Frontiers in Environmental Research
Print ISSN: 2960-0251
Online ISSN: 2960-026X
DOI: https://doi.org/10.61784/fer3053

AGRICULTURAL ECOSYSTEMS BASED ON DYNAMIC SIMULATION (AEDSM) MODEL

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Abstract: This article combines mathematical modeling, simulation, and multi-objective evaluation methods to solve five key problems in agricultural ecosystems. Firstly, an Agricultural Ecosystem Dynamics Simulation (AEDSM) model was constructed based on the Lotka Volterra equation. By dividing the ecological process into four stages (forest ecological stage, conventional agricultural production stage, initial ecological restoration stage, and ecological restoration stage), it accurately depicts the evolution of the ecosystem. This modeling method enables us to understand the complex interactions between species and environmental factors that vary over time. Secondly, in order to analyze the impact of integrating two native species into the ecosystem, this article uses the established AEDSM model for simulation. By comparing the simulation results of introducing and not introducing these species, the changes in species interactions and population dynamics can be clearly observed, providing insights for biodiversity management. In order to explore the stability of ecosystems during herbicide removal, a comparative simulation scenario was established in the AEDSM model. Finally, in order to evaluate the impact of farmers adopting organic farming methods on the ecosystem, this paper developed a multi-objective evaluation model for organic agricultural ecosystems. This model integrates factors such as market incentives, technological support, and conversion costs. Using weighted scoring and scenario analysis methods, evaluate different organic agriculture scenarios from aspects such as crop yield, biodiversity, and economic costs. Sensitivity analysis is also applied to identify key parameters that can guide decision-making in organic agriculture practices.
Keywords: Agricultural ecosystem; Lotka Volterra equation; Organic agriculture; Ecosystem stability; Multi objective evaluation

1 INTRODUCTION

Agricultural ecosystem is a complex system with both production function and ecological characteristics, and its dynamic evolution and stability mechanism have always been important directions in ecological research [1]. Ecosystem stability refers to the ability of an ecosystem to maintain its core structure and function when disturbed by external factors, mainly including resistance, resilience and temporal stability [2]. In order to analyze the species interaction, population dynamics and succession process of agricultural ecosystems more accurately, this paper constructs a dynamic simulation model of agricultural ecosystems to provide theoretical support for the optimization and sustainable management of ecological agriculture.

2 Agricultural Ecosystem Dynamics Simulation (AEDSM) Model

In agricultural ecosystems, the interactions between biological populations and environmental factors have a crucial impact on their dynamic changes. This article will construct a mathematical model based on the Lotka Volterra equation in four time stages to accurately describe the evolution process of ecosystems.

2.1 Ecological Characteristics

Producer: Original forest producer (such as trees), whose Lotka Volterra equation is:

$$\frac{dT}{dt}=r_T T(1-\frac{T}{K_T})-\sum_i \alpha_{iT} C_i T-\gamma_{HT} H_T-\alpha_{TWe} W_e \tag{1}$$

Among them, r_T is the intrinsic growth rate of trees, which sharply decreases or even becomes negative due to deforestation; K_T is the environmental capacity, significantly reduced; α_{iT} is the predation coefficient of leaf feeding insects and other predators on trees, while C_i is the number of these predators; γ_{HT} is the damage coefficient of herbicides on trees, and H_T is the intensity of herbicide use in deforested areas; α_{TW_e} is the competition coefficient between weeds and trees, and We is the number of weeds.

Deforestation leads to a sharp decline or even negative values, greatly reducing environmental capacity, and causing the disappearance of a large number of predators (such as insects that feed on leaves). However, this has not stopped the sharp decline in tree numbers.
At this time, the equation for the newly planted crop (taking wheat W as an example) is:

$$\frac{dT}{dt} = r_T T(1 - \frac{T}{K_T}) - \sum_i \alpha_{iT} C_i T - \gamma_{HT} H_T - \alpha_{TWe} W_e \tag{2}$$

r_W has relatively high artificial planting management; K_W depends on agricultural resources; β_{SW} is the promotion coefficient of soil fertility S on wheat growth; α_{AW} is the predation coefficient of aphid A on wheat; γ_{HW} is the damage coefficient of herbicides on wheat, and H_W is the intensity of herbicide use for wheat fields; α_{WWe} is the competitive coefficient between weeds and wheat.
Junior consumer: Taking aphid A as an example, the equation is:

