Study on the explanation rate of Fungi based on Ecological Model

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Abstract. This article analyzes the relationship between fungal decomposition rate and its two important characteristics: extension rate and moisture resistance by establishing a fungal lignocellulose decomposition model when multiple types of fungi decompose wood fibers in the same area, and further predicts the role of the diversity of fungal communities in an ecosystem. We first divide fungi into two categories based on temperature: fast-growing but highly affected by the environment, called RABBIT; and slow-growing but relatively stable fungi (less affected by the environment), called TORTOISE. Humidity is an independent variable, using regression analysis method to establish a fungal growth decomposition model, we can find that the fungal decomposition rate and the logarithm of the expansion rate and the logarithm of moisture resistance are roughly linear. According to the fungal decomposition model obtained in question1, we use cellular automata and Lotka-Volterra model to establish interaction models between different types of fungi, and find two types of bacteria with different competitiveness, RABBIT and TORTOISE, when competition coefficient of the mare different, we can find that the two groups of fungi will produce different competition results (may coexist, or one group of fungi may be eliminated).

Keywords: Decomposition Rate, Fungal Interaction, Cellular Automaton, Lotka-Volterra Model.

1. Introduction
The geobotanical cycle of carbon controls the migration of carbon between the surface or near-surface sediments and the atmosphere, the biosphere and the ocean. This cycle is important for maintaining a stable climate and carbon balance on Earth [1]. The carbon cycle describes the process in which carbon atoms continually travel from the atmosphere to the Earth and then back into the atmosphere. The decomposition of compounds in the carbon cycle allows carbon to be renewed and used in other forms. The most common thing in this process is the decomposition of plant materials and wood fibers [2].

The decomposition of plant materials and wood fibers is inseparable from the life activities of fungi. In the decomposition process, the fungus is largely a hidden role. Although we know that they are essential to the carbon cycle, it has always been difficult to determine the effects of different decomposers in causing rapid or slow decomposition. In the research process, the decomposition rate of
plant materials and wood fiber is an important indicator of our research. According to previous studies, environmental temperature, humidity, pH, and fungal density are all factors that affect the decomposition rate. The temperature directly affects the enzyme-producing ability of white rot fungi, and if it is too high, the degradation rate will be reduced; if the temperature is too low, the progress of fungal fermentation will be slow. In our research, we mainly focus on the decomposition rate, inter-species relationship and species diversity of fungi [3].

![Figure 1. Global Fungi Distribution](image)

Using the model, we want to find the trend of fungi’s decomposition rate under the influence of temperature, humidity and moisture tolerance. Also, we need to figure out how the interaction between different categories of fungi influence their growth.

Considering that a sharp change in the environment will not happen, we discuss the arid, semi-arid, temperate and tropical rainforest trees and the four kinds of typical environmental effects on the fungal growth [4-5].

2. Fungi’s Decomposition Rate and Interactions

2.1. Model for decomposition rate

To clearly describe the physiological characteristics of fungi, we classified the fungi into two categories: those that grow rapidly but are highly affected by the environment, and those that grow slowly but are relatively stable (less affected by the environment). Meanwhile, to ensure the fungi can survive for a long time, we assume that they can obtain sufficient nutrients from the region during its growth and maturation [6]. Also, based on biology, the size of community cannot be increased indefinitely. Similarly, the fungi should be the same, which guarantees that when the fungi grow to maturation, its decomposition rate will be limited. Looking at the literature [7], we know that the growth of the fungus itself is largely dependent on the temperature, but we use the extension of the fungus to measure the dynamic expansion of the fungus. The expansion of the fungus is also closely related to the relative humidity of the environment [8]. Thus, our process of solving the problem is as follow:

1. Find a function describe the relationship between fungi’s growth rate.
2. Considering the influence of relative humidity, get the function of fungi’s extension rate.
3. Combine extension rate and moisture tolerance finally get fungi’s decomposition rate.

