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Analysis of Fungal Decomposition based on Fungal Decomposition Model

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Abstract: Fungi, as decomposers, are critical in carbon cycle by decomposing woody fibers. In order to describe the dynamic process of decomposition of wood through fungal activities incorporating the interactions between different species of fungi, we abstracted a set of differential equations and established Fungal Decomposition Model based on the predator-prey relationship between fungi and wood and the competition relationship among fungi species. Then, for describing the short-term and long-term trends of the dynamics of interactions among fungi, we used MATLAB to simulate the decomposition progress and got a result that in the short term, different communities of fungi work together and the decomposition speed gets faster, while in the long term, the severe competition among fungi makes the more competitive colonies develop and the less competitive colonies go extinct.

1. Introduction

Carbon cycle is the migration of carbon elements among animals, plants and environment. It plays quite an important role in life activities on earth. And ground litter is an irreplaceable carbon pool, which stores about 184Gt carbon [1]. Its decomposition process, accompanied by the transformation of energy and the renewal of matter, occupies a key position in the global carbon cycle. This widespread chemical process has a profound impact on global climate change. Meanwhile, it provides a large amount of mineral elements and nutrients for plant growth, which determines the productivity of terrestrial ecosystem to a large extent. According to statistics, 70% of the global carbon flux comes from litter decomposition [1].

The wood-rotting fungi in the soil are an important force to decompose the ground litter rich in woody fibers. They are mainly divided into three types: white-rot fungi, soft-rot fungi and brown-rot fungi [2]. Due to the different composition and activity of the internal decomposing enzymes, these three fungi have different decomposing abilities. Interacting and competing with each other, they achieve the decomposition of woody fibers.

Last year, several researchers identified some fungi traits, especially the growth rate and the moisture tolerance, that determine the decomposition rates [3]. In addition, the impact brought by environmental changes should also be considered throughout this chemical process.

2. Fungus Decomposition Model Establishment

2.1 Lotka-V olterra Predator-Prey Model Establishment

We define the relationship between fungi and decomposed deadwood (including dead leaves, etc.) as predators and preys. The numbers of predators (white rot fungi, soft rot fungi, brown rot fungi) and prey(deadwood)are denoted as N and M, respectively . When fungi were not taken into account, the amount of decomposed rotten wood increased naturally at a small growth rate r_M. However, the existence of fungi reduces the growth rate of wood, that is, wood is gradually decomposed by fungi.

Considering that the effect of wood in providing energy for fungi is equivalent to

Reducing its mortality rate and assume that this effect is proportional to the amount of wood, then N(t) satisfies the equation:

$$\frac{dN}{dt} = (-r_d + \lambda M) N \tag{1}$$

2.2 Population Competition Model Establishment

When considering the survival of a single fungal population in an environment with limited wood resources, we often use the logistic growth model to describe the evolution process of its population.

If the decomposition effect of white rot fungi on wood is taken into account alone, and the influence of soft rot fungi and brown rot fungi is not taken into account, the change of the number of white rot fungi's population is supposed to obeys the logistic growth model.

If consider the competition effects of soft rot fungus and brown rot fungus on white rot fungus, they consume the same resources will affect the growth of white rot fungus, we have to add two other factors into Equation 5 which are proportional to the number of soft rot fungus N_2(relative to the K_2), and the number of brown rot fungus N_3(relative to the K_3) respectively . Therefore, for white-rot fungus:

$$\frac{dN_1}{dt} = r_{1g}\left(1 - \frac{N_1}{K_1} - \sigma_{12}\frac{N_2}{K_2} - \sigma_{13}\frac{N_3}{K_3}\right) N_1 \tag{2}$$

In Equation 2, we define the coefficient of competition σ_{ij}, which means that the amount of wood consumed by colony j per unit is σ_{ij} the amount of food consumed by colony i per unit. For example, in this situation σ_{12} and σ_{13} mean that the consumption of unit quantity of soft rot fungus group of wood times the amount of wood that is consumed by white rot fungus as σ_{12} , and the units of brown rot fungus' consumption of wood times the amount of wood which is consumed by white rot fungus as σ_{13} .