$$\frac{dA}{dt} = r_A A(1 - \frac{A}{K_A}) + \beta_{WA} W - \alpha_{LA} L \tag{3}$$

r_A is the intrinsic growth rate of aphids, which is relatively high; K is the environmental carrying capacity of aphids; β_{WA} is the promotion coefficient of wheat for aphid growth; α_{LA} is the predation coefficient of ladybug L on aphids; δ_{pA} is the killing coefficient of insecticides against aphids, I_{pA} is the intensity of insecticide use against aphids. The new crop resources have increased the $\beta_{WA} W$ term, resulting in a higher intrinsic growth rate r_A of aphids, which have begun to reproduce in large numbers. However, due to habitat changes, species such as the Seven Star Ladybug L, which originally preyed on aphids, have decreased in number, leading to a decrease in $\alpha_{LA} L$.
Secondary consumers: such as the Seven Star Ladybug L, equation is:

$$\frac{dL}{dt} = -r_L L + \beta_{AL} A - \zeta_{pL} I_{pA} \tag{4}$$

r_L is the mortality rate of ladybugs in the absence of food and suitable environments; β_{AL} is the promotion coefficient of aphids on the growth of ladybugs; ζ_{pL} is the damage coefficient of insecticides to ladybugs. Due to the initial distribution changes of food aphids and the loss of their own habitats, $-r_L L$ dominates and the population sharply decreases. However, this has not stopped the sharp decline in tree numbers [3,4].

2.2 Conventional Stage of Agricultural Production

The agricultural ecosystem is gradually stabilizing, but it faces a series of challenges. Due to the continuous planting of crops, soil fertility continues to decline, as crops continue to absorb nutrients from the soil and replenishment is often insufficient. The problem of pests persists, as they have adapted to the agricultural environment and may gradually develop drug resistance. Meanwhile, farmers use herbicides and insecticides to ensure crop yields, which not only control weeds and pests but also have negative impacts on other organisms in the ecosystem. In addition, weeds grow vigorously and compete with crops for soil nutrients, water, and sunlight resources.
Producer: The growth of crops (such as corn C) is affected by multiple factors, and the equation is:

$$\frac{dLc}{dt} = r_{Lc} L_C (1 - \frac{Lc}{K_{Lc}}) + \beta_{CLc} C - \alpha_{FLc} F - \delta_p I_p(t) Lc - \alpha_{LcWe} We \tag{5}$$

As time goes by, soil fertility S decreases due to continuous planting, the effect of $\beta_{SC} S$ weakens, and pest A continues to pose a threat. At the same time, the intensity of herbicide use $I_h(t)$ has the potential to cause damage to maize, which is reflected in $\gamma_h I_h(t) C$.
$I_h(t)$ is the intensity of herbicide use that varies over time; α_{CWe} is the competition coefficient between weeds We and corn, reflecting the competition of weeds for corn growth resources; γ_{pC} is the coefficient of indirect damage to corn caused by pesticide drift, while P_C is a pesticide related factor that may affect corn (such as the diffusion effect of pesticide use in surrounding areas).
Primary consumer: The equation for pests (such as locusts AAA) is:

$$\frac{dLc}{dt}=r_{Lc}L_C(1-\frac{Lc}{K_{Lc}})+\beta_{CLc}C-\alpha_{FLc}F-\delta_p I_p(t)Lc-\alpha_{LcWe}We \tag{6}$$

The intensity of insecticide use is controlled by controlling the number of locusts. Although predators such as frogs exist, their numbers are limited, and $\alpha_{FL_c}F$ is small. r_{Lc} is the intrinsic growth rate of locusts; K_{Lc} is the environmental capacity of locusts; β_{CLc} is the promotion coefficient of corn on locust growth; α_{FLc} is the predation coefficient of frogs on locusts; δ_p is the killing coefficient of insecticides against locusts, while $I_p(t)$ is the intensity of insecticide use that varies over time. Although weeds are generally not the main food source for locusts, they may compete with them in terms of space and other aspects.