First, we develop a model for fungi growth as a function of temperature. The temperature dependence of the specific growth rate of fungi may be modeled by means of the square root model with the cardinal parameters (e.g., the minimum temperature for growth, Tmin and the maximum temperature for growth, Tmax as follows:

\[
\sqrt{\mu} = a_1(T - T_{\text{min}}) \left(1 - e^{b(T-T_{\text{max}})} \right)
\]  \hspace{1cm} (1)
Where \( \mu \) is growth rate, \( a_1 \) and \( b_1 \) are design parameters.

Analogizing the relationship between temperature and fung’s growth rate, we can assume that the relative humidity RH has a similar relationship with growth rate, so we can write an equation with a similar form, as follows:

\[
RH = a_2 \left( RH - RH_{\text{min}} \right)^* \left( 1 - e^{b_2(RH - RH_{\text{min}})} \right)
\]  

We further consider the influence of humidity on extension rate, let RH be the relative humidity, use linear regression we can define:

\[
r = a_\mu + b_\text{RH}
\]  

We have found from the reference materials that the decomposition rate \( U \) of fungi is roughly linear with its logarithm of extension rate \( r \) and logarithm of moisture tolerance \( MT \), so we can finally define the following function:

\[
u = c \ln r + h \ln MT
\]

2.2. Decomposition rate Model Solution

Undoubtedly, the race between the tortoise and the rabbit is a well-known story, and, by analogy, we’ll use it to name the fungi we’re studying, regardless of the positive or negative implications of the story. The previous discussion in our paper have divided fungi by observation into two categories: the ones that grow rapidly but are greatly affected by the environment, here we call them RABBIT, and the ones that grow slowly but steadily, we call them TORTOISE.

As for different fungi, we used some data [4] to figure out the relationship between their growth rate and temperature, and also, we figure out the values of constants \( a \) and \( b \), the results are shown in Table1. Similarly, we obtained the curve between relative humidity RH and growth rate \( \mu \) through regression analysis, and obtained the coefficients of different fungi. The results are shown in Table 2:

We draw these curves on the same axis as shown in Figures 2 and 3, using different colors to distinguish them.

**Table 1. Coefficient of \( \mu \)**

| fungi  | \( a_1 \)   | \( b_1 \)   |
|--------|-------------|-------------|
| a. gal1. s | 6.8463      | 0.00011     |
| a. gal10. n | 0.0344      | 0.02982     |
| a. gal2. s | 7.6975      | 0.00012     |
| a. gal3. s | 5.9033      | 0.0001      |
| a. gal4. s | 6.2083      | 0.00013     |

**Table 2. Coefficient of \( RH \)**

| fungi  | \( a_2 \)   | \( b_2 \)   |
|--------|-------------|-------------|
| a. gal1. s | 0.0704      | 2.8885      |
| a. gal10. n | 0.0743      | 3.6707      |
| a. gal2. s | 0.0729      | 2.2633      |
| a. gal3. s | 0.0665      | 2.6869      |
| a. gal4. s | 0.0604      | 2.089       |
Besides considering the extension rate of the fungi, we should take the decomposition rate of fungi into account to better describe the breakdown of ground litter and woody fibers through fungal activity in the presence of multiple species of fungi. In this process we set a constant moisture tolerance, then the relationship between decomposition rate and extension rate is as below:
3. Interactions between different fungi

The notion of competition between plant species may be based on the idea that resources such as water, light, soil minerals, and growing space are in limited supply. For example, for two plant species growing in a desert environment, water would be in limited supply and so plants whose roots permit the greatest acquisition of water would have an advantage. However, the species that cannot obtain sufficient water may suffer from limited growth or the risk of extinction.

While competition is frequently considered as the only common way in which individuals and species interact, it turns out that other interactions are important and have been observed experimentally. Mutualism is a symbiotic relationship in which both partners benefit.

