ISSN 2616-5767 Vol.4, Issue 2: 57-60, DOI: 10.25236/AJETS.2021.040209

Research on the Model of influencing factors of strain decomposition rate based on Analytic hierarchy process

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Abstract: *According to the fungal decomposition pattern, a differential function was obtained. Which can describe the phenomenal. Then we get a function of growth rate and decomposition ability. Furthermore, the environmental factors, such as temperature and humidity, are taken into account. After integrating the differential equation and finishing the curve fitting. To incorporate the interactions between different species of fungi, we introduce the concept of comprehensive competitive ability index, which can measure the competitive ability in different species and its expression can be solved by Analytic Hierarchy Process (AHP). According to these index, reduction factor can be defined. Thus the expression which describes the actual interactions between different species of fungi is now available. A Dominant Model is built to describe the advantages and weaknesses for fungus of a combination of fungi in different environmental conditions, which can be expressed in terms of sensitivity. Then we analyse relative advantages of three species of fungi by Cellular Automata. At last, a multi-species sustainable survival model is constructed to predict the trends with a value of competition threshold B, which is 0.5 through experiments.*

Keywords: *Relative Competition Index, Cellular Automata, Analytic Hierarchy Process, Sensitivity Theory, Succession Model*

1. Introduction

As a vital component for life on the planet, carbon cycle allows carbon to be renewed and used in other forms by decomposing compounds. In particular, fungi plays a significant role in decomposition of woody fibres or ground litter [1]. However, it is known just a few details about the inside process of decomposition through fungal activity untie now, which makes this research interest so popular. Obviously, there are different decomposition rates under the different conditions. In the past researches, we found that the decomposition rate is influenced by the fungus' traits as well as the external factors of environment. Additionally, the most notable traits are growth rate and tolerance to moisture, which we should focus on merely in this problem [2]. At the same time, the temperature and humidity should be also concentrated on.

The paper establish four models to solve the problems in our paper. Fungal activity model is used to analyze the effect of a single strain on the decomposition rate. Comprehensive considering external factor such as temperature, we build a fungal activity model to describe the behaviour of decomposition under the common influence of humidity and temperature [3]. After calculating some parameters, we can obtain the relationship between decomposition rate and growth rate of one certain fungus. To incorporate the interactions, we combine three key factors to define the reduction factor after competition between different species of fungus, and clearly express the interaction through the total decomposition rate. Then we use Analytic Hierarchy Process (AHP) to obtain the weights of three factors [4].

2. The Fungal Activity Model Generalization

The paper focus on a simple mathematical model which can describe the fungal activity of certain fungal community without considering the interaction between different fungi. According to the data and result of the original research article by Lustenhouwer, et al, it is known that 'Weight loss' could be expressed as a function of internal traits and external factors. Including growth rate, moisture niche width, temperature, humidity and so on. Firstly, ' Area' is a representation for the number of fungi, so we can express the weight loss for a moment as following, where C means the decomposition ability of certain

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fungus in the given environment.

$$\Delta M = C \cdot A(t) \tag{1}$$

As the area can be calculated by:

$$A(t) = \int_0^t P_t dt \tag{2}$$

Incorporate the expression (1) and (2), then transform it as following:

$$\frac{\Delta M}{\Delta t} = C \cdot \frac{\int_0^t P_t dt}{\Delta t} \tag{3}$$

Next, replace the $\frac{\int_0^t P_t dt}{\Delta t}$ with $\overline{\Delta P}$. Therefore, with Taylor Formula, $\overline{\Delta P}$ could be expressed as:

$$\begin{aligned} \overline{\Delta P} &= \overline{\Delta P_0} + \sum_{n=1}^{\infty} \frac{1}{n!} \cdot \frac{\partial^n \overline{\Delta P}}{\partial t^n} \cdot t^n \\ &= \overline{\Delta P_0} + \sum_{n=1}^{\infty} K_n \cdot t^n \quad \left(K_n = \frac{1}{n!} \cdot \frac{\partial^n \overline{\Delta P}}{\partial t^n} \right) \end{aligned} \tag{4}$$

There is no denying that the decomposition of wood by fungal community is a continuous process, so we deal with the equation (3) with differential method.