Secondary consumer: The equation for Frog F is

$$\frac{dF}{dt}=-r_F F+\beta_{LcF}L_c-\alpha_{BF}B-\zeta_p I_p(t)F-\gamma_{hF}I_h(t)F-\alpha_{FWe}We \tag{7}$$

r_A is the intrinsic growth rate of aphids; K is the environmental capacity of aphids; β_{WA} is the promotion coefficient of wheat W on aphid growth; α_{LA} is the predation coefficient of ladybug L on aphids; α_{BA} is the predation coefficient of bat B on aphids; α_{WAp} is the predation coefficient of woodpecker W_p on aphids; Although weeds are not the main food source for aphids, there may be competition in terms of habitat and other aspects. Woodpecker W_P regression, along with bat B, increases predation pressure on aphids, as demonstrated by $\alpha_{BA}B$ and $\alpha_{WA_p}W_p$, respectively

The equation for third level consumer: Bat B is:

$$\frac{dB}{dt}=-r_B B+\beta_{AB}A+\beta_{FB}F \tag{8}$$

The number of aphids A and frogs F, which are food sources, has changed due to ecological restoration, affecting the growth of bats. r_B is the mortality rate of bats in the absence of food and suitable environments; β_{AB} is the promotion coefficient of aphid A on bat growth; β_{FB} is the promotion coefficient of frog F on bat growth; ζ_{pA} is the damage coefficient of insecticides to bats, and $I_p(t)$ is the intensity of insecticide use; γ_{hB} is the potential damage coefficient of herbicides on bats, as herbicides may indirectly affect bat survival by affecting their food sources or habitat environment.

2.3 Early Stage of Ecological Restoration

Producer: Taking soybean S_{oy} as an example, the equation is

$$\frac{dSoy}{dt}=r_{Soy}Soy(1-\frac{Soy}{K_{Soy}})+\beta_{SSoy}S-\alpha_{ASoy}A+\beta_{BSoy}B-\gamma_{hSoy}I_h(t)Soy-\alpha_{SoyWe}We \tag{9}$$

Bat B regression, $\beta_{BSoy}B$ reflects its promoting effect on soybean reproduction, pest A quantity is affected by new returning species, and changes in $\alpha_{ASoy}A$ term affect soybean growth.

Primary consumer: Aphid A equation becomes

$$\frac{dA}{dt}=r_A A(1-\frac{A}{K_A})+\beta_{WA}W-\alpha_{LA}L-\alpha_{BA}B-\alpha_{WAp}W_p-\delta_{pA}I_p(t)A-\alpha_{AWe}We \tag{10}$$

r_A is the intrinsic growth rate of aphids; K is the environmental capacity of aphids; β_{WA} is the promotion coefficient of wheat W on aphid growth; α_{LA} is the predation coefficient of the seven spotted ladybug L on aphids; α_{BA} is the predation coefficient of bat B on aphids; α_{WAp} is the predation coefficient of woodpecker W_p on aphids; δ_{pA} is the killing coefficient of insecticides against aphids, and $I_p(t)$ is the intensity of insecticide use over time; α_{AWe} is the competition coefficient between weeds and aphids in terms of living space or other resources. Woodpecker W_P regression, together with bat B, increases the predation pressure on aphids, which is reflected through $\alpha_{BA}B$ and $\alpha_{WA_p}W_p$, respectively

The equation for secondary consumer: Bat B is:

$$\frac{dB}{dt}=-r_B B+\beta_{AB}A+\beta_{FB}F \tag{11}$$

The number of aphids A and frogs F, which are food sources, has changed due to ecological restoration, affecting the growth of bats.

r_B is the mortality rate of bats in the absence of food and suitable environments; β_{AB} is the promotion coefficient of aphid A on bat growth; β_{FB} is the promotion coefficient of frog F on bat growth; ζ_{pA} is the damage coefficient of insecticides to bats, and $I_p(t)$ is the intensity of insecticide use; γ_{hB} is the potential damage coefficient of herbicides on bats, as herbicides may indirectly affect bat survival by affecting their food sources or habitat environment.

