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A Fungal Degradation Model Based on Dynamic Simulation

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Abstract: The decomposition between plant material and wood fibers by fungi is a crucial part of the carbon cycle, which is an important part of life on Earth. Therefore, the study of fungi decomposition rate has great practical significance. The decomposition process of single species of fungi is analyzed. We *quantify* the growth of a single species of fungi based on an improve Logstic model, taking temperature and humidity into account. Then, considering the growth rate and moisture tolerance of fungi, the decomposition dynamics model of single fungi is established. It will lay a foundation for the model analysis of multiple fungi.

Keywords: *Fungi Decomposition Model, Simulates, Climate Influence Factor*

1. Introduction

Fungi, as decomposers, have been playing the role of "cleaners" to promote the carbon cycle. The decomposition of fungi is crucial to the carbon cycle, so it is of great significance to study the decomposition rate of fungi.

In the research on the decomposition efficiency of lignin fiber by fungi, in the short term, the decomposition of lignin fiber is mainly completed by individual fungi. Under ideal conditions, we can make short-term prediction of fungal decomposition efficiency according to individual characteristics (growth rate and humidity tolerance). The growth of single fungus was predicted by using the improved Logistic model, and the kinetic model of wood fiber decomposition by fungus was established according to the literature [1]. Finally, the model is simulated by setting environment parameters.

2. Model Building

2.1 Single Fungal Decomposition Dynamic Model

In the process of decomposition, fungi grow and reproduce with wood fibers as food, and the number of fungi affects the efficiency of fungal decomposition to a certain extent. Considering the ideal condition of only a single strain, the more fungi there are, the better and the decomposition efficiency will be, so we first study the growth law of fungi. We use the Logistic model to express the number of fungi as follows:

$$\frac{dN}{dt} = rN\left(1 - \frac{N}{N_{max}}\right)$$

Where, N represents the number of fungi, t represents the time, r represents the intrinsic growth rate, and $Nmax$ represents the maximum number of fungi that can be accommodated in the environment. According to literature [1], we present the expression of innate rate of increase r for the propagation characteristics of fungi as follows:

$$r = \sqrt{\frac{2}{\lambda ln\left(1 - \frac{\mu_{max}}{N_{max}}\right)}}$$

Where, λ represents the retardation period of fungus growth, and μ_{max} represents the maximum growth rate of fungus. Substituting Equation(2) into Equation(1), we can get:

$$N(t) = \frac{N_{max}}{\left\{1 + \exp\left[\frac{4\mu_{max}}{N_{max}}(\lambda - t) + 2\right]\right\}}$$

Since wood fiber is an organic substance mainly containing carbon compounds, the process of fungal degradation of wood fiber is considered as a primary degradation process [2]. For the primary degradation process, we have the following mathematical expressions:

$$\frac{dm(t)}{dt} = -\mu_{O,B} \times N(t)$$

Where, $m(t)$ is the mass of wood fiber at time t, and $\mu_{O,B}$ is the specific growth rate. $\mu_{O,B}$ is calculated by the following formula:

$$\mu_{O,B} = k\mu_{max} f_B^T f_B^{SW}$$

Where, k is the positive definite coefficient, and f_B^T is the positive definite coefficient, f_B^{SW} is moisture tolerance, and its value range is $[-1, 1]$ (which will be discussed in detail in the subsequent model). The temperature and humidity limiting factors are related to external temperature and humidity conditions in the fungal decomposition process.

2.2 Dynamic Model of Multiple Fungi Decomposition

Based on the above analysis, we know that moisture tolerance f_B^{SW} is the moisture tolerance of fungi. Under the coexistence of multiple fungi, each fungus has different moisture tolerancef_B^{SW}. In order to distinguish the sensitivity of different fungi to the environment, these two parameters are quantified as follows. According to literature [4], it can be known that moisture tolerance is the difference between competitive ranking and water niche width, and the greater the moisture tolerance of fungi, the stronger the decomposition ability. Thus there are:

$$f_B^{SW(i)} = \hat{\sigma}_i - \hat{\beta}_i$$

Where, $f_B^{SW(i)}$ represents the moisture tolerance of the ith fungus, $\hat{\sigma}_i$ represents the normalize competitive ranking of the ith fungus, and $\hat{\beta}_i$ represents the normalized water niche width of the ith fungus. Obviously, the value range of moisture tolerance $f_B^{SW(i)}$ is $[-1, 1]$, which meets the requirements of the question.

Different from the decomposition of single bacteria, the co-decomposition of multiple fungi requires consideration of the competitive relationship between different strains, and then based on this analysis of the decomposition rate of wood fiber under the co-action of multiple fungi.

