International Journal of Multidisciplinary Research and Development
www.allsubjectjournal.com
Online ISSN: 2349-4182, Print ISSN: 2349-5979
Received: 07-07-2021, Accepted: 22-07-2021, Published: 03-08-2021
Volume 8, Issue 8, 2021, Page No. 39-48

Research on factors affecting fungus decomposition based on model simulation

Shuqin Lai, Yubo Wang, Jingyi Yan
Department of Automation, School of Artificial Intelligence, Nanjing Agricultural University, China

Abstract
Since fungi decomposing organic matter is the key to the carbon cycle, we mainly focus on the decomposition rate of fungi. This paper focuses on the influence of environmental factors, fungi's own traits and interactions between communities on the decomposition rate. For this task, we first established a fungal decomposition rate model, in which the influence weights of the respective variables were determined by the fuzzy comprehensive evaluation method. The role of the community is given by the population competition model. The simulation analysis of the model shows that the number of superior communities tends to stabilize after an increase in the short term, while the number of inferior communities decreases and tends to die out in the short term. This article also discusses the advantages and disadvantages of fungal growth in the case of single species and multi-species. At the same time, a multi-community evolution model was established to describe the influence of the diversity of the fungal community on its decomposition efficiency. Our research shows that the existence of multiple communities is beneficial to improve the overall decomposition efficiency.

Keywords: fungal decomposition rate, model simulation, population competition model, community diversity

Introduction

As the main decomposer of wood and ground litter, fungi play an important role in the global carbon cycle. Fungi include molds, yeasts, mushrooms, etc. They release part of the carbon into the atmosphere by decomposing waste, and the remaining carbon is stored in the form of organic matter. The carbon dioxide released during the decomposition process is an important component of the global carbon cycle.

Many scholars have done research on related topics before. Song Fuqiang *et al* [1] used the method of pure culture experiment to study the decomposition ability of 10 main culturable filamentous fungi in the litter of variabilis oak forest to the community and the main associated leaves. The results showed that different fungi have different ability to decompose leaves, even if they are there are also significant differences between fungi of the same genus. He Xingbing *et al* [2] isolated and identified endophytic fungi from senescent leaves, and carried out culture to test their role in decomposition, and concluded that high abundance of endophytic fungi has a significant impact on the decomposition process, which may affect carbon and Nutrient cycle. The results of this study indicate that the litter has great potential to decompose plants, but the interaction between the colonies remains to be studied. Luo Jingyi *et al* [3] identified wood-rot fungi collected in the environment and analyzed their ligninase and cellulase activities, and concluded that there is no correlation between the fungal lignocellulase activity and its wood decay ability. However, despite the many studies that have been carried out, since the decomposition rate of wood by fungi is greatly affected by the environment, it is still difficult for us to effectively link the fungal community with the ecosystem. Therefore, analyzing the decomposition rate of organic matter by fungal communities is an important part of improving the global carbon cycle model.

The decomposition ability of different fungal communities is very different, from slow-growing and poorly competitive fungi to fast-growing and highly competitive fungi, their decomposition ability changes along a spectrum [4]. Relevant studies have found that where the fungus lives is closely related to its decomposing ability. For example, fungi with poor decomposing ability are more likely to survive in arid forests with seasonal rainfall. Considering the above factors comprehensively, it is necessary to explore the relationship between the decomposing ability of fungi and the environment, as well as the interaction between fungal communities, which has a great effect on predicting and improving the forest carbon cycle.

Since fungi have very different decomposing capabilities, this study aims to establish a model to describe how external conditions and internal characteristics affect the rate of fungi’s decomposition of wood. The main tasks are: (1) Establish a fungal growth and decomposition model to describe its decomposition rate, and study the effect of fungi on the decomposition of plants when the temperature, humidity, and PH are different. Combine this model to consider the relationship between fungal growth rate and moisture resistance. (2) Establish a population competition model to describe the interaction between fungal communities. (3) Predict the relative advantages and disadvantages of "single fungus" and "fungus combination" when the environment changes, and the community evolution under different initial environments. (4) Use the succession model of multiple groups to compare the decomposition amount of fungi when the number of fungi is different, and get the importance of biodiversity.

Model

In order to study the factors affecting the decomposition rate of fungi, we gradually established model analysis. From external environmental factors to its own traits, a model of fungal decomposition rate is established. Then the analysis of a single fungal community is extended to the competition relationship among multiple communities, and a population competition model is established. We combine the fungal growth model and competition model in the differential equation dynamics system to analyze the relative advantages and disadvantages of single species and multiple species. The diversity of populations will directly affect the decomposition efficiency of fungi, so a community evolution model of multiple populations is established for diversity analysis. The flow chart of our model is shown in Figure 1.

