th edible fungus.

Where both $\tilde{r}_{zz}$ and $\tilde{p}_i$ are fuzzy variables. Because of the different production condition, $\tilde{r}_{zz}$ is different and it may belong to some interval. In literature [7], it mentions the biological conversion rate raising 6%. But it may be different in other experiments and production. So $\tilde{r}_{zz}$ is a fuzzy variable. And the price fluctuation is also in edible fungus market, therefore $\tilde{p}_i$ is a fuzzy variable too. Among them, $i = 1, 2, 3, 4$ are asparagus, oyster mushroom, agaricus bisporus, and coprinus comatua. $j = 1, 2, \cdots, 10$ are straws (cotton seed hulls), wheat bran, corn flour, gesso, ordinary superphosphate, urea, lime, asparagus chaff, dregs, and oyster mushroom chaff.

Objective functions

Because the circular production of edible fungus is mainly used in the production enterprises, and the production process of edible fungi has various strains yield maximization, edible fungus profit maximization, the best collocation to use of different agricultural wastes of and other objectives. According to the variable settings, the objective function can be expressed as follows:

$$\text{Revenue maximization:} \qquad \max f_1(x) \cong \max \sum_{i=1}^{4} \tilde{p}_i x_i; \tag{1}$$

$$\text{Wastes utilization maximization:} \qquad \max f_2(x) \cong \max \sum_{i=1}^{4} \sum_{j=6}^{9} x_i \cdot t_{ij}. \tag{2}$$

Where the symbol $\cong$ is the fuzzified version of $=$ and refers to the fuzzification of the aspiration levels.

In real-world fungus production problems, the environmental coefficients and operation parameters especially the prices of the edible fungus are typically uncertain because some information is incomplete or unobtainable in a medium time horizon. Accordingly, Eq. (1) and Eq. (2) are fuzzy with the production parameters and the prices in the decision maker's judgments concerning the solutions of fuzzy multi-objective optimization problems. For each of the objective function of the proposed model, this paper assumes that the decision maker has such imprecise goals as, 'the objective functions should be essentially equal to some value'. These conflicting goals are required to be simultaneously optimized by the decision maker in the framework of fuzzy aspiration levels.

Constraints

According to the circular system modeling ideas, we can divide the constraints into two groups. They are mainly raw material supply constraints and material balance constraints.

$$\text{Raw material supply constraints:} \qquad \begin{cases} \mathrm{M_{min}} \leq \sum\limits_{i=1}^{4} x_i \cdot t_{i1} \leq \mathrm{M_{max}} \\ \mathrm{J_{min}} \leq \sum\limits_{i=1}^{4} x_i \cdot t_{i2} \leq \mathrm{J_{max}} \\ \sum\limits_{i=1}^{4} x_i \cdot t_{ij} \leq b_j \qquad\qquad (j = 1, 2, \cdots, 5) \end{cases} \tag{3}$$

Where $\mathrm{J_{max}}$ and $\mathrm{J_{min}}$ are the maximum and minimum of cotton seed shell and straw which producer can provide respectively; $\mathrm{M_{min}}$ and $\mathrm{M_{max}}$ are the maximum and minimum of wheat bran which producer can provide.

$$\text{Material balance constraints:} \quad \begin{cases} \sum_{i=2}^{4} x_i \cdot t_{i8} \leq x_1 \cdot r_1 \\ x_3 \cdot t_{39} \leq x_2 \cdot r_2 \cdot \tilde{r}_{zz} \end{cases} \tag{4}$$

$$\text{Variable constraints:} \quad x_i \geq 0 \quad (i = 1, 2, 3, 4) \tag{5}$$

The Constraints (3) and (4) meet the quantity of consumption do not exceed the upper limit; Constraint (5) enforces the non-negativity restriction on the decision variables.

3 Case study

This section focuses on the analyzing the optimal model of circular producing which is multi-lever and multi-species. Moreover, a genetic algorithm (GA) based this model is developed for optimize the multi-objective functions.

3.1 The algorithm

In general, a GA has basic components, as summarized by Michalewicz[15]. The above fuzzy multi-objective problem shown can be formulated as a GA based search problem. In order to do so, it is necessary to define: a representation of the problem, i.e. a chromosome; and a fitness function defined in terms of this representation. Combined with the specific problem, the procedure of the proposed model can be stated as follows:

Procedure `The GA procedure for edible fungus circular economy system`

Step 1. The various of edible fungus, revenue, wastes utilization, and other problem parameters are represented as a N dimensional vector Ch_r;
Step 2. Set the generation counter at zero, Gen $= 0$;
Step 3. Initialize population: randomly generate initial population Gen(0) of trial vectors Ch_r for $r = 1, 2, \cdots, N$ from a feasible range in each dimension;
Step 4. Calculate the fitness value of each chromosome:
fitness value eval(ν_i), $\forall i \in$ popSize.
$\{z_k^{\max}\} \leftarrow \max_i\{f_k(\nu_i)\}$, $k = 1, 2$; //maximum extreme point z^+;
$\{z_k^{\min}\} \leftarrow \min_i\{f_k(\nu_i)\}$, $k = 1, 2$; //minimum extreme point z^-;
$w_k \leftarrow \frac{1}{z_k^{\max} - z_k^{\min}}$, $k = 1, 2$;
eval$(\nu_i) \leftarrow \sum_{k=1}^{q} w_k(f_k(\nu_i) - z_k^{\min})$, $\forall i$.
If the best solution has been generated, then it is over; else go to next step;
Step 5. Increase the generation counter by one, $n = n + 1$;
Step 6. Apply GA to produce gen$(n + 1)$: preserve the elite chromosomes, select Np parents from population of trial vectors by selection, crossover and mutation operators to produce Np child vectors;
Step 7. Evaluate fitness of each chromosome of current population by using the fitness subroutine and store the solution corresponding to the best fit chromosome;
Step 8. Apply the replacement operator and diversity mechanism to the current population;
Step 9. Check for the convergence criterion: if current generation number n is equal to Gen$_{\max}$, stop and print the results such as outputs of various edible fungus, revenue, wastes utilization, etc, corresponding to the best fit vector of the population. Otherwise, go to step 6;

The focus of the problem is to find out an optimal output to maximize the economic benefits and ecological benefits. So economic benefits and ecological benefits are both fitness measures. In the multi-objective mathematical model above, we can transform it into a single objective to gain the optimum solution by weight coefficients method. According to the concrete condition of the edible fungus industry, the importance degree of the two objectives can be considered as it is equally important to revenue maximization and wastes used maximization. The crossover 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.

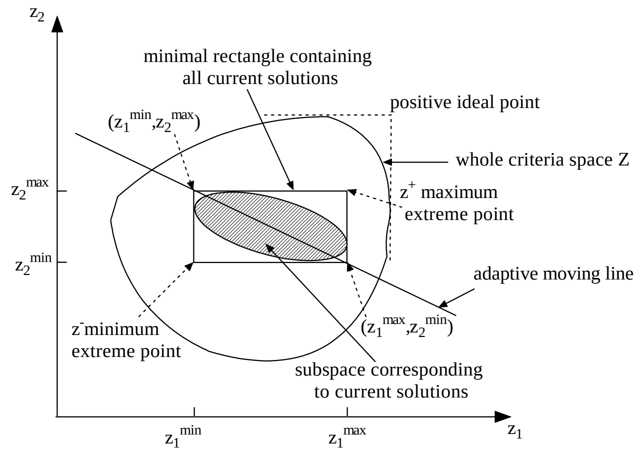

Fig. 2. Adaptive-weights and adaptive hyperplane (Maximization case)

3.2 The solving

Under the guiding principle of optimizing the production, referring to the circular production working procedure and the Tab. 1, combined the practical production with the market price of edible fungus, we will analyze the optimization scheme.

Table 1. Material consumption

	Asparagus	Oyster mushroom	Agaricus bisporus	Coprinus comatua
Corn flour	3%	—	2%	3%
Gesso	2%	2%	2%	—
Ordinary superphosphate	—	2%	2%	3%
Urea	—	—	2%	3%
Lime	—	2%	2%	—
Asparagus chaff	—	47%	—	55%
Dregs	—	—	45%	—
Cotton seed hulls	85%	47%	—	—
Wheat bran	10%	—	45%	36%

Table 2. Membership functions

Price	Membership function					
p_1	>12000	12000	10000	9000	8000	<8000
$f_1(p_1)$	0	0.5	0.75	0.8	1.0	1.0
p_2	>6000	6000	5000	4000	2500	<2500
$f_2(p_2)$	0	0.4	0.6	0.8	1.0	1.0
p_3	>8000	8000	7000	6000	4000	<4000
$f_3(p_3)$	0	0.5	0.7	0.8	1.0	1.0
p_4	>10000	10000	7000	6000	5000	<5000
$f_4(p_4)$	0	0.5	0.8	0.9	1.0	1.0
$\tilde{r}_{zz}$	>0.7	0.7	0.6	0.5	0.4	<0.4
$f_5(\tilde{r}_{zz})$	0	0.5	0.6	0.7	1.0	1.0

Solving the fuzzy multi-objective linear programming problem

This fuzzy multi-objective linear programming problem designed here can be solved using the fuzzy expected value model. To overcome the above problem, in this paper we use fuzzy expected value model (EVM) in which constraints are treated as fuzzy events. And the piecewise linear membership functions are specified to represent the fuzzy sets involved, and the minimum operator is adopted to aggregate all fuzzy sets. This defuzzification approach applies to various kinds of fuzzy data. Following the idea of expected value model, a fuzzy expected value model of multi-objective programming should be modeled as follows:

$$\begin{cases} \max\{E[f_1(x,\xi)], E[f_2(x,\xi)], \cdots, E[f_p(x,\xi)]\} \\ \text{s.t.} \quad E[g_j(x,\xi)] \geq 0,\ j = 1, 2, \cdots, m \end{cases} \tag{6}$$