We hypothesize that when multiple species of fungi live on the same wood fiber, each species only feeds on the organic carbon produced by the decomposition of the wood fiber, rather than devouring other fungi. Therefore, the multiple fungi only compete with each other. According to literature [3], we establish the population competition model of multiple fungi, as follows:

$$\frac{dN_1(t)}{dt} = r_1 N_1 \left(1 - \frac{N_1 + aN_2}{N_{1,max}}\right)$$
$$\frac{dN_1(t)}{dt} = r_1 N_1 \left(1 - \frac{N_1 + aN_2}{N_{1,max}}\right)$$

Where, $N_{i,max}(i = 1, 2)$ represents the maximum environmental accommodating quantity of the population, and a and b are interaction coefficients.

3. Results Analysis and Simulation Test

3.1 Single Fungi Decomposition

In order to solve the model, 10 different temperature and humidity factors and humidity resistance factors were given under the ideal condition of single bacterial decomposition and the variation of wood fiber quality was explored by controlling the variables.

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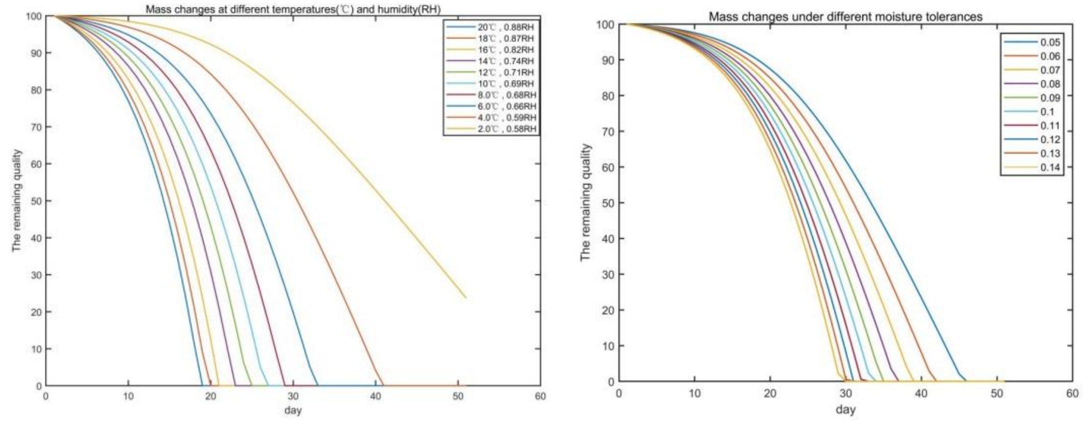
We set the initial amount of wood fiber to be 100 and the initial amount of fungus to be 3. According to the data, the most suitable growth temperature of fungi is 25 ℃ and the relative humidity is 0.74, so it can be estimated simply: $f_B^T = 25 \times 0.74 = 18.5$. By adjusting the parameters, the influence of temperature and humidity and humidity resistance on the decomposition amount of wood fiber is obtained.



(a) (b)

Figure 1: (a) Changes of wood quality under different temperature and humidity conditions (b) Variation of wood quality under different humidity resistance conditions

As shown in the figure 1 on the left, the decomposition rate of fungi becomes faster with the increase of temperature and humidity. As shown in the Figure 1 (b) on the right, the rate of fungal decomposition increases with the increase of moisture tolerance. In addition, according to the image, we can find that the decomposition efficiency of fungi is more affected by temperature and humidity than moisture tolerance, which is reasonable and unexpected in our study. Obviously, this relatively initial short-term model is difficult to be applied to express the long-term process of fungal decomposition, but it provides a theoretical basis for further long-term decomposition dynamics models of the co-existence of multiple fungi.

3.2 Multi fungi decomposition

Next, according to the change in the number of fungi, we solve the change of lignin fiber under the action of multi-fungi, as shown in figure 2 below:

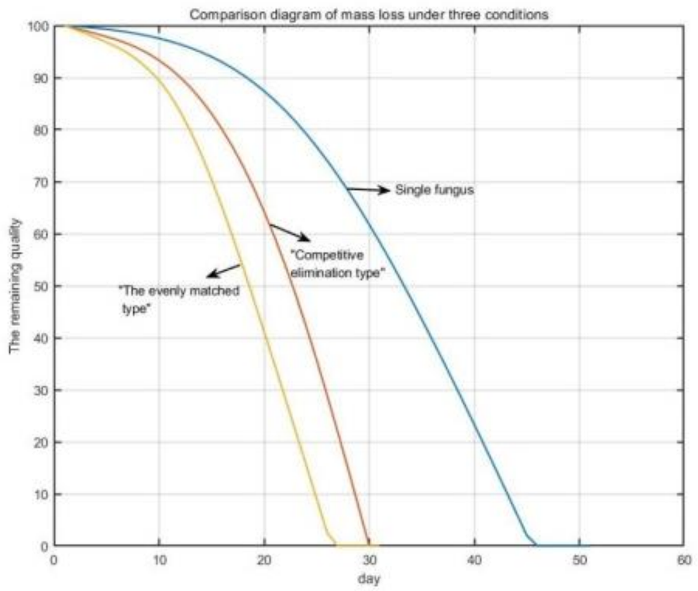


Figure 2: Wood fiber changes under three conditions

When the initial total amount of fungi does not change, the decomposition efficiency of wood fiber by single fungi is the slowest, while that by multiple fungi meeting the "Evenly matched" type is the

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fastest, while that by "Competitive Elimination" type is between the two. Therefore, no matter in which case, under certain external and initial conditions, the decomposition efficiency of multiple fungi is better than that of single fungi.