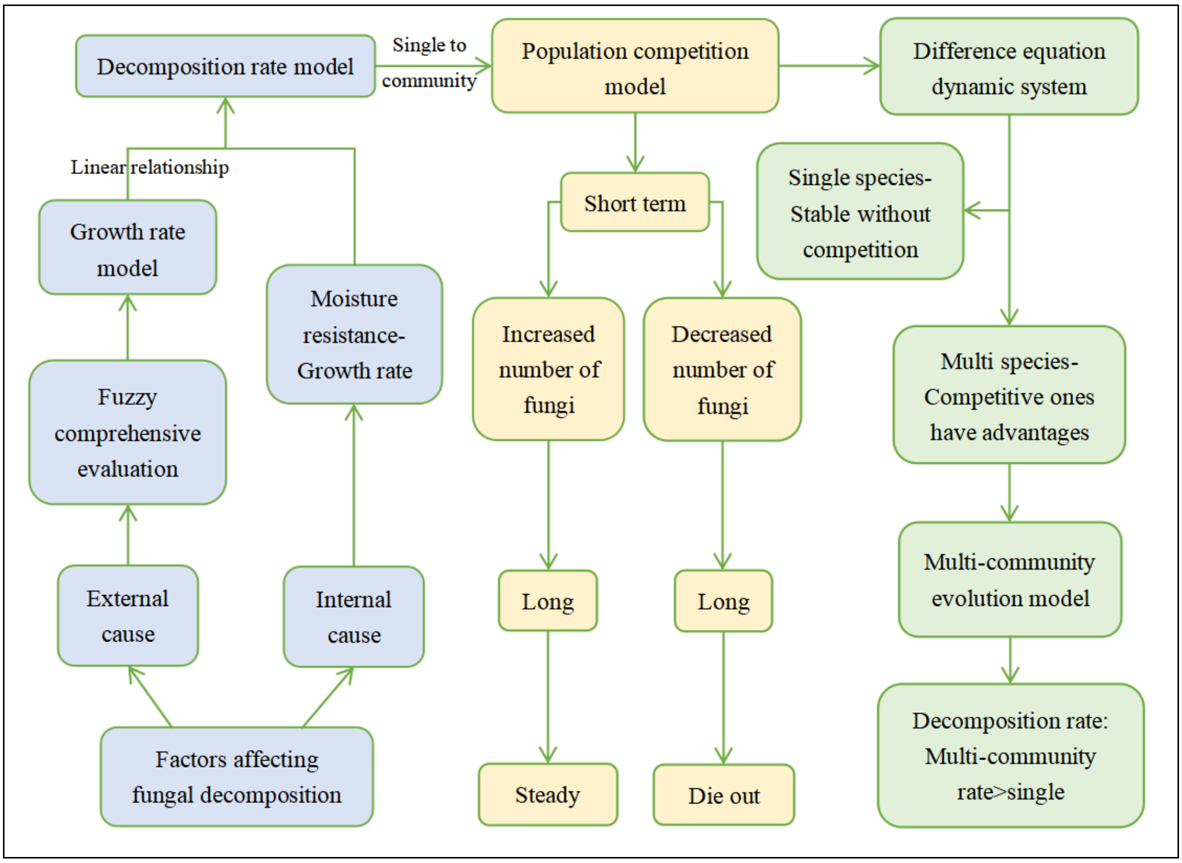


Fig 1: Model flow chart

Fungal Decomposition Rate Model

Since the decomposition rate of the fungus and the growth rate can be regarded as a linear relationship, we first establish the growth rate model of the fungus. The growth of fungi in the environment is affected by many factors, including environmental factors and their own traits. Environmental factors mainly include temperature, humidity, environmental PH, and their own traits such as humidity resistance [5-7]. First, we study the influence of environmental factors on the survival status of fungi. We select three different mature fungal plants A, B, C, which are in the same environmental state, and analyze the changes in their growth rate under the influence of different environmental factors [8-10]. We use the least squares method to fit these three types of fungi, and obtain the general expression of the fungal growth rate with different environmental factors:

$$\begin{cases} T_G = a_2 t^2 + a_1 t + a_0 \\ H_G = b_2 h^2 + b_1 h + b_0 \\ PH_G = c_3 p^3 + c_2 p^2 + c_1 p + c_0 \end{cases} \quad (1)$$

Where t represents the environmental temperature (°C), h represents the environmental humidity (%), p represents the environmental PH value, T_G represents the growth rate of the fungus under the influence of temperature, H_G represents the growth rate of the fungus under the influence of humidity, PH_G indicates the growth rate of fungi under the influence of PH. Since it is impossible to know which factors have a greater impact on the growth rate of fungi, we use a fuzzy comprehensive evaluation model to evaluate these three factors [11-12]. Proceed as follows:

(1) Determine the evaluation target factor set

$$U = \{temperature\ u_1, humidity\ u_2, PH\ u_3\} \quad (2)$$

(2) Determine the set of comments

$$V = \{excellent\ v_1, averge\ v_2, bad\ v_3\} \quad (3)$$

(3) Weight given to each factor

$$A = \{0.5, 0.3, 0.2\} \quad (4)$$

The fuzzy evaluation matrix R is used to determine the ratio, and the determined value is normalized. The results of the proportions of the three environmental factors are as follows:

The weight of temperature: 0.454

The weight of Humidity: 0.363

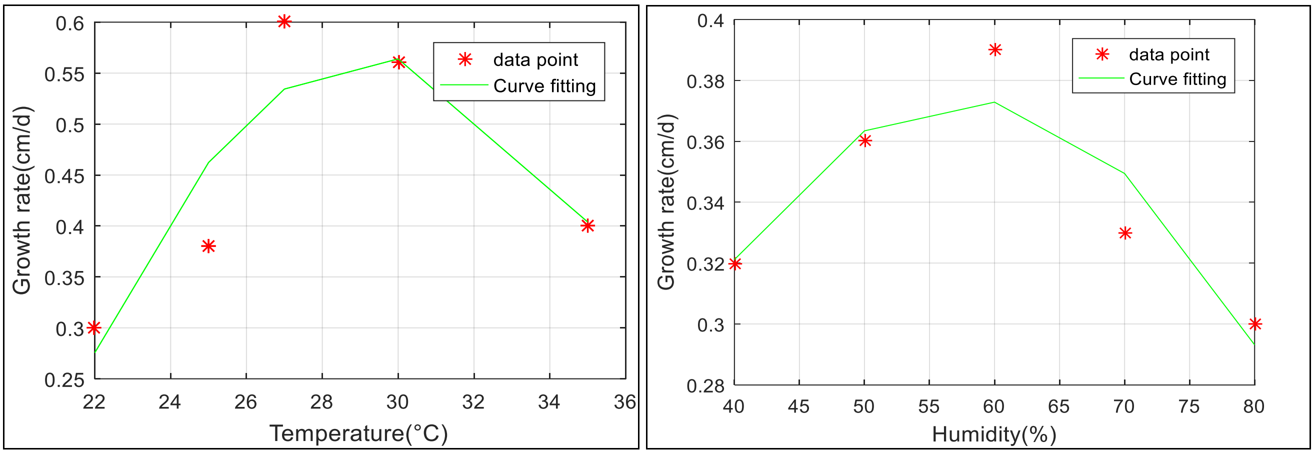
The weight of PH: 0.182

According to the proportions of the three factors, it can be seen that temperature and humidity have a more obvious effect on the growth rate of fungi, and the PH value has a smaller effect. Therefore, we ignore the influence of PH on the growth rate of fungi, and only consider the influence of temperature and humidity on the growth rate of fungi. Under the combined influence of temperature and humidity, taking type A fungi as an example, the fungal growth rate change model obtained by environmental factors is:

$$\begin{cases} G_{EA} = 0.454T_{GA} + 0.363H_{GA} \\ T_{GA} = -0.0063t^2 + 0.3621t - 4.6938 \\ H_{GA} = -0.0003h^2 + 0.0320h - 0.5666 \end{cases} \quad (5)$$

