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Study on fungal growth process based on K-means clustering and Lotka-Volterra interspecific competition Model

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Abstract: *The carbon cycle has a great impact on the environmental changes of the Earth, and fungus play a crucial role in the decomposition of ground litter and woody fibers in nature, so it is very necessary to study the growth process of fungus. First, we used the K-means Clustering Algorithm to classify the different species of fungus into four categories according to their growth rates as well as their moisture tolerance. This not only measures the similarity between various fungus more intuitively, but also reduces the difficulty of subsequent modeling work. Second, we considered environmental accommodation, intra- and interspecific competition, and used this to modify the Lotka-Volterra interspecific competition Model and to derive the relationship between fungal growth rate and time. Then, we used this model for long-term and short-term prediction of fungal growth. In the short term, the growth rate of fungi increased rapidly with time; in the long term, the fungal population tended to be stable.*

Keywords: *growth process of fungus, K-means Clustering Algorithm, Lotka-Volterra interspecific competition Model*

1. Introduction

The carbon cycle refers to the exchange of carbon elements in the biosphere, lithosphere, hydrosphere and atmosphere of the Earth, and the phenomenon of more than one cycle with the movement of the Earth. The carbon cycle is an important component of life on Earth. Part of the carbon cycle includes catabolism, which allows carbon to complete its cycle and be renewed in ecosystems. [1] A key component of this process is the decomposition of plant litter and woody fibers.

Soil organisms are a special functional group for the carbon cycle of an ecosystem, and most of them are considered to play a decomposer role in the ecosystem, mainly involved in the decomposition of some of the ecosystem's waste products (plant litter, animal carcasses and excreta, etc.). Their role in the ecosystem is just as indispensable as that of green plants. [2] It is conceivable that without their presence, the rich and colorful natural world would have been covered by the garbage and waste produced by the ecosystem itself. Most of the soil microorganisms are mainly fungi, so it is clear that fungi have a significant contribution to the carbon cycle.

2. K-means clustering

When fungi decompose ground apoplastic and woody fibers, their decomposition rates are affected in various ways. Genetically, genes that regulate the rate of fungal decomposition of fibers and genes that promote fungal moisture tolerance are negatively correlated [3]. However, it is unclear whether the decomposition rate of fungi is related to the traits they exhibit at the molecular level. Nicky and Daniel used data from a database of 37 fungal species widely distributed across the North American continent to analyze in detail the effects of various internal causal factors and external environmental conditions on fungal growth rates[4], while we used the K-means Clustering Algorithm in order to consider the effects of inter- and intraspecific competition on the efficiency of final fungal decomposition of wood fibers in the presence of multiple fungi, first from the perspectives of moisture tolerance and growth

Rate. The results of the cluster analysis are shown in Figure 1:

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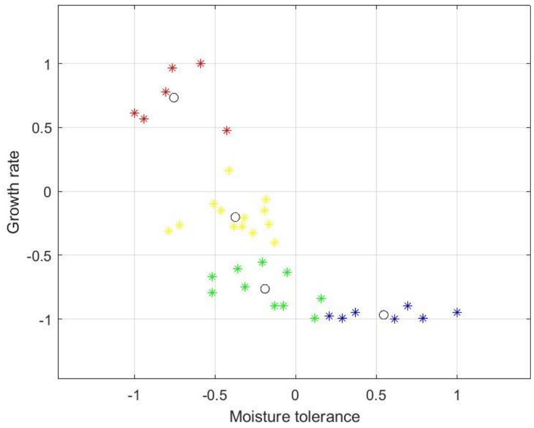

Figure 1: The result of K-means Clustering

In the cluster analysis of 37 fungi, we standardized two attributes (moisture tolerance and growth rate) of different fungi. The processed properties take values in the range $[-1,1]$. From the figure, it can be found that the fungi can be clustered into four representative fungal communities. The six fungi in red have the highest growth rate but are less tolerant to humidity. The seven fungi in blue have the slowest rate of decomposition of woody fibers but the highest tolerance to humidity in the environment,

Meaningthatthefungirepresentedinbluehaveabetterabilitytosurvivewhentheenvironmentchanges rapidly. This is also consistent with the previously obtained finding of a negative correlation between growth rate and moisture tolerance. The yellow and green fungi have similar tolerance to moisture and growth rate in the environment.

We later all analyzed and discussed these four categories of fungi with widely different properties to further consider the effects of environmental factors and ecological diversity on fungal decomposition efficiency. Moreover, the clustering method can simplify the numerous and complex fungal species and reduce the difficulty of subsequent modeling work. A schematic representation of the corresponding properties of the four categories of fungi is presented in Figure 2:

Figure 2: Relationship between GR and MT

3. Lotka-Volterra interspecific competition model

When a population is in a finite space, its growth rate is constrained by the maximum capacity of the environment. Lotka-Volterra Model [5], on the other hand, takes into account interspecific competition on top of this. After the analysis in the previous section, we divided all fungal communities into four species, and then considered the competition between each population and other populations during the growth process, and finally obtained the model of colony growth over time in a given area. First we set the following parameters:

ρ_1, ρ_2, ρ_3, ρ_4 are mass contribution of the four fungis(g/L)

r_1, r_2, r_3, r_4 are the inherent growth rate of the four colonies.

$\rho_{1,max}$, $\rho_{2,max}$, $\rho_{3,max}$, $\rho_{4,max}$ are the maximum environmental capacity of the four colonies respectively.

p_1, p_2, p_3, p_4 are interspecific competition coefficient .