Using Lotka-Volterra model [5] and Logistic model, we assume that population quantity of the two categories is N1 and N2; The environmental capacities of the two fungi are K1 and K2; The extension rates of the two fungi are respectively r1 and r2; N can be understood as the space already utilized, so1 N is unutilized space. When two species compete or exploit the same space, the "utilized space term" should be added to the space occupied by fungi population N2.

\[
\frac{dN_1}{dt} = r_1N_1 \left(1 - \frac{N_1}{K_1} - C_{21} \frac{N_2}{K_1}\right)
\]

\[
\frac{dN_2}{dt} = r_2N_2 \left(1 - \frac{N_2}{K_2} - C_{12} \frac{N_1}{K_2}\right)
\]

Since there are almost no two groups of fungi in nature that depend on each other, competition or symbiosis between the two species is considered here. When two species compete for the same food resources and living space, the common outcome is that the less competitive one goes extinct and the more competitive one reaches its maximum capacity. The model of population competition can be used to describe the process of competition between two populations and analyze the conditions that produce various outcomes. One possible outcome is shown as Figure 5. When C21 > 1 and C12 < 1, we can find that the two groups of fungi coexist with each other shown as Figure 6.
4. Interaction Model in different environments

4.1. Stable Environments without Rapid Change
Now we consider the impact of environmental factors on the growth of fungi, we discuss arid, semi-arid, temperate, arboreal, and tropical rain forests (Tropical). Four types of typical environments, through the fungal interaction model in Section 4, use cellular automata (CA) to simulate fungal short-and long-term trends. Special attention is that we do not consider the rapid changes in the environment for the time being. This situation is almost impossible in reality, but in order to study the evolution of fungal populations, we set this ideal condition.

We select temperature(T) and relative humidity (RH) as environmental factors and use tuples (T, RH) to express the above different environments. The corresponding growth rate can be obtained by equation (3), and all the information is summarized into table3:
Table 3. The \((T - RH)\) description of different environments

| Environment       | \((T, RH)\) | \(r\)    |
|-------------------|-------------|----------|
| arid              | (25, 0.5)   | 2.8885   |
| semi-arid         | (25, 0.6)   | 3.6707   |
| temperate         | (25, 0.8)   | 2.2633   |
| rain forests(tropical) | (35, 0.95) | 2.6869   |

Figure 7. Fungus growth trend

We use CA to simulate the growth of RABBIT fungus and TORTOISE fungus in different environments within 30 days. We consider a 150 150 area, which satisfies the general conditions for the growth of two fungi and is connected to the external environment. The two fungi enter the area from the outside with the probability of pexterior, they expand and die at a certain rate. The two kinds of fungi are mutually competitive and dependent. The simulation result is shown in Figure 7.

Figure 8. CA result
The blue area in the figure above represents the RABBIT fungus, the green area represents the TORTOISE fungus, and the yellow area represents the coexistence of the two fungi. We can see that regardless of the rapid changes in the environment, both fungi can grow smoothly. RABBIT fungi grow quickly and quickly occupy a large area, but the TORTOISE fungi are well tolerated and are more dominant in the competition with the RABBIT fungi. It can also be extended gradually, and eventually the two fungus coexist.

5. Sensitivity Analysis
In the previous analysis of the four different temperature bands, dramatic changes in the environment were not taken into account, but are now taken into account. Since RABBIT grow fast but are greatly affected by rapid environmental changes, while TORTOISE grow slower than rabbits but are less affected by environmental fluctuations, it will eventually be found that the size of TORTOISE catches up with the size of RABBIT, and eventually the two coexist.

6. Conclusion
In this paper, regression analysis, cellular automata, Lotka-Volterra model and other methods are used to classify fungi into two categories: fungi that grow rapidly but are highly affected by the environment, called RABBIT; and fungi that grow slowly but relatively stable (less affected by the environment), called TORTOISE, to build a model of fungi decomposition of woody fibers.

Using the model, we found that the rate of fungal decomposition increased first, reached a peak, and then gradually decreased. When a sharp change in the environment will not happen, we discuss the arid, semi-arid, temperate and tropical rainforest trees and the four kinds of typical environmental effects on the fungal growth and found that both fungi can grow smoothly, RABBIT fungal growth is rapid, covers an area of big, but the TORTOISE fungal is well tolerated, more advantageous in the competition with the RABBIT fungi, and can also extends gradually, finally two fungi coexistence.

However, the size of the fungal population varies among the four environments, and this change in population size ultimately affects the rate of wood decomposition.
Finally, we analysed the role of fungal communities in diversity in the ecosystem and found that the more diversified the fungal community is, the higher will the overall efficiency in decomposition of litter on the ground be. Therefore, it is important to maintain the diversity of the fungal community.

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