

# Research on Ecosystem Changes Based on LV Technology and Entropy Weight Method

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**Abstract.** In this study, the interrelationships between several ecological factors were analyzed in order to construct an agroecosystem model. The aim is to manage agricultural ecosystems, maintain sustainability and stability, and increase crop yields. Based on the Lotka-Volterra model, the curves of crop growth and insect population size over time were plotted, while the effects of species diversity, number of organisms, and human activities on ecosystem stability and resilience were evaluated using the entropy weighting method, and the agro-ecosystem model was finally constructed successfully. What's more, with the removal of herbicides and the introduction of bats as insectivores and pollinators, in order to study the stability of the ecosystem, another beneficial species was identified to help restore the balance of the ecosystem and to compare their impacts. An ecological model that accurately describes the multi-species interactions of plants, bats, bees and insects was developed based on the Lotka-Volterra model. Able to accurately describe multi-species interactions among plants, bats, bees and insects, the population dynamics of each species over time was mapped, and the effects of bees and bats on ecosystem structure and functioning under independent action scenarios were further comparatively analyzed. A simulated annealing algorithm was used to globally optimize the unknown parameters in the model, and the mechanism of the effect of different parameter combinations on ecosystem stability was analyzed, and the mechanism of the effect of different parameter combinations on ecosystem stability was also explored.

**Keywords:** Simulated annealing algorithm, Lotka-Volterra model of competition, entropy weighting, Euler method, Agro-ecosystem models.

## 1. Introduction

Forest ecosystems are one of the most important ecosystems on earth, playing an important ecological role in carbon storage, carbon balance, carbon regulation and carbon cycle [1]. With the gradual deterioration of the environment, the once thriving forest ecosystems inhabited by birds, insects and animals have disappeared and have been replaced by rows of crops. The fertile soil became infertile and pests began to harm the crops.

To solve this problem, farmers began to use chemicals, but this upset the ecological balance of the land. From then on, the forest ecosystem was gradually replaced by the human-dominated agricultural cycle, creating a whole new food chain based on the agro-ecosystem. Agro-ecosystems are an important part of terrestrial ecosystems, which not only have the function of producing livelihoods by providing humans with products such as food, fiber, and fuel, but also have significant ecological and environmental as well as socio-cultural functions [2]. At the same time, bats, birds and other species will re-emerge. Soil carbon and nitrogen cycling in agroecosystems is a complex biogeochemical process that includes organic matter production, decomposition, nitrification, denitrification and fermentation [3].

Therefore, in the face of changes in the natural environment in contemporary society, it is worthwhile to develop an ecological model based on the Lotka-Volterra model [4], i.e., a predator-bait system with a harvesting term in order to take into account the long-term survival of the species [5], as well as the uninterrupted and maximized harvesting of the natural biotic chain. It is necessary to develop an ecological model that hypothesizes and constructs scenarios for the conversion of

forests to agricultural land in order to track habitat changes during the conversion of forests to agricultural land, taking into account the multiple impacts of the ensuing changes in natural processes and human decision-making. The LV model developed in this study, combined with the entropy weight method found that the use of chemical substances (such as pesticides) has a significant impact on the population number of insects. This characteristic makes it particularly suitable for the pest control in modern green agriculture.

## 2. Research methodology

### 2.1. Data acquisition and pre-processing

Based on the modeling of the dynamic system of the ecological environment in question and satisfying the idea of differential equations, in order to simplify the original existence of the complex model, we choose the Eulerian method for simplified numerical simulation. Assume initial conditions and parameters:

- (1) Initial population of the crop  $C_0 = 50$ .
- (2) Initial population of weeds  $W_0 = 30$ .
- (3) Crop and weed growth rate  $r_c = 0.1, r_w = 0.2$ .
- (4) Environmental carrying capacity of crops and weeds  $K_c = 100, K_w = 200$ .
- (5) Competition coefficient between crops and weeds  $\alpha=0.01, \beta=0.02$ .
- (6) Simulation time step  $\Delta t = 0.1$ (in years)
- (7) Total simulation time  $T = 50$ (in years)

### 2.2. Introduction to the methods

#### 2.2.1. The advantages of the methods

The Lotka-Volterra model effectively describes the dynamics of the predator-prey relationship, revealing the pattern of change in their numbers over time. It is also simple and intuitive, containing only a few parameters, which are easy to understand and interpret.