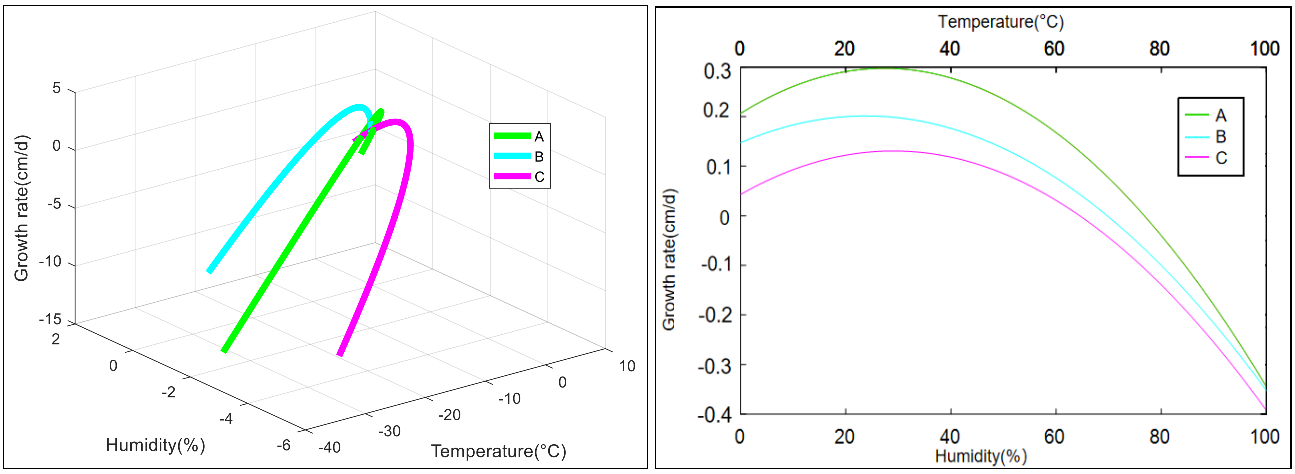
G_{EA} is the growth rate under the combined influence of environmental temperature and humidity. When temperature changes and humidity changes act on the fungus at the same time, the growth rate at this time can be obtained. According to the growth rate model of fungi, image fitting is performed on the influence equations of temperature and humidity, as shown in Figure 2. It can be seen from the figure that the influence trend of the two factors on the growth rate of fungi is also similar, and there are the most suitable environmental factors for fungal growth. Outside this range, the growth rate of fungi will decrease.

The growth models of B and C fungi are similar to A fungi. We plot the relationship between temperature and humidity on the growth rate of the three fungi on the three-dimensional axis, as shown in Figure 3 (a). In order to observe the relationship between the three more intuitively, project it on a two-dimensional plane, as shown in Figure 3 (b). Therefore, the growth rate can be determined by determining environmental factors. By observing Figure 3(b), we can see that under the same temperature and humidity conditions, type A fungi have a higher growth rate, type C fungi have a lower growth rate, and type B fungi have a growth rate between A and C. When the temperature is within 20°C -40°C and the humidity is within 30%-50%, the growth rate of fungi reaches the highest value. When the temperature is greater than 60°C and humidity is greater than 60%, the growth rate of fungi decreases rapidly. Excessive temperature and high water content will cause serious obstacles to the growth of fungi.



(a) The relationship between temperature and growth rate (b) The relationship between humidity and growth rate

Fig 2: Influence of environmental factors on the growth rate of type A Fungi



(a) Three-dimensional image (b) Three-dimensional projection image

Fig 3: Temperature and humidity relationship between fungal growth rates

At the same time, in addition to the influence of the external environment, the characteristics of the fungus itself are also an important factor affecting its growth. The moisture resistance of fungi has a crucial influence on the growth rate of fungi. The relationship between fungal moisture resistance-fungal decomposition rate and fungal growth rate-fungal decomposition rate can be approximated as a linear relationship:

$$D = a \cdot MR + k \quad (6)$$

$$D = b \cdot G + k_2 \quad (7)$$

In the formula, D is the fungal decomposition rate, G is the fungal growth rate, a is the relationship coefficient between fungal moisture resistance and decomposition rate, b is the relationship coefficient between fungal growth rate and decomposition rate, and k_1 and k_2 are constant terms. Therefore, we can think that there is also a linear relationship between fungal growth rate and fungal moisture resistance:

$$G_{MR} = c \cdot MR + k_3 \quad (8)$$

G_{MR} Represents the change of moisture resistance to growth rate, MR represents the moisture resistance of fungi, c is the relationship coefficient between moisture resistance and growth rate, and k_3 is a constant term. Therefore, we comprehensively consider the main external factors (temperature, humidity) and internal factors (humidity resistance) that affect the growth rate of fungi. Similar to the fungal growth rate change model under environmental factors, we use the fuzzy comprehensive evaluation model to evaluate the weights of external factors and internal factors, and obtain their proportions: m、 n ($\mathrm{m} + n = 1$). Therefore, the influence model of the fungus's external and internal factors on the decomposition rate can be obtained:

$$\begin{cases} G = \mathrm{m} \cdot G_E + n \cdot G_{MR} = \mathrm{m} \cdot G_E + n \cdot (c \cdot MR + k_3) \\ D = b \cdot G + k_2 \end{cases} \quad (9)$$

The above is the fungal growth rate model we obtained. Where G_E represents the change in growth rate caused by environmental factors. Through this model, it is only necessary to determine the influence of external environmental factors and internal fungal factors on the growth rate of fungi, to determine the change of fungal growth rate, and thus determine the decomposition rate. When multiple types of fungi exist, it is necessary to consider the effects of various factors on different types of fungi.

Fungal Population Competition Model

In order to study the interaction between many different fungal types, we considered that the relationship between different fungal communities is mainly based on the competition between nutrients in lignin and oxygen in the air, so we established a population competition model for short-term and long-term analysis. Environmental factors such as temperature and humidity will have an impact on the model's competition. After establishing a population competition model, we can evaluate the atmosphere and predict the weather.

If there are two or more populations in a natural environment, the relationship between them can be roughly divided into the following categories: mutual competition, interdependence, the weak and the predator (predator and predator), or there may be nothing to do. As above, the fungi are divided into three categories: A, B, and C, assuming that they are all distributed on the same wood. A, B, and C all belong to fungi, and the three are the same species, so the competitive relationship between the three is mainly considered. The competitive relationship is shown in Figure 4. We analyzed the competition relationship between different populations and established a population competition model [13-14]. Assuming that the three populations A, B, and C all live in the same natural environment, their quantity changes obey the Logistic law. In the model, we use the competitive relationship of A, B, and C to reasonably plan the inherent growth rate of the population r_1、r_2, and the maximum capacity of the population n_1、n_2, and calculate the consumption unit multiples s_1、s_2. All values are shown in Table 1.

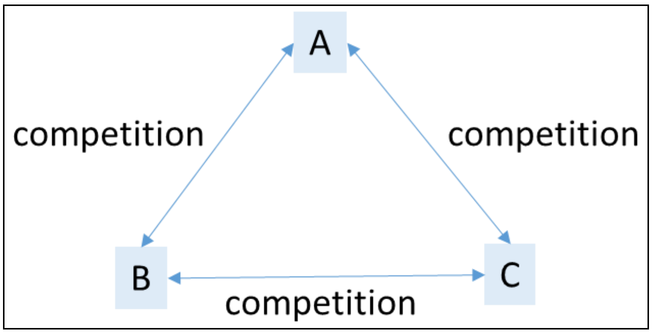


Fig 4: The interaction between A, B and C

Table 1: Value Table

r_1	r_2	n_1	n_2	s_1	s_2
1	1	100	100	0.5	2

We take the inherent growth rate of the population r_1、r_2 in the competition model, the maximum capacity of the population n_1、n_2 and, and the consumption unit multiples s_1、s_2 as input parameters, and the number of population $x_1(t)$、$x_2(t)$ as output parameters. Finally get the following model:

$$\dot{x_1}(t) = r_1 x\left(1 - \frac{x}{n_1} - \frac{y}{n_2} s_1\right) \quad (10)$$

$$\dot{x_2}(t) = r_2 y\left(1 - \frac{y}{n_2} - \frac{x}{n_1} s_2\right) \quad (11)$$