2.3 Result

According to the given information, we know that the fungi's decomposition ability of wood is directly proportional to the growth rate of fungi and inversely proportional to the moisture tolerance level [3], which is defined as m, of fungi. By observing Figure 1, we can give conclude the relationship formula:

$$\begin{cases} R_d = k_1 r_{ig} + e^{-k_2 m_i} = \dfrac{t}{M} \cdot \dfrac{dM}{dt} \\ \lambda_i = k_{3i}\left(k_1 r_{ig} + e^{-k_2 m_i}\right) \end{cases} \tag{3}$$

Where R_d means decomposition rate. $k_1$and $k_2$are the slopes of the curves in Figure 1 which reflect the influence of fungus' growth rate and moisture tolerance level on its decomposition ability respectively, and k_3 is an arbitrary undetermined constant.

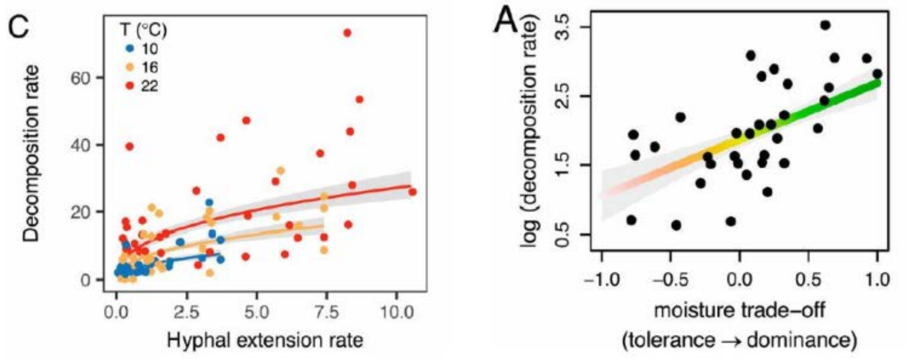


Figure. 1 The relationship between growth rate, moisture tolerance and decomposition rate.

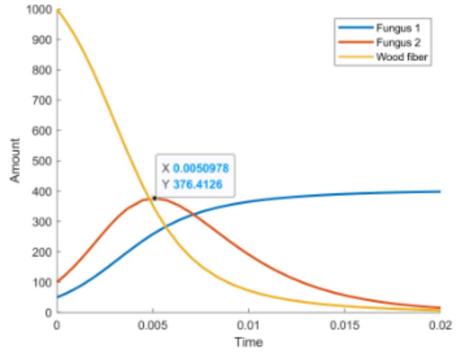
By comprehensively considering the predator-prey model and the population competition model, we can describe the breakdown of ground litter and woody fibers through fungal activity in the presence of multiple species of fungi. As follows:

$$\begin{cases} \dfrac{dN_i}{dt} = r_{ig}\left(1 - \dfrac{N_i}{K_i} - \displaystyle\sum_{j=2}^{n} \sigma_{ij}\dfrac{N_j}{K_j}\right)N_i + \left(-r_{id} + \lambda_i M\right)N_i \\ \dfrac{dM}{dt} = \displaystyle\sum_{i=1}^{n} \left(r_M - \lambda_i N_i\right)M \\ R_d = k_1 r_{ig} + e^{-k_2 m_i} = \dfrac{t}{M} \cdot \dfrac{dM}{dt} \\ \lambda_i = k_{3i}\left(k_1 r_{ig} + e^{-k_2 m_i}\right) \end{cases} \tag{4}$$

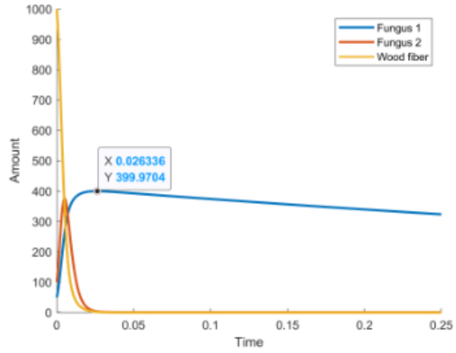
3. The Short-term and Long-term T rends of the Dynamics of Interactions