In addition, the model is a system of ordinary differential equations, which is convenient for mathematical analysis and solution, such as stability analysis and phase plane analysis, and can demonstrate the phenomenon of periodic fluctuations in the number of predators and prey, which is in line with the actual observation of certain ecosystems, and provides an in-depth understanding of the mechanism of species interactions and the maintenance of ecological balance.

We would also like to recognize that the model can be extended to study a variety of ecological relationships such as competition and symbiosis, as well as multi-species interactions. The establishment of relevant model parameters with clear ecological significance, such as predation rate and prey growth rate, facilitates the integration with actual data, and the use of the LV model can also be used to predict the trend of predator and prey population size, providing a reference for ecological management.

The entropy weight method is highly objective, which is based on the discrete degree of the data itself to determine the weights, reducing the interference of subjective judgment and making the results more objective. Moreover, the calculation steps of entropy weighting method are clear and easy to be realized by programming, which is suitable for dealing with large-scale data.

At the same time, the weights are completely determined by the data, which can reflect the intrinsic structure and characteristics of the data, and the weights can be adjusted when the data change to adapt to the dynamically changing environment. Its advantage also lies in its ability to deal with the complex problem of multiple indicators and criteria, provide a comprehensive and integrated evaluation, and reduce human interference.

#### 2.2.2. The principle of the methods

The Lotka-Volterra model, also known as the predator-prey model, is used to describe the dynamic interactions between two species (predator and prey). After performing hypothetical analyses, two

basic ordinary differential equations are constructed to analyze their periodic oscillations and trends around the equilibrium point by simplifying the factors that in reality contribute to the changes in the ecosystem model, providing an important tool for ecological studies and analysis of population dynamics.

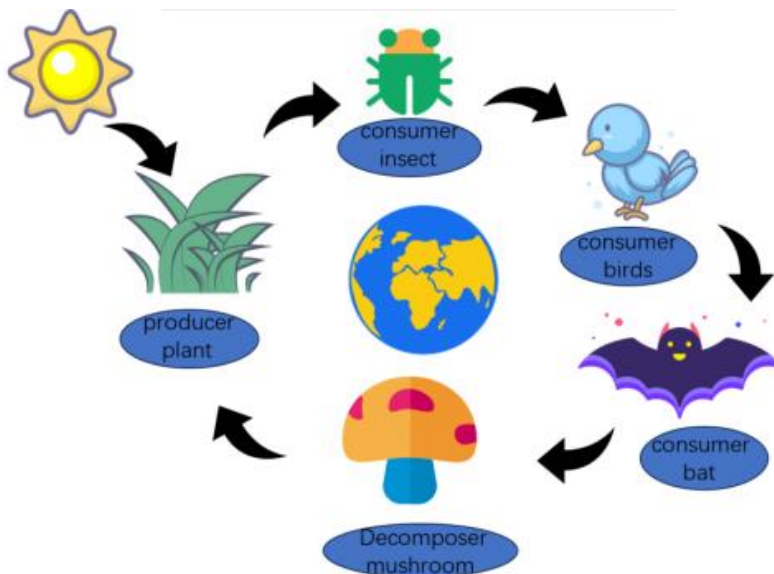


Figure 1. Ecological relationship map

Entropy weight method [6] is an objective assignment method based on information entropy, which is used in the comprehensive evaluation problem of multiple indicators. Its core principle is to use the degree of discrete data itself (information entropy) to determine the weight of each indicator, thus reducing the influence of subjective factors. After standardizing different data to a certain extent and calculating the coefficient of variation, the weight of the data is determined, which belongs to the category of multi-indicator comprehensive evaluation method, and it can reduce the subjectivity and improve the objective fairness of the data. Figure 1 above is the indicator that has an impact on the results in this study.