Since the interaction between fungal communities may be different in the short-term and long-term, short-term and long-term effects are considered separately. Based on the analysis of the above competition model, the short-term trend images are shown in Figures 5 and 6. According to the image, it can be found that because the competitive relationship among A, B, and C is: A>B, B>C, when the external environment is the same, the three will compete for nutrients and oxygen. If the number of survival days is less than 10 days, according to the model, we can see that one of the three will inevitably have a declining trend due to competition, but there is no loss of the last party in the long-term trend. The long-term trends are shown in Figures 7 and 8, and we can see that the competitive relationship between the three has not changed. When the external environment is the same, the three will compete for nutrients and oxygen. If the number of days to survive is greater than 10 days, one of the three will inevitably die out due to competition. Since then, the consumption of nutrients and oxygen will no longer change, so the remaining two will coexist and continue.

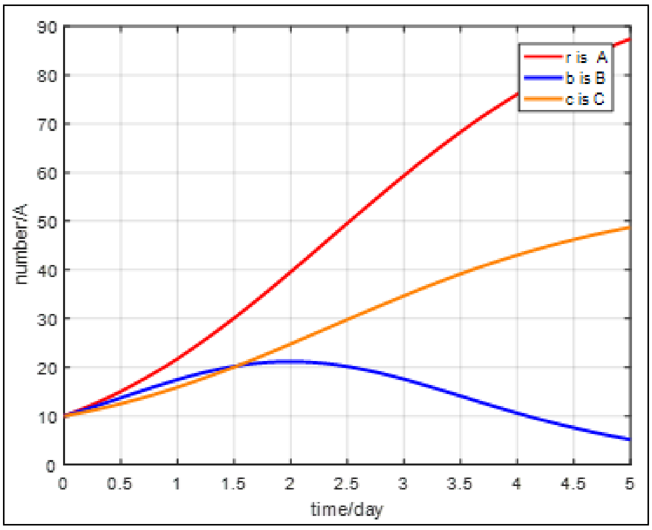


Fig 5: A, B, C short-Term competitive relationship

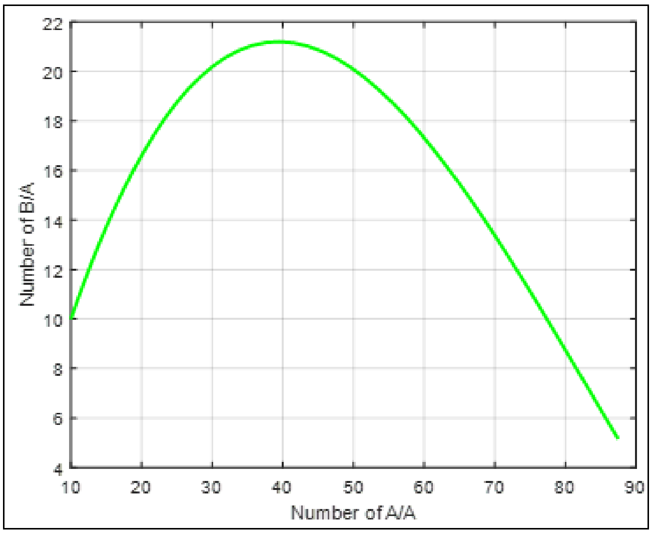


Fig 6: The short-term final quantity of A, B, and C

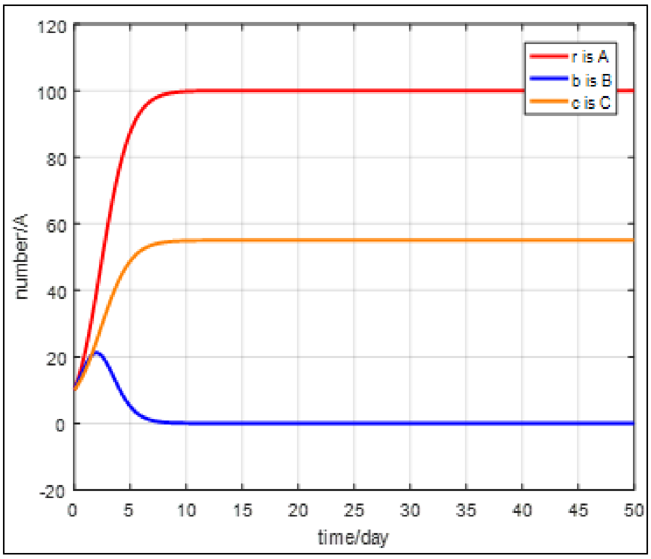


Fig 7: Long-term competition among A, B and C

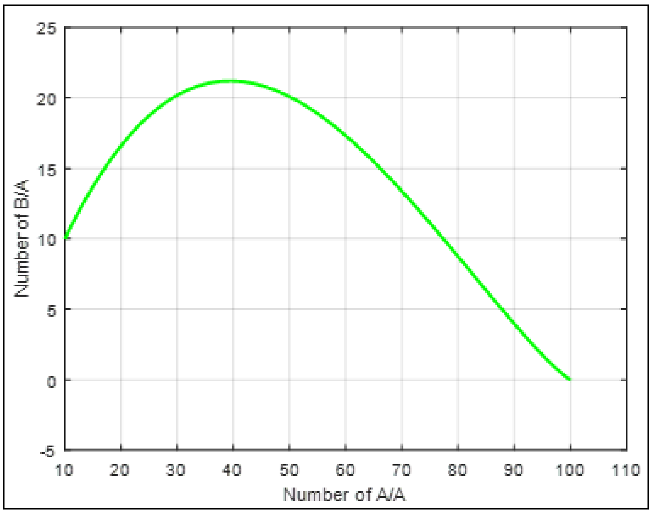


Fig 8: The long-term final quantity of A, B, and C

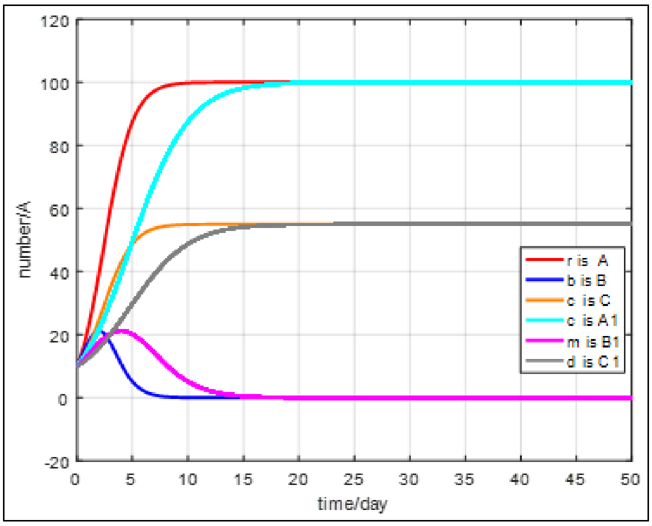


Fig 9: The temperature remains unchanged and the humidity changes

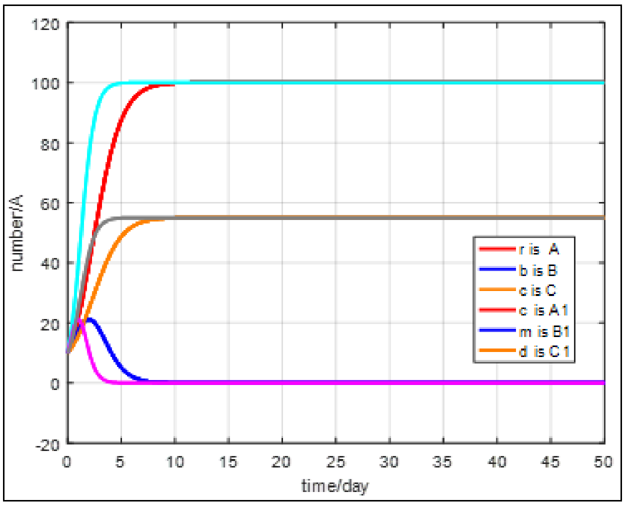


Fig 10: The humidity remains unchanged and the temperature changes

Table 2: Temperature and humidity weather table

Weather	Temperature	Humidity
sunny day	+++++	+
heavy rain	+++	+++++
Light rain	+++	+++
Snow day	+	+++

Based on the independent variables in the fungal growth rate model, we can see that temperature and humidity will affect the growth rate of the population, that is, affect the inherent growth rate r_1、r_2 in the competition model. When the temperature increases, the growth rate will first increase and then decrease. The optimal position for the growth rate is between 26°C and 28°C. When the humidity increases, the growth rate will increase first and then decrease. The optimal position for the growth rate is between 50% and 70% humidity. However, due to the different weather, the temperature and humidity will change to different degrees. The specific changes are shown in Table 2.

In order to analyze the sensitivity to rapid environmental fluctuations, the overall impact of changing atmospheric trends should be determined to assess the impact of changes in local weather patterns. When the temperature and other factors remain unchanged, we changed the humidity, and the result is shown in Figure 9. When the humidity and other factors remain unchanged, we changed the temperature and obtained Figure 10. According to the schematic diagram, we found that when the temperature and humidity change, the inherent growth rate of the competitive model changes, and the error can be controlled within 5%. According to the relationship table of temperature, humidity and weather, it can be seen that the corresponding environmental temperature and humidity will change when the weather is different. Atmospheric particles can change the climate of the earth by absorbing or reflecting sunlight. These particles are usually produced by biological activities such as fungi. Therefore, it can be seen that atmospheric particles affect the weather. The weather is different, the temperature and humidity of the environment are different, and it will affect our model, so we can predict the weather through the model.