Further, we verify the correctness of the above results through programming simulation, and dynamically simulate the process of fungal decomposition:

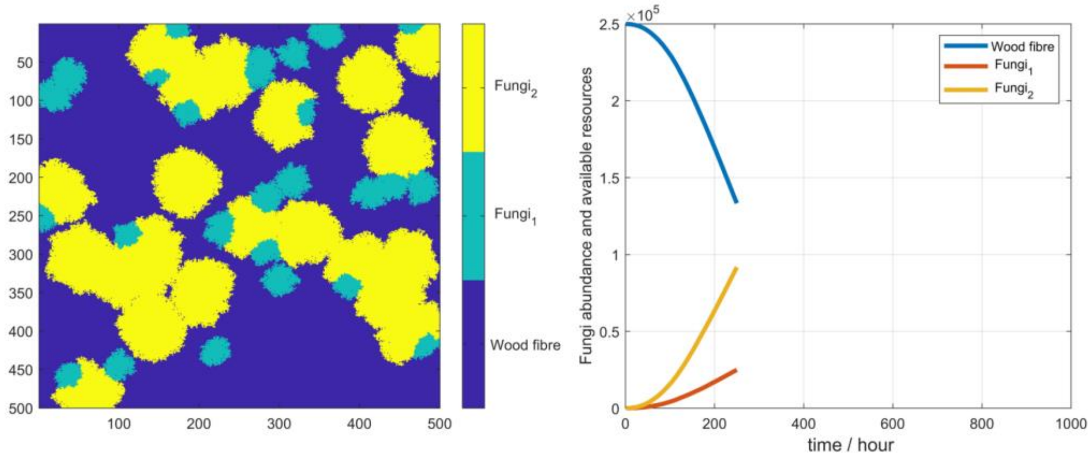

Figure 3: Simulated decomposition state diagram of stage one(a=b=1)

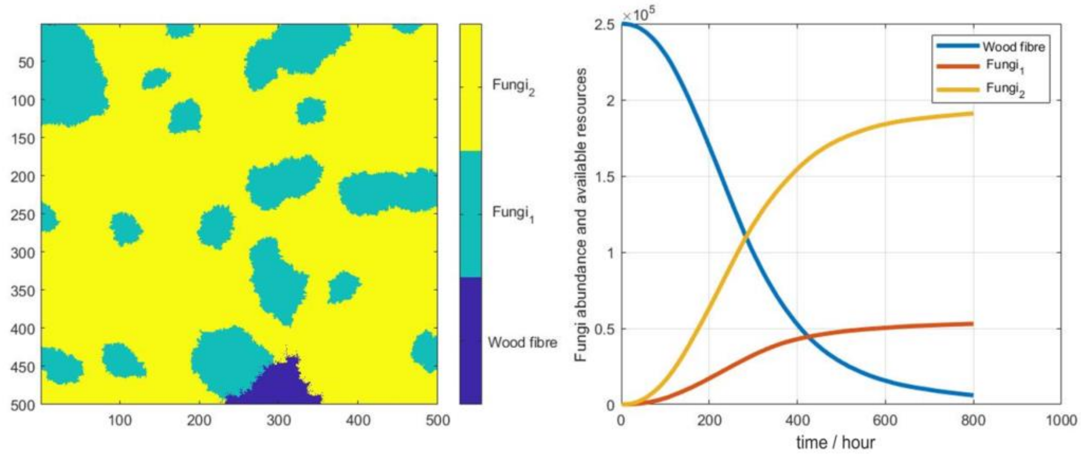

Figure 4: Simulation decomposition state diagram of stage two (a=b=1)

4. Summary

We use the improved Logistic model to make it more consistent with the growth law of fungi, so that the model is closer to the reality and ensure the rationality and stability of the model. The results of the model can be visualized by computer simulation of fungal growth and competition.

The simulation results are consistent with the reality, which further verifies the correctness and feasibility of the model established by us. But the model still has some drawbacks. We only collected temperature and humidity data for one month, without considering other possible effects of seasonal factors.

By establishing a single fungi decomposition dynamic model and a multi-species decomposition dynamic model, we find that: the decomposition efficiency is the best when multiple fungi co-exist and have the same competitive ability ("Evenly matched" type), and the time for a single fungi to decompose 100*g* wood fiber is about 46 days. The decomposition of "Evenly matched" multiple strains take 30 days. The optimal "Competitive Elimination" model takes 27 days.

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