2.4 Ecological Restoration Stage

The ecosystem has entered a relatively stable mature state, with a high level of biodiversity, forming a complex and stable food web. Harmonious coexistence of crops and wild plants, achieving a balance in resource utilization. The hunting and competition relationships among various consumers are stable, and the ecosystem has strong self-regulation ability, which can better cope with external disturbances such as short-term climate change and small-scale pest outbreaks. However, although the residual effects of herbicides and insecticides used in the early stages have been reduced, they may still exist. Weeds, as a part of the ecosystem, compete with other plants for resources.

Producer: Multiple crops and wild plants coexist. Taking rice R_i as an example, the equation is:

$$\frac{dR}{dt}=r_R R(1-\frac{R}{K_R})+\sum_j \beta_{jR}S_j-\sum_k \alpha_{kR}C_k+\sum_l \beta_{lR}S_l-\gamma_{hR}H(t)R-\delta_{pR}P(t)R-\alpha_{RWe}We \tag{12}$$

S_j represents favorable factors such as different soil nutrients, C_k is a variety of consumers, S_l is a variety of beneficial organisms (such as bees, bats, and other pollinators), and various parameters are relatively stable, achieving ecosystem balance.

$\sum_j \beta_{jR}S_j$ represents the promoting effect of different soil nutrients and other favorable factors S_j (such as mineral content such as nitrogen, phosphorus, potassium, soil acidity, etc.) on rice growth, and β_{jR} is the corresponding promoting coefficient. $\sum_k \alpha_{kR}C_k$ represents the predation or damage effects of various consumer C_k (including primary consumers such as pests, secondary consumers such as predatory insects, etc.) on rice, and α_{kR} is the corresponding damage coefficient. $\sum_l \beta_{lR}S_l$ represents the promoting effect of various beneficial organisms (such as bees, bats, and other pollinators) S_l on rice reproduction, and β_{lR} is the corresponding promoting coefficient. γ_{hR} is the potential damage coefficient of herbicides on rice.

Primary consumers: The number of pests remains stable within a certain range, such as the aphid A equation:

$$\frac{dA}{dt}=r_A A(1-\frac{A}{K_A})+\sum_m \beta_{mA}P_m-\sum_n \alpha_{nA}C_n-\delta_{pA}P(t)-\alpha_{AWe}W_e \tag{13}$$

P_m refers to various producers, while C_n refers to various predators, achieving a balance between predation and prey relationships. r_A is the intrinsic growth rate of aphids, which reproduce rapidly and typically have a high value. K_A is the environmental capacity of aphids, limited by factors such as food resources and living space. $\sum_m \beta_{mA}P_m$ refers to the food provided by various producers (including crops and wild plants) to aphids, and their impact on aphid populations.

Secondary consumers: The number of each species is stable, for example, the O equation for owls is:

$$\frac{dO}{dt} = -r_O O + \sum_p \beta_{pO} C_p - \zeta_{pO} P(t) O - \gamma_{hO} H(t) O \quad (14)$$

C_p is its food source (such as field mice), and at this time, the food web relationship of the ecosystem is stable, with stable energy flow and material cycling. r_O is the mortality rate of owls when they lack food. $\sum_p \beta_{pO} C_p$ represents the promoting effect of its food source C_p (such as primary consumers like field mice) on the growth of owls, and β_{pO} is the corresponding promoting coefficient. ζ_{pO} is the damage coefficient of insecticides on owls, as owls are located at a higher position in the food chain and insecticides may affect them through other consumers. The ecosystem has strong self-regulation ability and can better cope with external disturbances such as short-term climate change and small-scale pest outbreaks [5,6].

2.5 The Solution of AEDSM Model

Assuming that this article wants to simulate the ecosystem changes during the T year of the conventional stage of agricultural production, the total time is divided into N time steps. The calculation formula for time step h is $h = \frac{T}{N}$. For example, setting T=20 years, N=2000， Then h=0.01 years. The size of the time step has a significant impact on the calculation accuracy and efficiency. The smaller h, the higher the calculation accuracy, but the greater the computational complexity; On the contrary, the larger h, the higher the computational efficiency, but the accuracy may decrease.