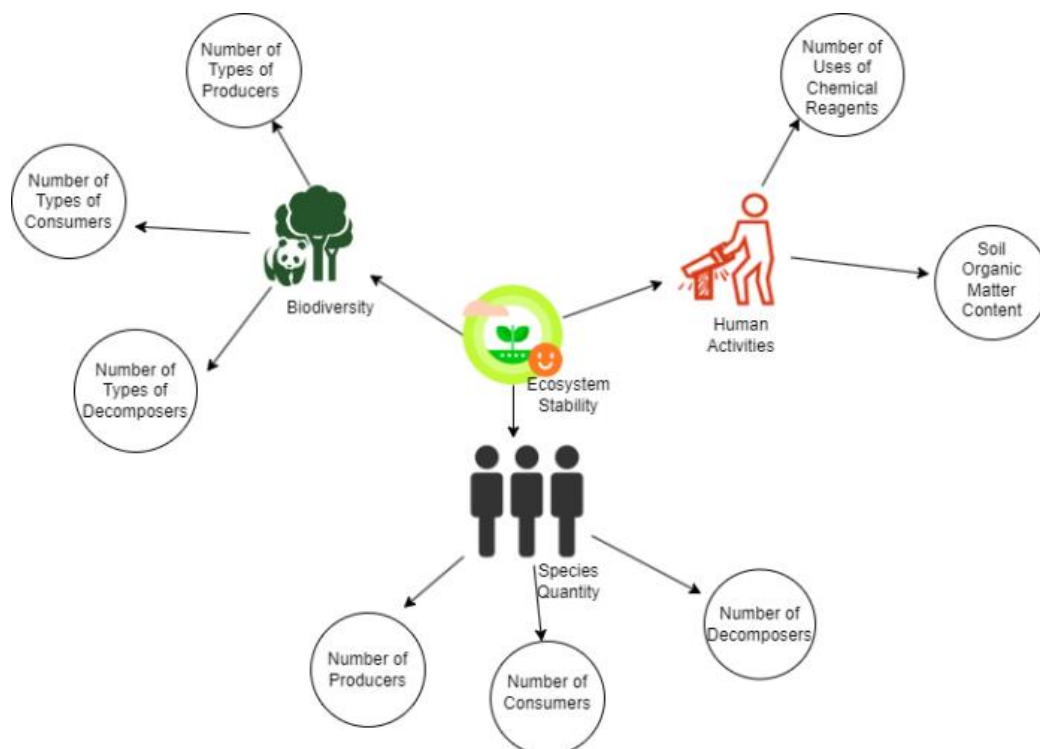


Figure 2. Various indicators that affect the outcome

### 3. Results

#### 3.1. The establishment of simulation model

##### 3.1.1. Plants (producers)

$$\frac{dp}{dt} = rp\left(1 - \frac{p}{k}\right) - \alpha pc \quad (1)$$

$$r = r_0 + (r_{max} - r_0)\left(1 - e^{-\frac{c}{c_0}}\right) \quad (2)$$

$$K_s = \beta s \quad (3)$$

P is the number of crop populations, k (s) is the environmental capacity, and both of them are related to soil quality s; c is the concentration of chemicals (herbicides, pesticides) used; r is the plant growth rate.  $\alpha$  is the soil quality decline factor.

##### 3.1.2. Insects (consumers)

$$\frac{dI}{dt} = bI\left(1 - \frac{I}{I_{max}}\right) - yIc \quad (4)$$

This paper assumes that insects as consumers eat plants. In the above equation, I am the number of insects, b is the growth rate of insects,  $I_{max}$  is the carrying capacity of the environment for insects, y is the coefficient of influence of the chemical on the insects, and c is the concentration.

##### 3.1.3. Birds (predators)

$$\frac{dB}{dt} = \beta B\left(1 - \frac{B}{B_{max}}\right) - yBI \quad (5)$$

Birds as the predators, they eat insects as their food. In the above equation  $\beta$  is the growth rate of the bird, B is the number of birds,  $B_{max}$  is the maximum capacity of the bird and  $\delta$  is the predation efficiency of the bird on insects.

##### 3.1.4. Bats (consumers)

$$\frac{dv}{dt} = \zeta v\left(1 - \frac{v}{v_{max}}\right) - \eta vI \quad (6)$$

Bats as the consumers, they can control the number of insects. In the above equation, v is the number of bats,  $\zeta$  is the growth rate of bats,  $\eta$  is the predation efficiency of bats on insects,  $v_{max}$  is the maximum carrying capacity of bats in the environment, and I is the number of insects.

##### 3.1.5. population competition

Consider population competition between weeds and crops, especially if herbicides are no longer used, weeds may reoccupy the land, affecting crop growth and agro-ecosystem stability.