Analysis of the advantages and disadvantages of the number of fungal species

In order to better study the relative advantages and disadvantages of each species and the combination of species that may continue to exist, we combine the fungal growth model and the competition model in the differential equation dynamics system to analyze the relative advantages and disadvantages of single species and multiple species [15]. Because different geographical locations have different environmental climates, which lead to different temperature and humidity in the environment, this feature can be used to predict the evolution of the fungal community.

Through the analysis of the competitive relationship model and the decomposition rate model, we found that if a single strain exists in the environment, the strain will not die out due to insufficient nutrients and other factors, but is only limited by external conditions such as temperature and humidity. When conditions such as temperature and humidity are suitable, the decomposition rate of a single strain increases nonlinearly and then approaches equilibrium. When there are multiple species of bacteria, in addition to factors such as temperature and humidity, there will also be competition with each other, resulting in a change in the decomposition rate of the entire bacteria species on the litter.

The fungal growth model analysis in the dynamic system of difference equations. Under suitable conditions, we change the external conditions such as temperature and humidity to observe the relative advantages and disadvantages of a single species to the environment. The model is as follows:

$$P_{i+1} = P_i + 0.000818(665 - P_i)P_i \tag{12}$$

P_{i+1} Represents the number of fungi at the next moment and P_i represents the number of fungi at a certain moment. According to the model, it can be found that under suitable temperature conditions, the overall number of bacteria has an upward trend, and the result is shown in Figure 11. Changing the temperature and humidity, the overall result of the strain is shown in Figure 12. When the humidity is constant, the temperature gradually increases from low, and the decomposition rate decreases again from low to high. The most suitable temperature is 25°C -27°C. Fungi have a relative advantage over the environment as the temperature rises in an environment of less than 25°C. When the temperature is greater than 27°C, as the temperature changes, it has a relative disadvantage to the environment. Between 25°C and -27°C, it has an absolute advantage for the environment at this moment. When the temperature is constant, the humidity gradually increases from low, and the decomposition rate decreases again from low to high. The most suitable humidity is between 50% and 70%. In an environment with a humidity of less than 50%, fungi have a relative advantage to the environment as the humidity rises. When the humidity is greater than 70%, as the humidity changes, it has a relative disadvantage to the environment. Between 50% and 70%, it has an absolute advantage over the environment at this moment.