2.5.1 Initialize variables

The Lotka Volterra equation for corn

$$\frac{dC}{dt} = r_C C\left(1 - \frac{C}{K_C}\right) + \beta_{SC} S - \alpha_{AC} A - \gamma_h I_h(t) C \quad (15)$$

For example, in the nth time period, given C_n, calculate according to the fourth-order Runge Kutta method:

Calculate k_1:

$$k_1 = h \times \left[r_C C_n\left(1 - \frac{C_n}{K_c}\right) + \beta_{SC} S - \alpha_{AC} A - \gamma_h I_h(t_n) C_n\right] \quad (16)$$

Calculate k_2:

$$k_2 = h \times \left[r_C\left(C_n + \frac{k_1}{2}\right)\left(1 - \frac{C_n + \frac{k_1}{2}}{K_C}\right) + \beta_{SC} S - \alpha_{AC} A - \gamma_h I_h\left(t_n + \frac{h}{2}\right)\left(C_n + \frac{k_1}{2}\right)\right] \quad (17)$$

Calculate k_3:

$$k_3 = h \times \left[r_C\left(C_n + \frac{k_2}{2}\right)\left(1 - \frac{C_n + \frac{k_2}{2}}{K_C}\right) + \beta_{SC} S - \alpha_{AC} A - \gamma_h I_h\left(t_n + \frac{h}{2}\right)\left(C_n + \frac{k_2}{2}\right)\right] \quad (18)$$

Calculate k_4:

$$k_4 = h \times \left[r_C (C_n + k_3)\left(1 - \frac{C_n + k_3}{K_C}\right) + \beta_{SC} S - \alpha_{AC} A - \gamma_h I_h(t_n + h)(C_n + k_3)\right] \quad (19)$$

Update C_{n+1}:

$$C_{n+1} = C_n + \frac{1}{6}(k_1 + 2k_2 + 2k_3 + k_4) \quad (20)$$

Similarly, for the equations of locusts and frogs, the calculation and update should also follow the steps of the fourth-order Runge Kutta method mentioned above.

2.5.2 Update parameters and variables

As time progresses, some parameters may change. For example, soil fertility S will gradually decrease due to continuous planting, assuming that its decline follows a linear function $S_{n+1} = S_n - \Delta S$, where ΔS is the decrease in soil fertility at each time step, which can be confirmed based on the soil nutrient consumption model.

Meanwhile, update the quantities of each species based on the equation forms of each stage. For example, when entering the next time step, calculate C_{n+1} using variables such as C_n、S_n、A_n and updated parameter values from the previous time step.

2.5.3 Repeat iteration

Repeat the above steps continuously until all time steps have been calculated. In this way, the changes in the number of species such as corn, locusts, and frogs over time during the entire simulation period can be obtained, as shown in Figure 1.

