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Recycle Bin of Nature: The Manipulator of Waste Utilization in Ecosystem

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Abstract: The decomposition of litter on the ground is one of the significant elements of matter cycle and energy flow in the entire ecosystem, and the role of fungi is pronounced in this process. In order to understand how the diversity of the fungal is associated with the overall decomposition efficiency of the system, we design the model firstly of many factors and the decomposition rate of fungi. Then we take account of effects of intraspecies interactions on the population size and environmental changes step by step. After careful optimization of the preliminary model, finally, we make a conclusion related to the importance of fungal biodiversity to the ecosystem. At the beginning, considering the chemical theory of fungal decomposition, we establish a decomposition rate model based on enzyme activity to represent this process. According to the experimental data, we use the differential equations and enzyme activity. Using the same method, it is easy for us to find the relationship between enzyme activity and decomposition rate, and the mathematical model of fungal decomposition rate and t, T, N, pH is obtained by combining the two. Then, paying attention to the interaction between different species of fungi, we improve the mathematical expression of growth rate and moisture tolerance on the basis of the Logistic model, and obtain their short-term and long-term development trends. Next, we add environmental factors, which predicted the possibility of dominant species in different regions. At the same time, we also carry out sensitivity analysis on the model to verify the stability of the model under the rapid temperature fluctuation. The main strength of our model is used as a preventive reference to increase external intervention to prevent a species from becoming extinct in advance, which is conducive to maintaining a stable ecosystem. What's more, we analyze the influence of fungal community diversity on litter decomposition rate. We find that the dominant populations in different environments are different. If there are more species in an area, it will be able to adapt to environmental changes and can be a vital component in the decomposition of litter. Thus, biodiversity ensures the normal material circulation and energy flow of the biosphere and promotes the stability of the ecosystem. Finally, we prepare a two-page article on the role of fungi in ecosystems, which would fit as an introductory outline in a university biology textbook species.

Keywords: Enzyme's activity; Logistic model; Clustering analysis; Dominant species

1 Introduction

1.1 Background

Carbon Cycle(Figure1) is a vital component for lives on the planet. Organic decomposing renews carbon in inorganic or simple organic(ODI) form. Within this process, plant material(PM)'s and woody fibers(WF)'s decomposition plays an important part.

Fungi have great influence on the plant-soil-atmosphere carbon cycle, one of which is decomposing the organic compounds and releasing carbon dioxide through respiration. Understanding the role of fungi in the lignin fiber decomposition is of great significance for further understanding of the fungal role in ecosystems.

1.2 Restatement of the problem

Fungi are a critical agent in the decomposition of PM and WF. The tracts of fungi affect the decomposition rates and there are links between certain traits. In this paper, we should consider two tracts:

· Growth Rate(GR)

· Moisture Tolerance(MT)

After induction and arrangement, the following aspects need to be explored and addressed in this paper:

· Build a mathematical model that describes the decomposition rate.

· Determine the relationship between fungi and decomposition rate, representing through fungal activity.

· Based on the GR and MT, classify the species of fungi and the interactions between different species. Then, we can describe the short - and long-term trends of the model.

· Considering the overall impact of atmospheric trends, we should optimize the model and do the sensitivity analysis of the model as well as local environmental changes and rapid climate fluctuates.

· We should predict relative strengths, weaknesses of species and the species combination including the stability of the model in arid, semi-arid, temperate, arboreal, and tropical rainforest environments.

· How does the diversity of fungal community affect the overall efficiency of DWF in the system? Analyze the importance and role of biodiversity when the local environment changes in various degrees.

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2 Assumptions and justification

To simplify our problems and improve the accuracy of model application, we make the following basic assumptions, each of which is properly justified.

·We regard temperature and pH of the same place as a constant value.

→Jusification:The temperature and pH of the same land will change with time. From a short term's perspective, due to the stability of the ecosystem, the range of this change is small, therefore, we didn't take it into account while analysising the short-term trend.

·The middle stage is consistent for other stages of decomposition.

→Jusification:Woody materials break down through multiple stages. In reality, the results may differ from decay stages. But in order to simplify our model ,we assume that every stages of decay are same.

· We assume that plant material and woody fibers are the only supporting resourse.

→Jusification: Plant materal and woody fibers account for most of the resource decomposed by fungi, so we ignore the other resources for the survival of fungi.

To simplify analysis for individual sections, we make additional assumptions, which will be discussed at the appropriate locations.

3 Notation

We list the symbols and notations used in this paper in Table **1**. P.s. Other symbols instruction will be given in the text.