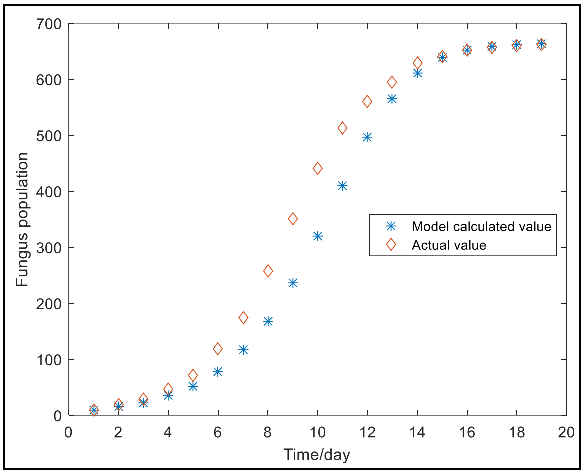


Fig 11: Temperature and humidity are suitable for fungal growth

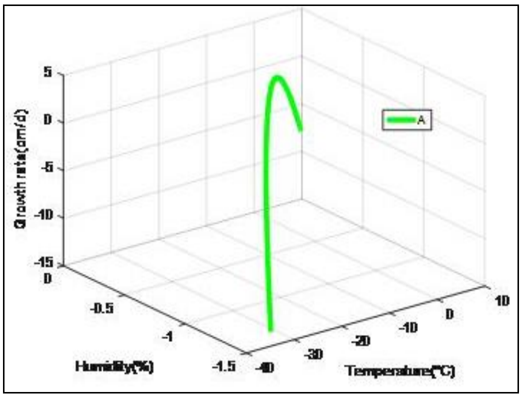


Fig 12: Decomposition rate of fungi by changing temperature and humidity

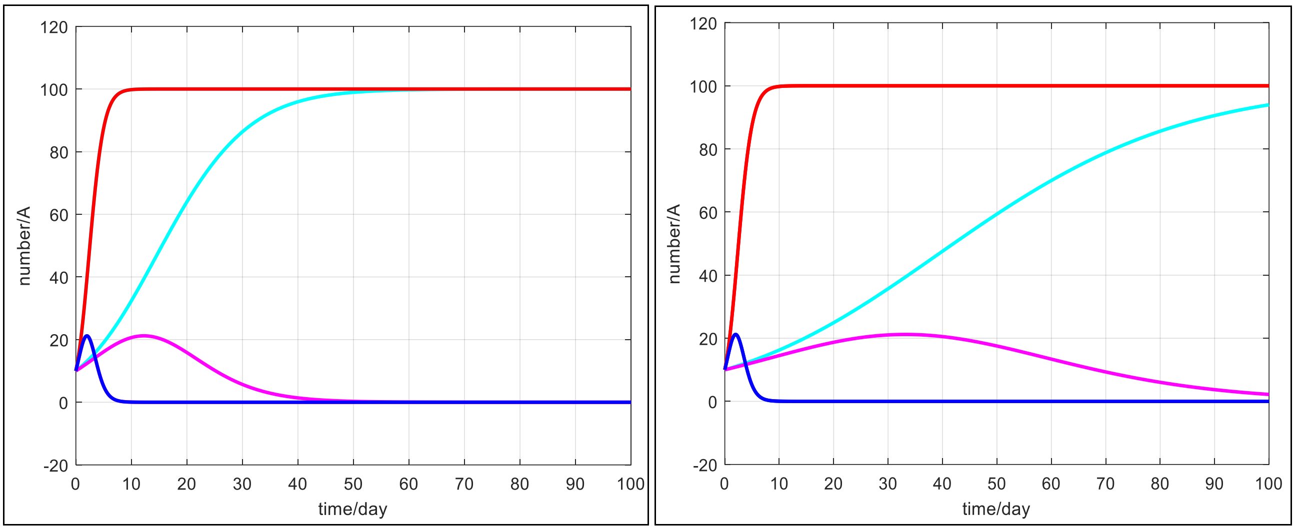


Fig 13: Population size under the temperature and humidity conditions

In the presence of multiple species, there will be competition in the ecosystem. We use competition models for analysis. Because in the competition model, the inherent growth rate r_1、r_2 are related to the environmental factors in the ecosystem, so we take different temperature and humidity in the decomposition rate model and substitute it into the competition model. Figure 13 shows the population competition when the temperature is 17°C and the humidity is 47%, and when the temperature is 16°C and the humidity is 26%. In the case of constant temperature and humidity, for two or more competing species, the species with strong competitiveness is at a relative advantage, and the species with weak competitiveness is at a relatively weak point. For populations with the same competitive relationship have different temperature and humidity, the closer the temperature and humidity are to the optimal range, the faster the growth rate and the faster the decomposition rate, which has a relative advantage in the environment. If the temperature and humidity are farther away from the optimal range, the growth rate will be slower, and the decomposition rate will be slower, which will have a relative disadvantage in the environment.

The influence of fungal community diversity on decomposition rate

Because the interaction relationship between different populations is different, the diversity of the population is different, which will directly affect the decomposition efficiency of fungi. We establish a community evolution model of multiple groups for diversity analysis [16-18]. In the local environment, we take the decomposition of ground waste as an example to analyze the decomposition efficiency. When there are varying degrees of variability in the local environment, the importance and role of biodiversity can be predicted from this. The interaction between fungal populations will affect the decomposition rate of garbage, and the decomposition of garbage by fungi will produce organic matter. The decomposition process is shown in Figure 14.

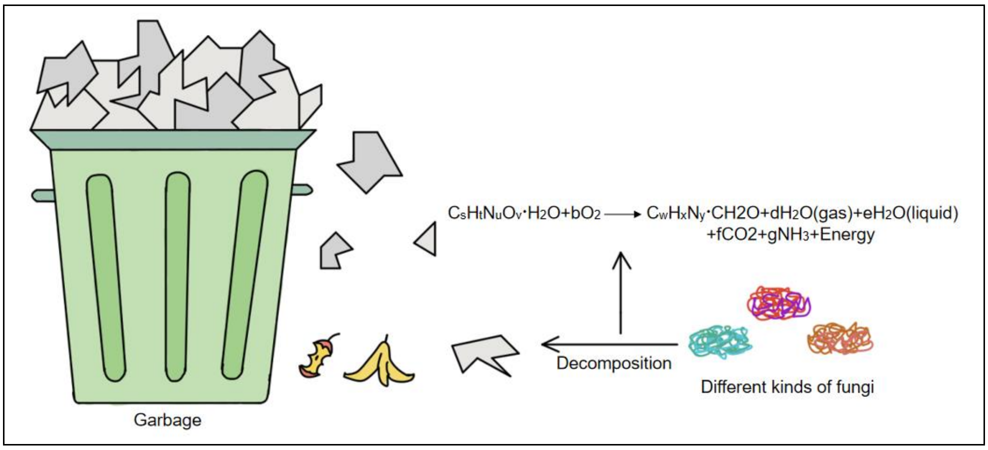


Fig 14: Process of fungi decomposing garbage

The fungus produces organic matter in the process of breaking down garbage. Many fungal communities exist in the same environment, and the competition between them is obvious. For this reason, we established a community evolution model of multiple communities to analyze the overall efficiency of the system that affects the classification of ground waste due to fungal diversity [19-22].

Let Q_n be all the populations in the community, C_n is the colonization rate, and m_n is the mortality rate. As an idealized approximation, they can be considered as constants, and the following model is established:

$$Q_1^{\cdot}(t) = C_1Q_1(1-Q_1) - m_1Q_1 \quad (13)$$

$$Q_2^{\dot{}}(t) = C_2Q_2(1 - Q_1 - Q_2) - m_2Q_2 - C_1Q_1Q_2 \quad (14)$$

$$Q_i^{\dot{}}(t) = C_iQ_i\left(1 - \sum_{j=0}^{i} Q_j\right) - Q_i\sum_{j=0}^{i-1} Q_jC_j - m_iQ_i \quad (15)$$

$$Q_n^{\dot{}}(t) = C_nQ_n\left(1 - \sum_{j=0}^{n} Q_j\right) - Q_n\sum_{j=0}^{n-1} Q_jC_j - m_nQ_n \quad (16)$$

According to the analysis of the succession model of multiple communities, it can be seen that when multiple communities exist, the overall decomposition rate is significantly higher than when a single community exists. However, due to the competition between the fungal populations, the growth rate of the populations is slightly lower than when they were alone. When external factors such as temperature and humidity remain unchanged, the growth rate of the population can be regarded as the rate of decomposition of garbage, so the fungal diversity affects the growth rate and thus the decomposition rate. If the fungal population is too competitive, the decomposition rate will increase first and then stabilize, and the stable value will be less than the rate when a single strain exists.