3.1 Analysis

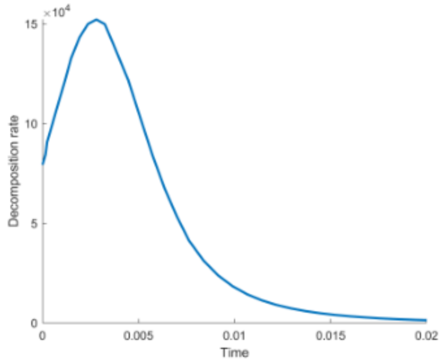
Figure 2(a) demonstrates the short-term evolution process; Figure 2(b) shows the long-term evolution process; and Figure 2(c) represents the overall decomposition speed change diagram. As can be seen from Figure 2(a) and Figure 2(b), fungus colony 1 presents a process of first growth and then slow decline, and similarly, fungus colony 2 has the same trend. However, the maximum of fungus colony 2 is less and earlier than that of colony 1, and its growth rate is rapid, but its decay rate is also fast. By contrast, the growth rate of colony 2 is slightly slower than that of colony 1. From the long-term perspective, there is no striking difference in the growth rate between them. But the damp rate of fungus 1 is significantly slower.



(a) Short term



(b) Long term



(c) Decomposition rate

Figure. 2 Differences between short term and long term

It can be seen from the yellow line in Figure 2(a) which indicates the dynamic process of wood fiber and Figure 2(c) that the overall decomposition rate of two colonies initially increased and then decreased.

3.2 Result

Based on the above analysis, we can draw the following conclusions:

In the short term, at the beginning of wood decomposition, wood resources are relatively abundant, fungi decompose wood together, and there is less competition between each other, and each community grows at the same time, making the decomposition speed faster.

- But over time, as the amount of wood that can be broken down decreases and competition between colonies increases, decomposition efficiency gradually declines.
- The more competitive colonies will continue to grow, the less competitive colonies will go into a phase of decay and considering their own mortality , they will start to decline in size.
- As time keeps going on, until the wood in the area is exhausted, even the competitive and resolving colonies lose their energy source, and their natural mortality will result in the death of the colony , which will eventually return to zero in time.

4. Conclusion

- By considering the Predator-Prey relationship between fungi and wood, the competition among fungi species and the correlation of temperature and moisture to the mortality rate of fungi, we establish a Fungi Decomposition Model which can be shown as the formulas as follow:

$$\begin{cases} \dfrac{dN_i}{dt} = r_{ig}\left(1 - \dfrac{N_i}{K_i} - \displaystyle\sum_{j=2}^{n} \sigma_{ij}\dfrac{N_j}{K_j}\right) N_i + \left(-r_{id} + \lambda_i M\right) N_i \\ \dfrac{dM}{dt} = \displaystyle\sum_{i=1}^{n} \left(r_M - \lambda_i N_i\right) M \\ r_{id} = -k r_{ig} - k_m m_i + b \\ R_d = k_1 r_{ig} + e^{-k_2 m_i} = \dfrac{t}{M} \cdot \dfrac{dM}{dt} \\ \lambda_i = k_{3i}\left(k_1\left(T\right) r_{ig} + e^{-k_2 m_i}\right) \end{cases}$$

- In the short-term, different communities of fungi work together and make the decomposition rate of wood faster. In the long-term, there exists competition among different kinds of fungi, the more competitive colonies will continue to grow, the less competitive colonies will go to extinction. If the wood resources are depleted, all species will die out.
- Using Grey Correlation Analysis, we found that fungi decomposition speed of wood is significantly sensitive to the fluctuations including soil moisture, total nitrogen and soil temperature.
- Considering trends in the atmosphere under global warming condition, wood-rotting fungi decompose wood at an accelerated rate as local weather patterns move toward hotter and wetter.

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