4 Analysis and modeling

4.1 Model 1 - Decomposition rate & Enzyme's activity

Decomposition of wood fiber (DWF), actually degrades cellulose and lignin and other wood components in wood fiber of which fungi releases the enzymes can catalyze. Because of enzyme specificity, DWF can be catalyzed by cellulase. On the other hand, Figure3 also shows that in the same conditions, group with cellulase has a better DR. Therefore, we focus on the process of cellulase catalyzing the decomposition.

P.s. The code will be given in the appendicies.

4.1.1 The factors of EA(Enzyme's Activity)

We select four factors, including temperature(T), pH(PH), inoculum amount(percentage of fungi amount)(I) and time(t). Through the control variable method, weanalyze the relationship between factors and EA. To demonstrate the conclusions visually, we show it in the Figure4.

In the Figure above, enzyme's activity has non-linear relationship with each factor. According to the definition of inoculum amount,

I=V_1/V

To set the EA - DR model, we define the volume of liquid medium is 100mL.

V_1 = V * I

= 100 * I

Inoculum volume has a linear relationship with inoculum amount. Each population quantity(N) in per unit can be approximated as n.

N = V_1 * n = 100 * I * n

Therefore, we consider temperature, pH, population quantity(N) and time as independent variable, following with a multiple regression model between the determined factor and

$$EA \cdot EA = b_0 + \sum_{i=1}^{n} (b_i^2 x_i) + \sum_{i=1}^{n} (b_i x_i) + \sum_{i,j=1}^{n} (b_{ij} x_i x_j)$$

In Equation:

EA – the predictive value of enzyme's activity

b_0, b_i, b_{ii}, b_{ij} – coefficient

x_1, x_2, x_3, x_4 - N, T, t, PH

4.1.2 The impact of EA on decomposition rate DR_1

DR is closely related to enzyme avtivity. According to the regression fitted between litter leaf decomposition rate and litter enzyme avtivities, DR has a significant quadratic function relationship.

$$DR_1 = \alpha_1 + \alpha_2 EA + \alpha_3 (EA)^2$$

In Equation:

$\alpha_1 \alpha_2 \alpha_3$ – coefficient

To sum up, we set up a new model about the decomposition rate in the presence of multiple species of fungi, the formula of model is

$$\begin{cases} x_1 &= 100nI \\ EA &= b_0 + \sum_{i=1}^{n} (b_i^2 x_i) + \sum_{i=1}^{n} (b_i x_i) + \sum_{i,j=1}^{n} (b_{ij} x_i x_j) \\ DR_1 &= \alpha_1 + \alpha_2 EA + \alpha_3 (EA)^2 \end{cases}$$

To simulate DR changes with t and N. Considering about small change of t, we assume that T and PH are constant in this period of t. With the conditions of T=22 °C and PH=6.0. The results can be viewed in three-dimensional Figure5.

4.2 Model 2 - Establishment of population quantity model after interaction N

In order to better reflect the interaction between species, in model 2, we ignore the effects of weather change and just focus on two characteristics of species - GR and MT. We use hyphal extension rate(HER) to reflect GR because the hyphal extension rate is essentially the growth rate of a fungus.

4.2.1 Select the kind of fungi

Figure in the appendices1 shows DR measured for each isolation under standardized laboratory conditions at 10, 16 and 22 °C.

So the change of decomposition rates tend to be the same while the hyphal extension rate changes. We speculate that there is a certain substitution relationship between these fungi.

According to DR under different temperature, fungi are classified by using SPSS through hierarchical cluster analysis method.

According to the figure above, 34 species of fungi are classified . We selectt six species of fungi from four categories. The results are presented in Table2. HER is sorted from highest to lowest.

4.2.2 Relationship between GR & MT

GR and MT has a negative correlation relationship which can be proved by, the equation $M = \frac{\log(1.9E+7.75)-0.272}{1.12}$ obtained through nonlinear fitting can also prove it. Therefore, MT of F1-F6 is decreasing while GR rises. The following Figure9 shows the trend of HER and MT of six strains.

4.3 Model 3 - Prediction of population quantity in different environments

In order to optimize the model, we replace the population quantity with extension rate and supporting resource ratio. We predict population quantity in different environments including arid, semi-arid, temperate, arboreal, and tropical rain forests.

4.3.1 Different environmental condition

In order to find the nonlinear relationship between decomposition rate and temperature, we regress data by Matlab, data is from Figure9. The temperature and relative humidity in arid, semi-arid, temperate, arboreal, and tropical rain forests are shown in Figure10.