The Lotka-Volterra competition model can be used to describe population competition [7] between crops and weeds. Assume that there are two populations, crops (C) and weeds (W), which interact with each other through competition for resources. The model can be expressed as (where  $r_c, r_w$  are the growth rates of crops and weeds, respectively.  $K_c, K_w$  is the environmental carrying capacity of crop and weed.  $\alpha, \beta$  are coefficients of inter-population competition, indicating the degree of inhibition of crops and weeds on each other):

$$\frac{dC}{dt} = r_c C\left(1 - \frac{C + \alpha W}{K_c}\right) \quad (7)$$

$$\frac{dW}{dt} = r_w W\left(1 - \frac{W + \beta C}{K_w}\right) \quad (8)$$

### 3.2. Analysis of experimental results

#### 3.2.1. Visualization results of insect population changes with chemicals

I. Initialization parameters: Initial number of crops, insects, birds, bats:  $P_0, I_0, B_0, V_0$ , time step  $h$ , model parameters .... (All model parameters used in the model).

II. Calculated changes: Calculate the change in the number of individual populations and associated physical quantities, update the data, and at each time step  $h$ , repeat the calculation.

III. Data Visualization: We can obtain graphs of crop and insect populations over time. Crop and insect populations show periodic fluctuations.

As shown in Figure 3 and 4, by using the aforementioned methods, we can see that if chemical use is too high (high concentration of  $c$ ), insect populations may decrease rapidly, thus affecting crop growth, while if chemical use is too low (low concentration of  $c$ ), insect populations may rebound rapidly, leading to increased crop damage.