According to the Logistic model, the growth rate in each kind of fungi is as follows:

$$\frac{d\rho}{dt} = r \cdot \rho \left(1 - \frac{\rho}{\rho_{\max}}\right)$$

From the above equation: $\frac{\rho}{\rho_{\max}}$ can be interpreted as the space already used (called the "used space term"), and $1-\frac{\rho}{\rho_{\max}}$ can be interpreted as the space not yet used (called the "unused space term"). When multiple species compete for or use the same space, the space occupied by other populations should be added to the "used space term". Then the four equation is as follows:

$$\frac{d\rho_1}{dt}=r_1\cdot\rho_1\cdot\left(1-\gamma\frac{\rho_1}{\rho_{1,max}}-p_2\cdot\frac{\rho_2}{\rho_{2,\max}}-p_3\cdot\frac{\rho_3}{\rho_{3,\max}}-p_4\cdot\frac{\rho_4}{\rho_{4,\max}}\right)$$
$$\frac{d\rho_2}{dt}=r_2\cdot\rho_2\cdot\left(1-p_1\cdot\frac{\rho_1}{\rho_{1,\max}}-\gamma\frac{\rho_2}{\rho_{2,\max}}-p_3\cdot\frac{\rho_3}{\rho_{3,\max}}-p_4\cdot\frac{\rho_4}{\rho_{4,\max}}\right)$$
$$\frac{d\rho_3}{dt}=r_3\cdot\rho_3\cdot\left(1-p_1\cdot\frac{\rho_1}{\rho_{1,\max}}-p_2\cdot\frac{\rho_2}{\rho_{2,\max}}-\gamma\cdot\frac{\rho_3}{\rho_{3,\max}}-p_4\cdot\frac{\rho_4}{\rho_{4,\max}}\right)$$
$$\frac{d\rho_4}{dt}=r_4\cdot\rho_4\cdot\left(1-p_1\frac{\rho_1}{\rho_{1,max}}-p_2\cdot\frac{\rho_2}{\rho_{2,\max}}-p_3\cdot\frac{\rho_3}{\rho_{3,\max}}-\gamma\cdot\frac{\rho_4}{\rho_{4,\max}}\right)$$

From the above formula we can obtain:

When the environmental capacity of species i is $\rho_{i,max}$, the growth suppression of each individual in the population of species i to its own population is $\frac{\gamma}{\rho_{i,\max}}$; the effect of each individual in the species j on the species i can be expressed by the expression $\frac{p_j}{\rho_{i,max}}$.

4. Conclusion

With the Lotka-Volterra model we have identified the link between fungal growth rate and time, and inter- and intra-species interactions are also considered in the calculations. Again through the glucose consumption model of substrate we have found the link between the decomposition rate of the fungus and its growth rate [6]. And we can get the constant quantities b1, b2 in the experiment, and then further fit to get the relationship between fungal decomposition rate and time.

In the figure 3, we can find that the decomposition rate of fungi can be roughly divided into three stages: growth phase, dwindling phase and equilibrium phase, without considering the influence of external environment.

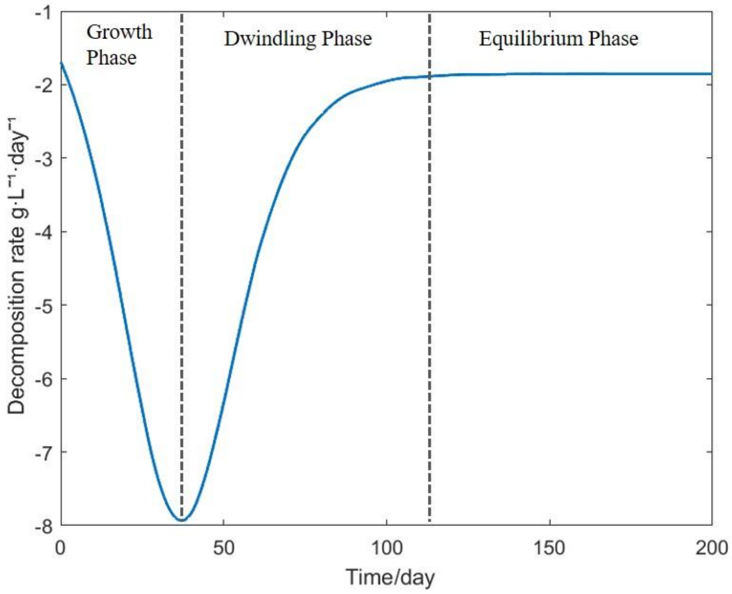

Figure 3: Decomposition rate (excluding environmental effect)

In the growth stage, because the competition between each fungus is not vigorous, there are sufficient resources and space for the fungus to grow freely, so the decomposition rate of the fungus on woody fiber increases gradually in this stage. The average rate of decomposition in this phase is 4.96g/(L day) When

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the highest decomposition rate is reached, the fungal growth rate is the fastest and the ability to decompose the ground litter is the strongest. After the maximum point, the growth rate of the fungus will gradually slow down due to environmental stress and intra-species competition because the fungal population has gradually reached the environmental capacity. And the third term on the right side of the equation also gradually becomes smaller when the growth rate decreases, which will cause the decomposition rate of the fungus to start decreasing after the highest point as well. The average rate of decomposition in this phase is 3.61g/(L ·day).

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