4.3.2 The effect of environments

Fungi index is a parameter that describes the characteristics of the environment, temperature and relative humidity has a non-linear relationship with fungi index

$$r_1 = -0.9955T^2 + 46.414T - 395.97$$
$$r_2 = 4.2826H - 245.99$$

Since temperature and relative humidity have different proportions of influence on fungal index, the expression of the fungal index r is as follows:

$$r = 0.54r_1 + 0.46r_2$$

The environment influence the extension rate and suportting resource ratio, the relationship is as follows:

$$Er_i = E_i e^{r\%}$$
$$S_{ij} = M(1-H)s_{ij}$$

Plugging Equation into the Equation, we obtain

$$\frac{dN_i}{dt} = E_{r_i} N_i \left(1 - \sum_{j=1}^{6} M(1-H)s_{ij}\frac{N_i}{K}\right)$$

4.3.3 The prediction results

We use the ode45 numerical integrator in MATLAB on differential equation to find the population quantity changing trend, the results are shown in figures below. There are three main arguments according to the figures. Fisrt of all, it is acknowledged that dominant fungi change with variation of environmental patterns. Second, the fungi with higher growth rate have more activity in the short term while these with higher moisture tolerance show better in the long term. Last, extreme environment can help fungi with excellent but singal trait, such F1 and F6 mentioned before.

4.4 Evaluate the role of biodiversity

Although there are some fungi of bad behaviours in certain environmental conditions, 'heros' always appears and takes responsiblity to carry them to improve the whole decomposition rate, which we are regard as the biological diversity. More kinds of fungi join in, more felxible adaptation to environment there is, finally, more stable the ecological system is.

5 Sensitivity analysis

Our model takes the interactions and environmental changes into account. It can predict the presence of species in different environments to assess changes in decomposition rates. However, the environment changes uncertainly, our model may be affected. To check the stability of our model, we set the tempreture as a cosine function of different periods.The sensitivity of temperature by calculation is obtained, as shown in the following Figure11. We can intuitively find from the figure, when the temperature fluctuate slightly in a certain range, the decomposition rate of fungi fluctuate in a short term, and it tends to be stable with the increas of time.

6 Strengths and weaknesses

6.1 Strengths

· Strenght 1:

Relating the decomposition rate to enzyme activity, we find the factors of determining enzyme activity, this simplified the difficulty of the model.

· Strenght 2:

We study the dominant population of fungi in different regions. It is of great significance to study the decomposition of litter in the future. It also has implications for forestry management and soil management.

· Strenght 3:

Due to the uncertain change of weather, we conduct sensitivity analysis on the model, which proves that our model is stable and has a wide range of application.

6.2 Weaknesses

We do not consider the effect of topographical factors on the number of fungi, such as altitude.

Fungi and Ecosystems

Everything is everywhere, the environment selects

-M.W.Beijerinck

Do you think that fungi are small? Do you know that mushrooms are one kind of fungi? Let's explore the world of fungi!

· Funi species

· Working conditions

Just like us human, fungi are actually very picky. Different fungi have their own unique requirements for living and working conditions. The temperature, pH and humidity of the external environment will affect the activity and decomposition rate of the fungus totally. Fungi of good behavior in the tropics, for example, may not be able to do their job in the temperate zone, so we need to know them like knowing ourselves before we can use them.

· Decomposition method

Chemically speaking, fungal degradation is essentially an enzymatic reaction in the way it works. The reason why fungi are so sensitive and harsh to the external environment is because the enzymes in the reaction have distinct activities under variable environmental conditions, resulting in difference of decomposition rates.

· Wastes

Fungi are known to attack the leaves and dead branches that fall off plants and are consist of lignin and cellulose. Cellulose is one of the most widespread and abundant polysaccharides in nature, while lignin is a complex organic polymer, especially in wood and bark, because it imparts rigidity and is resistant to decay. Both of them take an important role in the construction of plant cell walls. With the degradation of fungi, these 'wastes' can be re-absorbed and used by plants, forming the material cycle of the ecosystem.

· The effects of fungi on ecosystems

It is well known that microorganisms take a necessary part in biological systems. They as a disintegrator, will help the producers and consumers of organic matter decomposed into carbon dioxide, water and inorganic salt which can be absorbed by the plant and use to produce new organic material. In this way, material circulation and energy flow can be achieved followed with maintain of the ecological system and dynamic balance.

Fungi are an integral part of microbes. Therefore, fungi play a very important role in material cycle, interspecific relationship, community and ecosystem change. Mycorrhizal fungi, for example, form mycorrhizas in plants. Mycorrhizal fungi promote photosynthesis by increasing the uptake of mineral nutrients, and then transport large amounts of photosynthates to the ground.