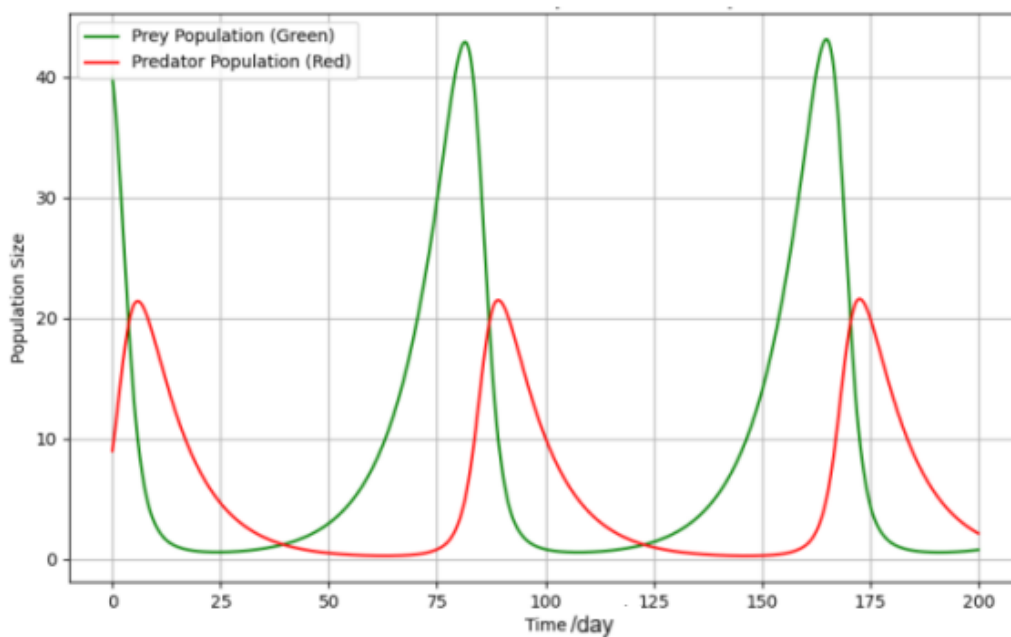


Figure 3. Lotka-Volterra Model of prey and Predator Dynamics

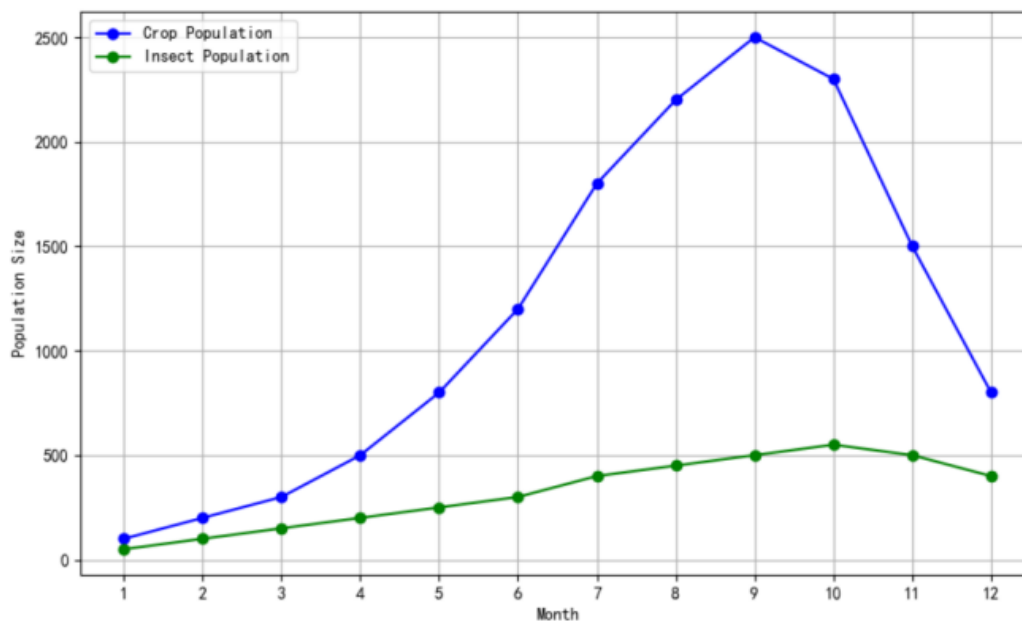


Figure 4. Crop and Insect Population Over Time (Monthly)

### 3.2.2. Analysis using the entropy weight method

#### I. Normalization and standardization of data

1) standardize the data of the (j) indicator

$$positive: z_{ij} = \frac{x_{ij} - x_{minj}}{x_{maxj} - x_{minj}} \quad (9)$$

$$positive: z'_{ij} = \frac{x_{maxj} - x_{ij}}{x_{maxj} - x_{minj}} \quad (10)$$

2) Calculate the entropy of the j indicator

$$E_j = -\frac{1}{\ln n} \sum_{i=1}^n P_{ij} \ln P_{ij} \quad (11)$$

The entropy value ( $E_j$ ) reflects the data distribution of the (j) indicator, the larger the value, the more information uncertainty value of the indicator; on the contrary, the smaller the value, the less information provided by the indicator [8].

3) Calculation of the coefficient of variation for indicator j

$$G_j = 1 - E_j \quad (12)$$

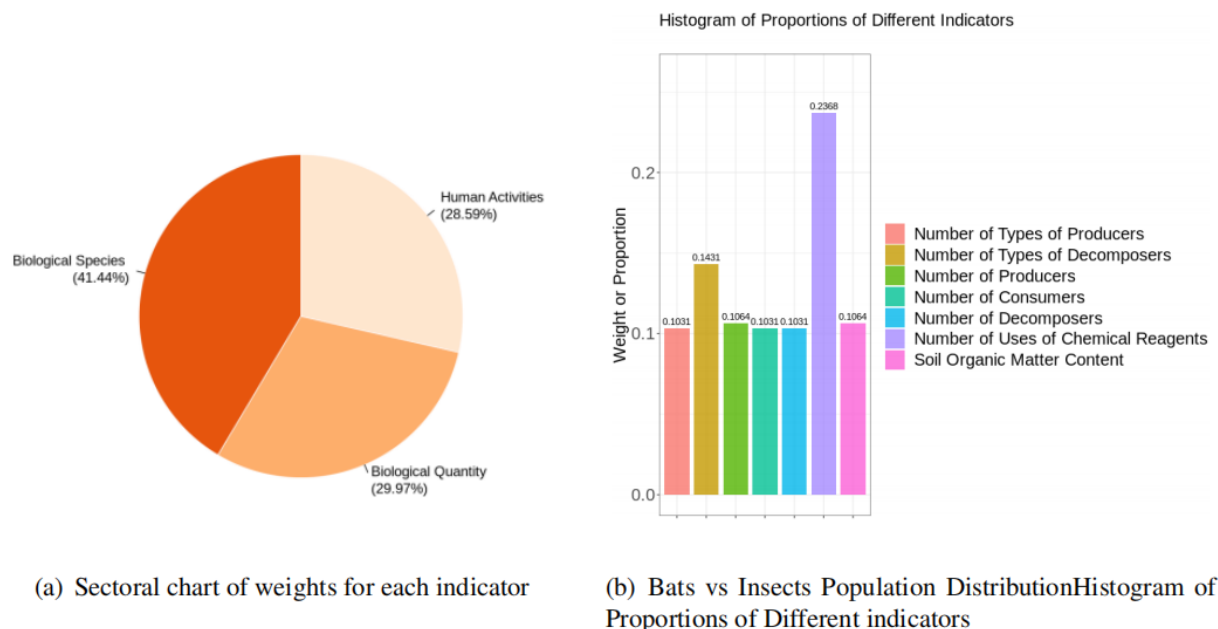
4) Calculation of the weight of the jth indicator

$$Weighting\ Calculations: W_j = \frac{G_j}{\sum_{j=1}^m G_j} \quad (13)$$

Through the calculation of the above formula, it is possible to obtain the importance of each indicator relative to the other indicators, and thus determine its weight in the overall score [9].