where $f_i(x, \xi)$ are objective function for $i = 1, 2, \cdots, p$ and $g_j(x, \xi)$ are constraints for $j = 1, 2, \cdots, m$. So the proposed fuzzy multi-objective linear programming in this paper can be converted into:

$$\begin{cases} \max\left\{E\left[\sum_{i=1}^{4}\tilde{p}_i x_i\right], E\left[\sum_{i=1}^{4}\sum_{j=6}^{9} x_i t_{ij}\right]\right\} \\ \text{s.t.} \begin{cases} \mathrm{M}_{\min} \leq \sum_{i=1}^{4} x_i \cdot t_{i1} \leq \mathrm{M}_{\max} \\ \mathrm{J}_{\min} \leq \sum_{i=1}^{4} x_i \cdot t_{i2} \leq \mathrm{J}_{\max} \\ \sum_{i=2}^{4} x_i \cdot t_{i8} \leq x_1 \cdot r_1 \\ E[x_3 \cdot t_{39} - x_2 \cdot r_2 \cdot \tilde{r}_{zz}] \leq 0 \\ x_i \geq 0 \quad (i = 1, 2, 3, 4) \end{cases} \end{cases} \tag{7}$$

Piecewise linear membership functions

First, determine the initial solution for the each of the objective function using the conventional LP model. The results are $z_1 = 2669519$, $z_2 = 346.4653$. Then Tab. 2 gives the piecewise linear membership functions of the proposed model.

According to the actual production condition, we can suppose the parameters as follows: the peak value of straw and the cotton seed shell is 120 tons (minimum 0), the maximum of wheat is 80 tons (minimum 0), And the rest of all the materials are 10 tons. The coefficients in the constraint condition of material balance are: 0.4, 0.5, 0.4, 0.8, 0.4, 0.5, 0.5.

By the mean above, we can get the results $x_1 = 141.1765$, $x_2 = 0$, $x_3 = 0$, $x_4 = 179.6791$. That means yields of the four kinds of edible fungus are 141.1765, 0, 0, and 179.6791. The economic benefit is 2669500 yuan. We can assume the cost of disposing the fungus chaff is one yuan per unit. So the total revenue is 2669800. By comparison, we can get a conclusion that is when we make the price is fuzzy, it is more logical. From the results, we can see the proposed model can meet the requirement for the practical application because it aims to maximize the revenue and wastes utilization. Next, the most important task of decision maker is to specify the rational degree of membership of each objective function and one needs to flexibly revise the range if the value of the degree of membership to yield satisfactory solutions.

3.3 The analysis

In this subsection, we will compare the FMOLP model presented in this paper to the LP and FLP models. Several significants characteristics distinguish the proposed model from the other models.

(1) The proposed model includes fuzzy multi-objective functions. In practice, the decision maker usually faces a fuzzy multi-objective planning problem when making a production decision. The proposed model can satisfy the requirement for practical application because it maximizes total income and ecological benefit which can determine the decision maker's overall degree of satisfaction.

(2) The proposed model provides the most flexible decision-making and adjustment processes. For instance, if the decision maker does not accept the initial weight as in the numerical example, then he may try to adjust the weight by taking account of relevant information to seek a set of rational output solutions for the production problem.

(3) The proposed model outputs more wide-ranging decision information than other models. This FMOLP model focuses on the multi-level and multi-species problem in edible fungus production. It can also

provide information on alternative edible fungus production collocation in response to variations in forecasted demand.

(4) To consider the conflicts among various objectives, several possible optimal planning production are first generated from the GA. Then a fuzzy decision method is adopted to select the best production scheme. Results from a practical case study show that the methodology is feasible and efficient.

(5) In practical production, some decision maker always ignore the ecological benefit, but we can see the ecological benefit is significant in the numerical example. In China, the total fungus chaff has reach about $8 \sim 11$ million tons every year and the main ingredients are cotton seed shell, sawdust, straw, corncob, and various agricultural straw bagasse. If the fungus chaff can be realized recycling production, it will be produce the huge economic benefit and ecological benefit.

4 Conclusion

In this paper, we build a fuzzy multi-objective mathematical model of recycling production according to the circular production of edible fungus by genetic algorithm. From the results, we can get two useful conclusions. First, using the edible fungus chaff reproduction can bring great economic benefits. Making full use of edible fungus chaff resources and producing multi-lever and multi-species edible fungus may obtain the economic products to the biggest extent. Second, edible fungus chaff comprehensive utilization should adjust measures to local conditions, and the focus is repeated use. Therefore, we must remember the aim to develop circular production is environmental protection. Moreover, the simulation of data is not accurate because the prices are the average in the calculations. In the further research, we will think over combining the mathematical model with computer simulation to get an result which is closest to the real problem and build the mathematical model linking edible fungus with other agricultural industries, such as rice planting and dry field farming for optimum utilization agricultural wastes.

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