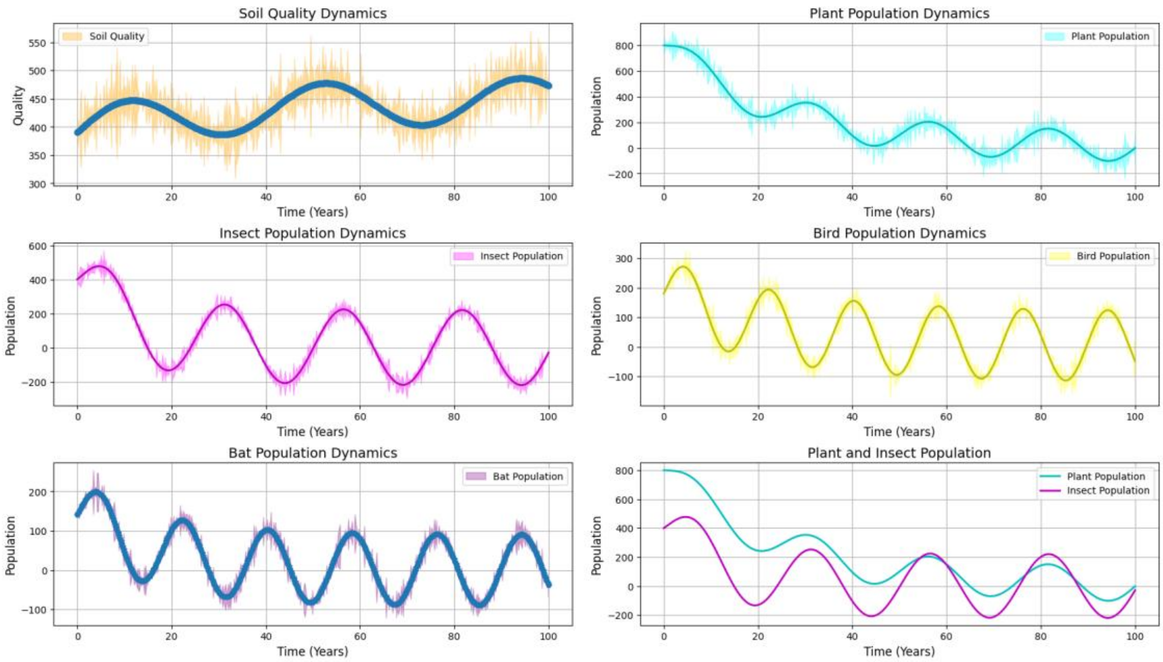

Figure 1 Ecosystem Dynamics: Changes in Soil Quality and Species Populations over 100 Years

3 SPECIES ECOLOGY BASED ON CELLULAR AUTOMATA

3.1 Basic Setting of Cellular Automata

Cellular space: Abstracting agricultural ecosystems into a two-dimensional grid, with each cell representing a specific spatial area, such as a small unit of farmland. Each cell has its unique coordinate (i, j), where $i = 1,2,..., M$, $j = 1,2,..., N, M \ and \ N$ represents the number of rows and columns in the grid.

Cellular state: The state of each cell is represented by a vector $S = (P_1, P_2,...., P_n)$, where P_i represents the number or density of different species. On the basis of the previous model, assuming that the existing species include maize C, aphid A, frog F, and bat B, and the two newly introduced native species are N_1 and N_2, $S = (C, A, F, B, N_1, N_2)$ is considered.

Neighbor rule: The common Moore's neighbor rule is adopted, which means that the neighbors of a cell include 8 adjacent cells in its top, bottom, left, right, and four diagonal directions. For boundary cells, periodic boundary conditions (treating the mesh as circular) can be used to avoid boundary effects.

Time discretization: Divide time into discrete time steps $t = 0,1,2,...$, and update the cell state according to rules within each time step. Cellular automata can effectively simulate the spatial distribution and dynamic changes of species in ecosystems [7,8].

3.2 Ecological Role and Equation Construction of New Species

New species N_1 (assumed to be herbivores)

The new species N_1 feeds on corn and is also preyed upon by frogs and bats. The differential equation of its quantity change is:

$$\frac{dN_1}{dt} = r_{N_1} N_1 (1 - \frac{N_1}{K_{N_1}}) + \beta_{CN_1} C - \alpha_{FN_1} F - \alpha_{BN_1} B \quad (21)$$

Among them, r_{N_1} is the intrinsic growth rate of N_1, reflecting its reproductive ability in an ideal environment; K_{N_1} is the environmental capacity of N_1, determined by factors such as the resources within the cell; βCN_1 is the promotion coefficient of corn on N_1 growth, reflecting the relationship between N_1 and corn as a food source; α_{FN_1} and α_{BN_1} are the predation coefficients of frogs and bats on N_1, respectively.

New species N_2 (assumed to be carnivorous beneficial birds)

The new species N_2 mainly preys on aphids, while it may also be preyed upon by bats. The differential equation of its quantity change is:

$$\frac{dN_2}{dt} = r_{N_2} N_2 (1 - \frac{N_2}{K_{N2}}) + \beta_{AN2} A - \alpha_{BN_2} B \quad (22)$$

Among them, r_{N_2} is the intrinsic growth rate of N_2, K_{N_2} is the environmental capacity of N_2, β_{AN_2} is the promotion coefficient of aphids for N_2 growth, and α_{BN_2} is the predation coefficient of bats for N_2.

3.3 Habitat Maturity and Species Regression Mechanism

Habitat maturity function: Define habitat maturity $H(t)$ to describe the development of edge habitats over time. A simple linear function $H(t) = \frac{t}{T_{\max}} (t \le T_{\max})$ can be used, where $T_{\max}$ is the total time steps required for the habitat to fully mature. When $t > T_{\max}$, $H(t) = 1$.