When it comes to factor C, which is relative to temperature and humidity in the environment, it's manifest that fungus would have relative higher decomposition rate in appropriate situation according to the reference research. With temperature increasing in an appropriate region, the decomposition rate of fungi shows a trend of gradually increasing initially, and then decreasing. At the same time, if the humidity of is not adaptive for fungus, the decomposition rate shows a downward trend. Therefore, we build an exponential model which can better describe the behaviour of fungus under the common influence of humidity and temperature. And it also have better statistical significance.

$$C = \frac{k}{1 + e^{aT+b}} \cdot \left(2 - e^{\alpha \left| \frac{2H - H_n}{H_n} \right| - \beta} \right) \tag{5}$$

3. Interaction Model

The paper need to analysis the specific interactions between different species of fungi. Here the paper only consider the competitive interaction of strains in this process, where we ignore others such as cooperation. In the given patch of land, we stipulate that there are N types of fungi with different growth rates and moisture niche widths. Without considering the interaction between different fungal communities, we can calculate the total decomposition of wood in this patch as the sum of Mi caused by each kind of fungus.

$$M_{total} = \sum \left(M_i + \varepsilon_i \right) \tag{6}$$

Now we integrate the competitive interaction within. In order to describe the impact caused by competitive interaction, we introduce the 'reduction factor yi to each kind of fungi, which means the decomposition ability loss in competition. So the total decomposition can be rebuild as:

$$M_{total} = \sum \left(y_i \cdot M_i + \varepsilon_i \right) \tag{7}$$

The reduction factors also indicate that how serious they are affected by the competitive interaction. The larger the factor yi is, the more competitive the fungal community can be. In order to obtain the reduction factors, we set a competitive index D to justify their competitive ability compared to other fungi. As well, the relationship of reduction factors and competitive index D identified as:

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4. The Model Results and Discussion

In the first step, we are required to solve the differential equation (6) we have obtained.

$$\int dM = \int C \cdot \overline{\Delta P}\, dt \tag{8}$$

Based on the data which is obtained in an invariant environment, we can consider that the average growth rate of a certain specie of fungi kept constant while time is going on. So the $\overline{\Delta P}$ is considered to be constant in the differential equation. Then the solution is as below:

$$M = C \cdot \overline{\Delta P} \cdot t + M_0 \tag{9}$$

Leading-in the data in 'Table S3' from the 'Supplementary Information' of original research article, then we provide a curve fitting program in MATLAB.

According to the dataset which is recorded in $122^{t}h$ day, the variable t can be considered constant. Therefore, the M is a linear function of variable $\overline{\Delta P}$. Following, we fit 3 linear curves with the data in 3 different temperatures. The solution we get is shown as following:

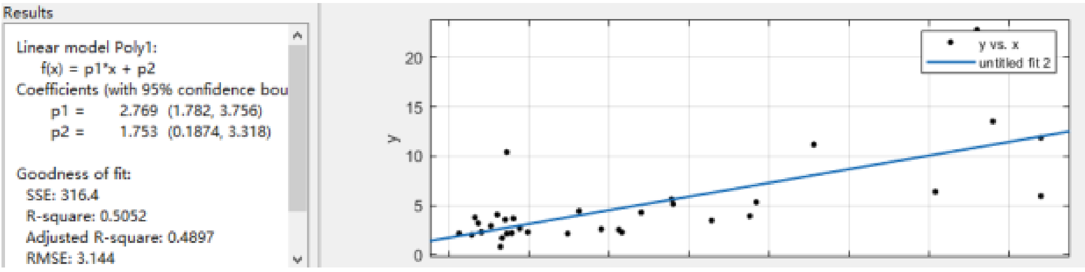

Figure 1: Curve fitting solution in $10^{\circ}C$

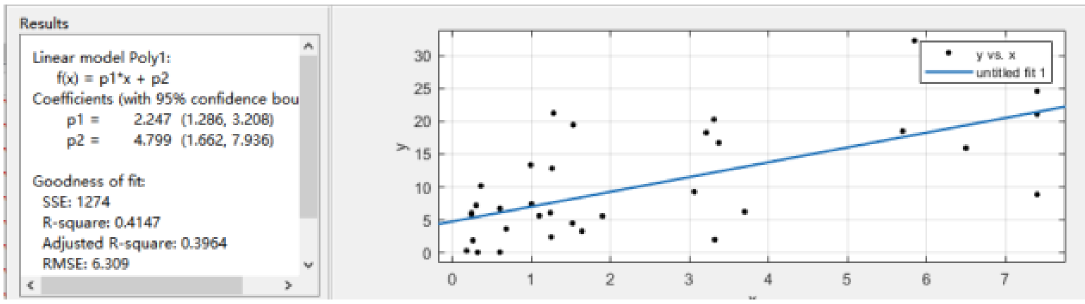

Figure 2: Curve fitting solution in $16^{\circ}C$

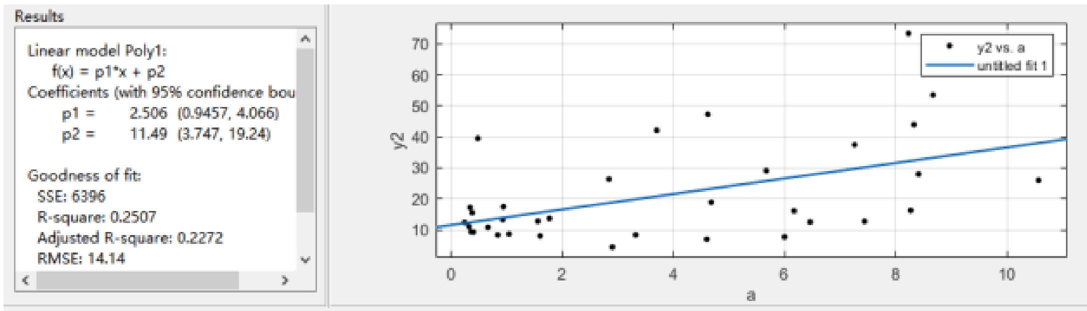

Figure 3: Curve fitting solution in $22^{\circ}C$

Table 1: Solution

Factors	$10^{\circ}C$	$16^{\circ}C$	$22^{\circ}C$
$C \cdot t$	2.769	2.247	2.506
M_0	1.753	4.799	11.49

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Next step, we are going to deal with the expression of C which is known as a function of temperature and humidity. In this research, the data of humidity was not recorded, and we treat them in a invariant humidity environment. As a result, we take value of the left part in equation (7) to be 1. So the simplified function C with the variable q is:

$$C=\frac{k}{1+e^{aT+b}} \tag{10}$$

We can find the value of C and q in 'Table 1', where t = 122. Therefore, we solve this equation with a MATLAB program and the result is shown as following:

```
f1 =

     General model:
     f1(x) = k/(1+exp(a*x+b))
     Coefficients:
       a =    -0.01914
       b =       2.827
       k =      0.2736
```

Figure 4: Solution of Function C

$$C=\frac{0.2736}{1+e^{(-0.01914)T+2.827}} \tag{11}$$

Therefore, final expression of fungal activity model which can describe the de composition activity caused by fungi with different traits and in different temperature was shown as below, where the value of M0 is relative to the temperature q shown in 'Table 1'.

5. Conclusions

Considering the external environmental factors, we describe the relationship between the decomposition rate and the growth rate of a certain fungus. A good fungal activity model was obtained by MATLAB curve fitting. Through the introduction of reduction factor and competition index, combined with three key factors, the interaction model was established scientifically, and then the weight of these factors was determined by analytic hierarchy process to reflect the interaction between different kinds of fungi.

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