Sensitivity analysis and model optimization

Sensitivity Analysis

In this part, we modify the maximum capacity n_1 and n_2 of the population in the competition model, and the consumption unit multiples s_1 and s_2, and analyze the competitive relationship between the populations. First, to study the sensitivity to the maximum capacity of the population, we modify n_1 and n_2 to 95 and 105. After the analysis results of the competition model are shown in Figures 15 and 16, we find that the number of populations after competition has changed accordingly. When studying the sensitivity to consumption unit multiples, we modify the sensitivity of consumption unit multiples s_1 and s_2 to s_1=0.25, s_2=2.25 and s_1=0.8, s_2=0.7. Finally, the results of competitive model analysis are shown in Figures 17 and 18. From the figure, we can see that when the consumption unit multiple changes too much, the competition state of the population will change, and the maximum capacity of the population will also change. If there is no obvious change in the consumption unit multiple, it will only affect the growth rate.

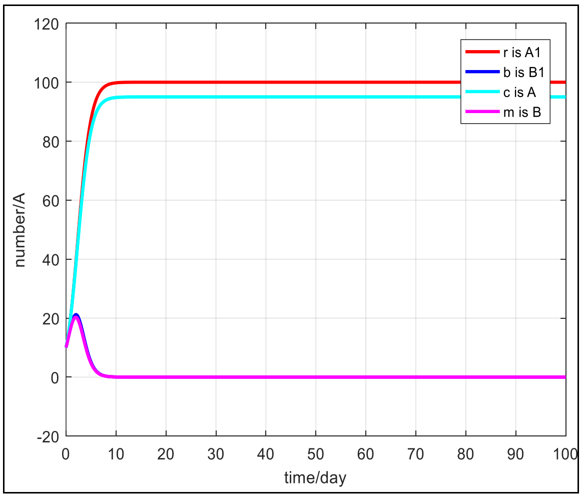


Fig 15: The maximum population capacity is 95

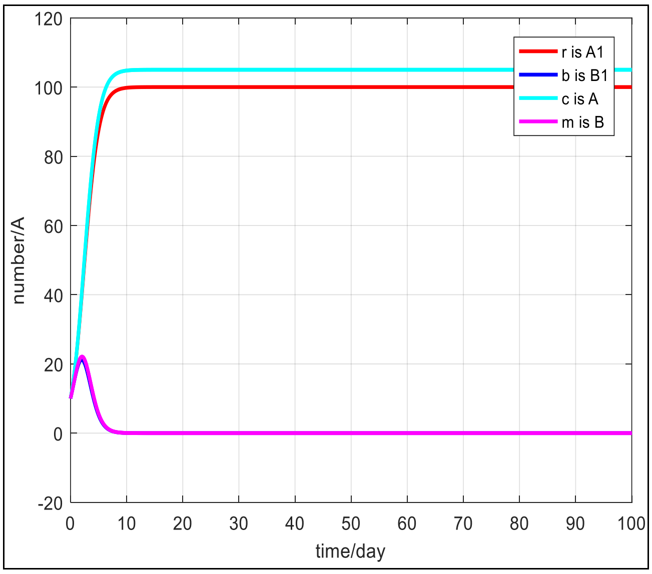


Fig 16: The maximum population capacity is 105

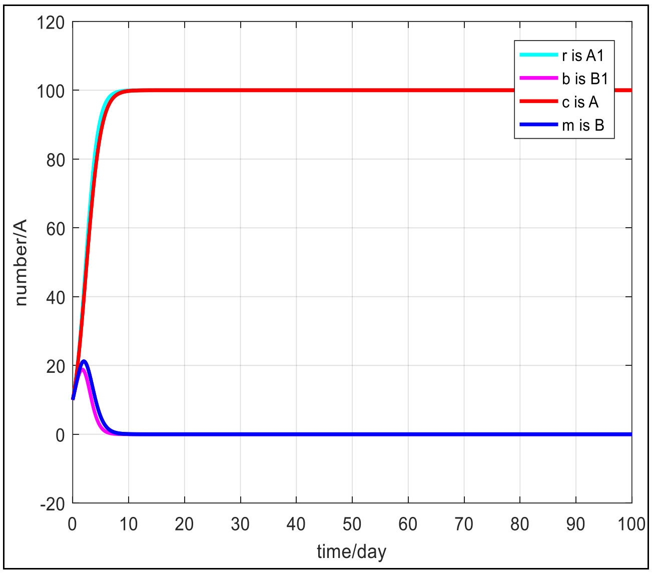


Fig 17: s_1=0.25, s_2=2.25

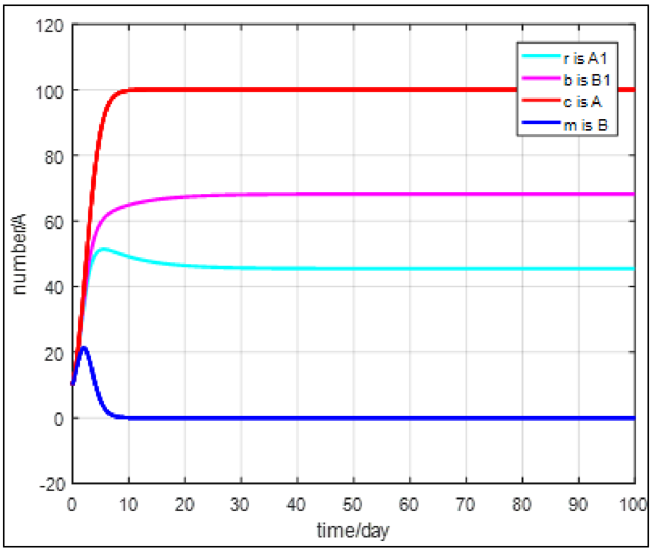


Fig 18: s_1 =0.8, s_2=0.7

Model optimization

In the first model, we regarded the growth rate and decomposition rate of fungi as a linear relationship, but we did not analyze the coefficients of the relationship in detail, so we used the microbial kinetic equation for in-depth analysis. When microorganisms decompose wood fibers and litter, they obtain carbon and energy, and synthesize their own substances. At the same time, the cytoplasm is also undergoing endogenous respiration, which runs through the life of microorganisms [23-24]. As the degradable components of wood for fungi are constantly decreasing, the number of fungi itself is also a process from less to more to less. Therefore, the growth of fungi is closely related to the decomposition of wood, and the relationship between the two can be expressed by the following formula:

$$X(\dot{t}) = Y(S(\dot{t})) - K_d X \quad (17)$$

In the formula, $X(t)$ represents the net growth rate of microorganisms, $S(\dot{t})$ represents the material decomposition rate, K_d represents the attenuation coefficient or endogenous respiration, Y represents the microbial yield coefficient, X and represents the microbial concentration in the wood. According to this model, we can better analyze the relationship between fungal growth rate and decomposition rate, thereby increasing the accuracy of the decomposition rate model.