Species regression rule: At each time step t, generate a random number $r \in [0,1]$ for each cell (i, j). If $r < H(t)$, there is a chance for new species to appear in the cell [9,10]. For new species N_1 and N_2, the occurrence probabilities p_{N_1} and p_{N_2} can be set respectively. If the random condition is met and $r_1 < p_{N_1}$ (where r_1 is another random number), then N_1 appears in the cell with an initial quantity of N_{10}; Similarly, if $r_2 < p_{N_2}$ occurs, N_2 appears in the cell with an initial quantity of N_{20}.

3.4 Rules and Solutions for Updating Cellular States

At each time step, the fourth-order Runge Kutta method is used to update the number of species within the cell by combining the states of the cell and its neighbors. Taking cellular (i, j) as an example:

Corn C

$$\frac{dC}{dt} = r_C C (1 - \frac{C}{K_C}) + \beta_{SC} S - \alpha_{AC} A - \gamma_h I_h(t) C - \alpha_{CWe} We - \gamma_{pC} P_C - \beta_{CN_1} N_1 \quad (23)$$

Aphid A

$$\frac{dA}{dt} = r_A A (1 - \frac{A}{K_A}) + \beta_{CA} C - \alpha_{FA} F - \delta_p I_p(t) A - \alpha_{AN_2} N_2 \quad (24)$$

Frog F

$$\frac{dF}{dt} = -r_F F + \beta_{AF} A + \beta_{LF} L - \alpha_{BF} B - \zeta_p I_p(t) F - \gamma_{hF} I_h(t) F - \alpha_{FW_e} W_e + \alpha_{FN_1} N_1 \quad (25)$$

Bat B

$$\frac{dB}{dt} = -r_B B + \beta_{AB} A + \beta_{FB} F + \alpha_{BN_1} N_1 + \alpha_{BN_2} N_2 \quad (26)$$

New species N_1

$$\frac{dN_1}{dt} = r_{N_1} N_1 (1 - \frac{N_1}{K_{N_1}}) + \beta_{CN_1} C - \alpha_{FN_1} F - \alpha_{BN_1} B \tag{27}$$

New species N_2

$$\frac{dN_2}{dt} = r_{N_2} N_2 (1 - \frac{N_2}{K_{N_2}}) + \beta_{AN_1} A - \alpha_{BN_2} B \tag{28}$$

Then, follow the steps of the fourth-order Runge Kutta method (calculate k_1、k_2、k_3、k_4 and update state) to update the number of each species within the cell.

3.5 Model Simulation and Analysis

Initialization: Set an initial time of $t = 0$, allocate an initial quantity for each species in each cell, and use literature data

The simulation process of determining model parameters (such as intrinsic growth rate, environmental capacity, interaction coefficient, etc.): Starting from $t = 0$, update the states of all cells at each time step according to the above rules until the preset total number of time steps is reached.

The response of ecosystems under different parameter settings (such as different probabilities of new species emergence, interaction coefficients, etc.) is shown in Figures 2 and 3.