#### II. Results Showcase

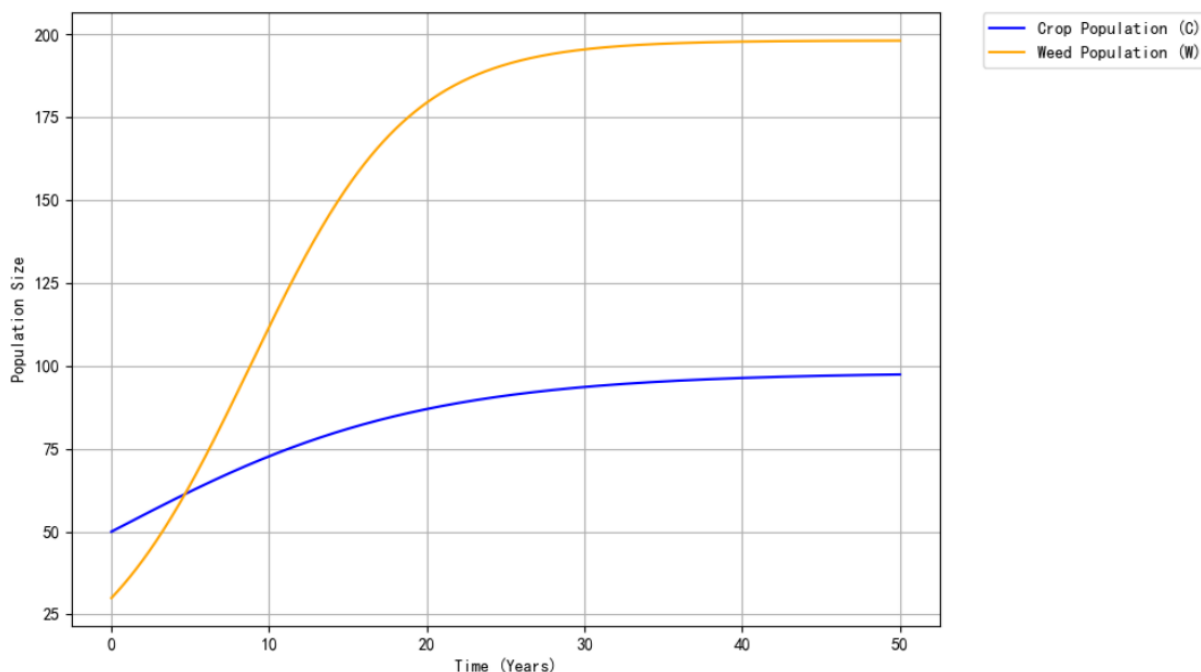
As shown in Figure 5, we can get the results of the weight share of each indicator.



**Figure 5.** Proportions and weights of different indicators' ratios and weights chart

### 3.2.3. Visualization results of crop and weed populations

As shown in Figure 6, based on the assumption above, images were obtained about the crop population and weed population over time. According to the analysis of this graph, in the short-term crop is in a dominant position and when the time is greater than five years, weeds are in a dominant position. Herbicide removal has allowed weed populations to grow rapidly without external control and has put significant pressure on crop populations. Crop populations grew slowly in competition but eventually reached some equilibrium [10].



**Figure 6.** Dynamics of Crop and Weed Populations After Herbicide Removal

#### 4. Conclusion

This study underscores the necessity of sustainable agricultural practices for agro-ecosystem stability and resilience. The findings highlight that balanced chemical use, introduction of beneficial species such as bats and bees, and effective weed management are essential strategies. Sustainable weed management, in particular, is a critical aspect of agricultural practices that can significantly impact crop yield and quality. The integration of these practices not only enhances ecosystem health but also promotes long-term agricultural productivity. Future research should focus on further refining these strategies and exploring their long-term impacts on agro-ecosystem health.

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