Conclusion

In this article, we have established several models related to fungal decomposition, which can point out some of the characteristics that determine the rate of fungal decomposition and describe the relationship between these characteristics. For this task, we first selected three types of fungi and established a fungal growth rate model, from the external environmental factors to the fungi's own traits. For the influence weight of the respective variables, the fuzzy comprehensive evaluation method is used to obtain the fitting image. In order to continue to consider the role of fungal communities, a population competition model was established. Our results show that fungi that increase in number in short-term competition will stabilize after a period of time, while fungi that decrease in number in a short period of time will tend to die out. This article also discusses the advantages and disadvantages of single species and multi-species. At the same time, it is concluded from the established multi-community evolution model that the diversification of fungal communities can promote fungal decomposition. As future work, we hope to start with a wider range of traits from different aspects of ecology and study what other characteristics can predict the decomposition of wood by fungi.

References

1. Song Fuqiang, Tian Xingjun, Hao Jiejie, Chen Bin. Decomposing ability of main filamentous fungi in Quercus variabilis forest. Acta Ecologica Sinica,2005:(01):89-95. doi:CNKI:SUN:STXB.0.2005-01- 014.
2. Xingbing He, Guomin Han, Yonghui Lin, Zaihua He. Diversity and decomposition potential of endophytes in leaves of a Cinnamomum camphora plantation in China. Ecological Research, 2012, (2). doi:10.1007/s11284-011-0898-0.
3. Luo Jingyi, Fu Weirui, Pan Chengyuan. Identification of wood-rot fungi and their decay ability on different woods. Journal of Zhejiang A&F University,2015:(01):1-10. doi:CNKI:SUN:ZJLX.0.2015-01- 001.
4. Nicky Lustenhouwer, Daniel S Maynard, Mark A Bradford, Thomas W Crowther. A trait-based understanding of wood decomposition by fungi. Proceedings of the National Academy of Sciences (prepublish), 2020. doi:10.1073/pnas.1909166117.
5. Wang Jingjing, Li Wei, Hu Mei. Research progress on the regulatory factors affecting fungal laccase expression. Journal of Hefei Normal University,2018:(03):31-34. doi:CNKI:SUN:AFJY.0.2018-03- 010.
6. Guo Fukuan, Wang Shurong, Meng Junlong, Liu Jingyu, Chang Mingchang. Screening of the best culture conditions for three large fungi. Northern Horticulture,2017:(13):161-164. doi:CNKI:SUN:BFYY.0.2017- 13-029.
7. Li Dan, Dai Yueting, Li Yu. Screening study on the best cultivation conditions for three large fungi. Anhui Agricultural Sciences,2013:(28):11325+11339. doi:10.13989/j.cnki.0517-6611.2013. 28.100.
8. Song Yunhe, Guo Liming, Wang Qing, Sun Jinghan, Zhai Xiaomeng, Liu Jin. Research on mathematical modeling of mushroom growth factors. Mathematics Learning and Research,2019:(06):140. doi:CNKI:SUN:SXYG.0.2019 -06-099.
9. Wang Zaiming, Shi Kun, Pan Lingling, Ma Yuxin, Cui Dalian. The effect of temperature on the growth of 8 kinds of edible fungi. Forestry Science and Technology 2015:(03):20-23. doi:CNKI:SUN:LYKJ.0.2015- 03-008.
10. Luo Qing, Feng Hongchang, Sun Shujing. The effect of different conditions on the mycelial growth and the production of melanin. Northern Horticulture,2019:(16):130-135. doi:CNKI:SUN:BFYY.0.2019- 16-022.
11. Cao Xi, Liu Hui, Zhao Huan. Research on the degradation of lignin by microorganisms. Southern Agricultural Machinery,2019:(03):88. doi:CNKI:SUN:NFLJ.0.2019-03-071.
12. Zhang Zhongqing, Zhang Aizhong, Jiang Ning. The effect of mixed fungal fermentation on the degradation rate of corn stover cellulose and lignin. Journal of Animal Nutrition,2019:(03):1385-1395. doi:.
13. S Si, Z Sun. Mathematical Modeling Algorithms and Applications, Beijing: National Defense Industry Press, 2016, (2).
14. Zhao Chunxi. Three-group competition model based on the growth retardation model. Science and Technology Information,2008:(34):4+6. doi:10.16661/j.cnki.1672-3791.2008.34.006.
15. Zu Jian. Research on the mathematical model and dynamics of biological evolution (Master's thesis, Southwest University), 2007.
16. Li Jiayao, Wang Weihua, Gao Dawen. Feasibility study on the treatment of corn stover cellulosic ethanol wastewater by indigenous white-rot fungi in Northeast China. Environmental Science Research,2018:(03):521-527. doi:10.13198/j. issn.1001-6929.2017.03.84.
17. Li Huiye, Lin Yonghui, He Xingbing. The effect of four endogenous fungi on the decomposition of masson pine

leaf litter. Southwest Agricultural Journal,2021:(03):618-625. doi: 10.16213/j.cnki.scjas. 2021.3.023.
18. Liu Yongxin, Hao Dunyuan, Mark Jian. Simulation of restoration and succession of degraded grassland communities in Inner Mongolia. Journal of Natural Resources,2003:(03):347-352. doi:CNKI:SUN:ZRZX.0.2003-03-012.
19. Han Mei, Jiao Ruzhen, Dong Yuhong. The distribution law of soil microorganisms and the screening of functional bacteria in deciduous broad-leaved forests in Wolong Nature Reserve. Forestry Science,2013:10:113-117. doi:CNKI:SUN:LYKE. 0.2013-10-018.
20. Li Xiaorong. A preliminary study on the community comparison of fungi and endophytic fungi on tea leaves and their interactions (Master's thesis, Fujian Normal University), 2009.
21. Hao Dunyuan, Liu Zhongling, Wang Wei, Liang Cunzhu. Research on the restoration and succession of degraded grassland communities in Inner Mongolia—a mathematical model for community succession. Chinese Journal of Plant Ecology, 1997, (06). doi:CNKI:SUN:ZWSB. 0.1997-06-001
22. Lu Xinping, Cai Yue. The role of AM fungi in ecosystems. Agriculture and Technology,2016:02:18. doi:CNKI:SUN:NYYS.0.2016-02-016.
23. Li Jiayao, Wang Weihua, Gao Dawen. Feasibility study on the treatment of corn stover cellulosic ethanol wastewater by indigenous white-rot fungi in Northeast China. Environmental Science Research,2018:(03):521-527. doi:10.13198/j. issn.1001-6929.2017.03.84.
24. Wang Wenchao, Zhang Hua. Biodegradation of organic pollutants in landfills. Design and Research of Nonferrous Metallurgy,2007:1:164-168. doi:CNKI: SUN:YSYJ.0.2007-Z1 -039.