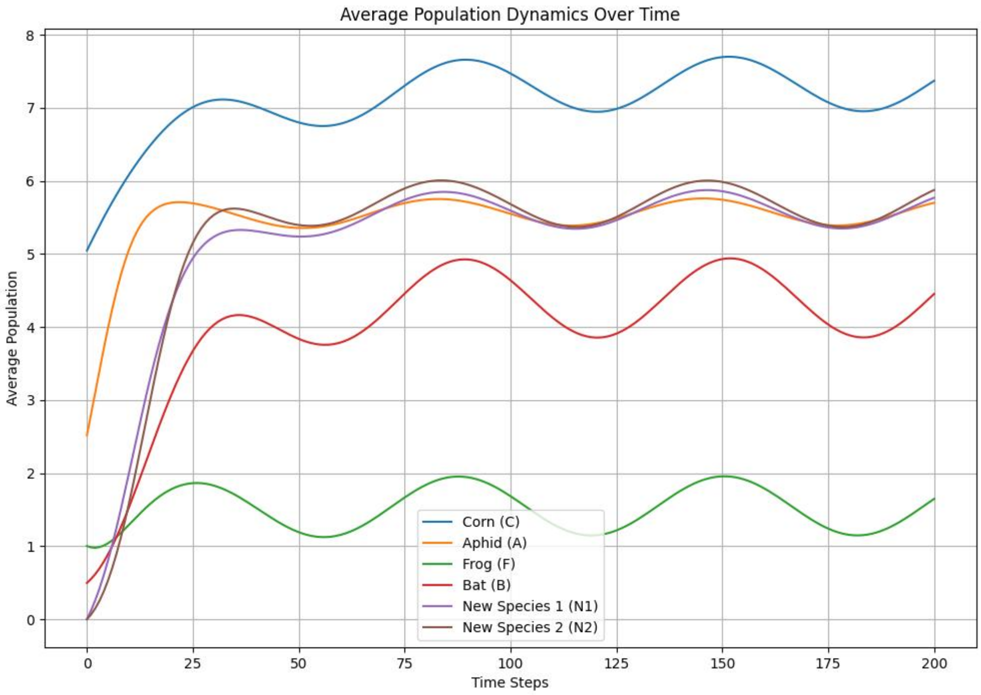

Figure 2 Average Population Dynamics Over Time

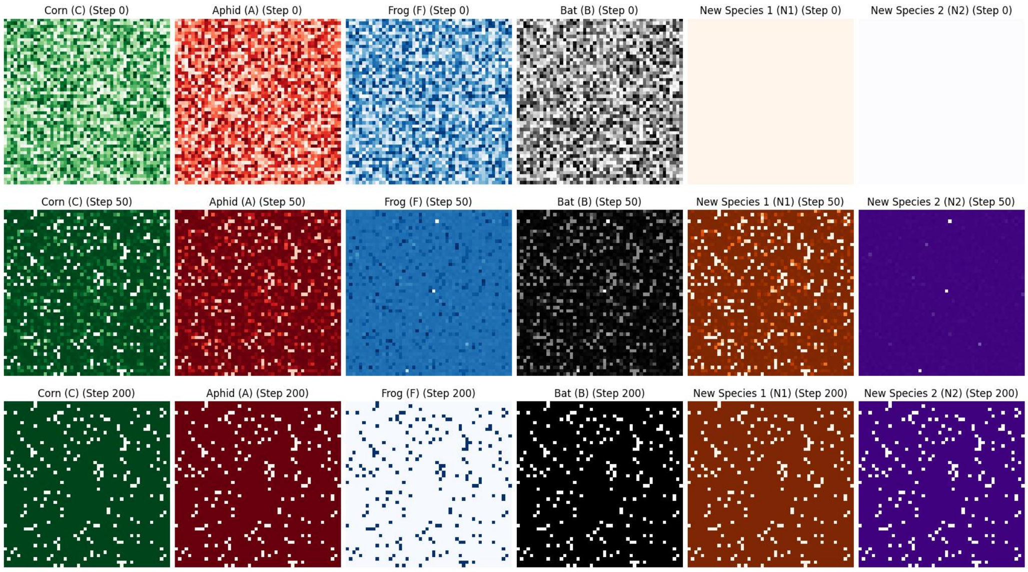

Figure 3 Spatial Species Distribution Dynamics Over Time Steps

4 CONCLUSIONS

This article successfully constructed and validated a comprehensive dynamic simulation model for agricultural ecosystems. The model results indicate that through rational management of pollinators, pests, and ecological restoration measures, agricultural productivity and ecological sustainability can be effectively improved. This study not only provides new insights into the interactions between different components in complex ecosystems, but also provides a scientific basis for developing more effective agricultural management strategies. Future research can further explore the applicability of the model in different regions and agricultural systems, as well as how to translate the model results into practical ecological agriculture practices.

I understand that you are exploring the practice of organic agriculture, which is a challenging but meaningful path. Organic agriculture not only helps protect the environment, but also improves soil quality, enhances biodiversity, and ultimately produces healthier and safer food. Here, I would like to provide you with some suggestions and strategies, hoping to help you walk more steadily and further on this path. Enhancing ecosystem stability helps to improve agricultural productivity and ecological sustainability simultaneously.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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