

# Research on the Stability and Marginal Habitat Effect of Agro-ecosystems Based on the Logistic Model

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**Abstract.** The paper constructed a model of the food web underlying a new agro-ecosystem. It reflected the changes in the population size of various organisms through a new model formed by partially adjusting the logistic model, and then optimized the population trends of multiple populations through a multi-objective optimization algorithm and hierarchical analysis, and ultimately selected the most reasonable population allocation scheme in the agro-ecosystem in order to maintain the stability of the agro-ecosystem. The paper found that the use of chemicals was not the most important factor in agro-ecosystem stability. In addition, the paper assumed the introduction of species 1 (herbivore) and species 2 (predator), and constructed the kinetic equations for the changes in the populations of plants, insects, species 1, and species 2, respectively, through logistic modeling, and after data review as well as quantification obtained a visual representation of the changes in crop health over time. The paper found that reasonable application of marginal habitat effect can reduce pest populations, improve soil health, increase plant reproduction with ecological diversity and stability, and contribute to environmental protection, with a fast growth rate in crop yields, and superior long-term economic benefits.

**Keywords:** Food web, Agro-ecosystem stability, Logistic model, multi-objective optimization algorithm, Hierarchical analysis.

## 1. Introduction

In the past, the lush, vibrant forest was like the green lung of the earth, breathing in the vitality of life and the rhythm of nature. In order to meet the growing demand for food, forests began to be cut down in a systematic way, and farmland came into being.

As to the edge effect, Bao's team used point count method and mist-net during the investigation [1]. This method is limited by sample size and space scope. As to the stability of agro-ecosystem, Cai's team took Yinlin Farm in Conghua District, Guangzhou as a case study to explore the vulnerability of alternative agricultural production from the perspective of social ecosystem and the formation mechanism of the resilience network of alternative agricultural production [2]. Yang Wanqing's team used InVEST, ROS and other models to quantitatively assess a variety of ecosystem services in Beijing [3]. Based on survey data from eight counties in Shanxi and Henan provinces, Li's team empirically analyzed the impact of regional brand ecosystems on the green development of characteristic agriculture [4]. Zheng Penghong's team found that combining livestock and poultry farming with agriculture is an important measure to strengthen resource utilization [5]. Lv Jingjing's team analyzed the importance of soil in agro-ecosystems and the impact of soil degradation on ecosystems [6]. These papers generally have the defects of few long-term monitoring data and no discussion of dynamic effects. As to the food chain model, Wang Yuxia's team mainly considered a kind of food chain model with nonlinear ecliptic sensitivity function [7]. Dong Yifu's team considered a three-population food chain model with protected areas, and gave its basic dynamic behavior, non-existence and existence of positive steady-state solutions [8]. Lu Xiaojin's team used methods such as mind mapping, snowflake building blocks, chess and diorama construction to construct a food web model [9]. By means of energy estimation method, operator semigroup and Moser iteration, Liu

Foxiang's team established the existence of the global classical solution of the three-level food chain model in two-dimensional space, whose diffusion coefficient depends on prey density [10]. These papers generally oversimplify their models by assuming that species interactions are linear or static, ignoring the possibility that climate change could lead to a collapse of predator-prey synchronous oscillations.

The highlight of the paper is that we used multi-objective optimization algorithm and hierarchical analysis, the long-term nature of the data is discussed, with many indicators tracked over 100 years, and the paper also takes into account dynamic effects, setting several parameters such as the attraction coefficient of plants to insects, and ultimately selected the most reasonable population allocation scheme in the agro-ecosystem in order to maintain the stability of the agro-ecosystem. The paper found that the proportions of plants, pests, bats and birds, herbicides and insecticides in ecological stability were 90, 70, 50, and 20-30, respectively, which concluded that the use of chemicals was not the most important factor in agro-ecosystem stability.

## 2. The Agro-ecosystem Model

### 2.1. Influencing factors

#### 2.1.1. Herbicides

Herbicides are effective in controlling weeds, thereby increasing crop yields and farm productivity, but overuse of herbicides can lead to reduced agro-ecosystem stability.

#### 2.1.2. Insecticides

Insecticides control and reduce pest populations to protect crops from pest damage, but overuse of insecticides can lead to the development of resistance in target insects, which can lead to reduced agro-ecosystem stability.

### 2.2. Basic food chain model of the ecosystem

The paper construct a food chain model to track the ecological transformation process from forest to farmland, due to the agro-ecosystem has a certain strong correlation between the major populations, we are in the various biological population changes through the logistic model part of the adjustment of the new model to reflect the changes in the number of biological populations.

The simple food web model is shown in figure 1.

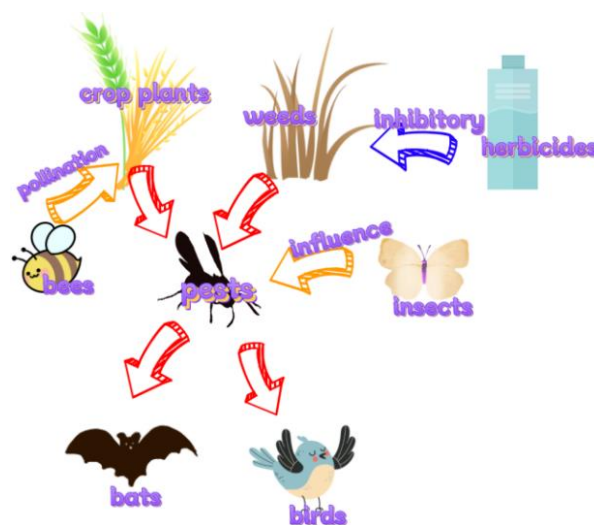


Figure 1. Simple food web model

### 2.3. Ecosystem species population change modeling

In farmland ecosystems, we want to study the effect of external factors on the ecosystem, that is, the study of the number of species in it. So we consider the logistic model to represent the change in the number of different species.

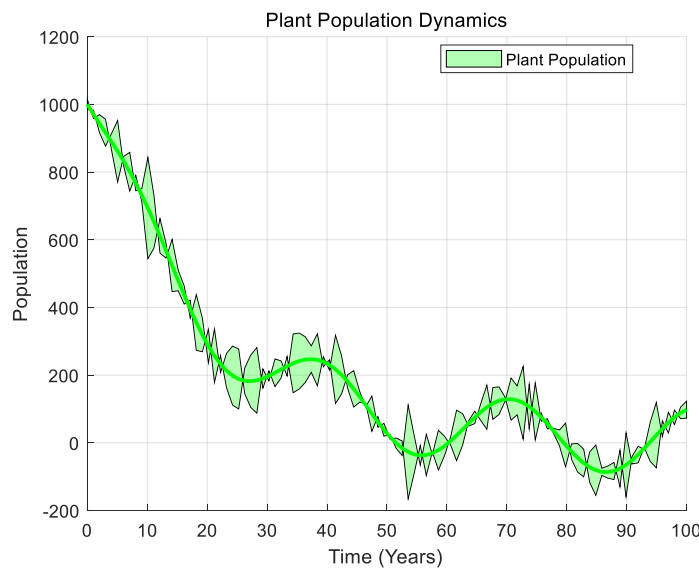
#### 2.3.1. Producer population changes

The number of producers increases, and their own first increase and then limited, and promote the growth of consumers, but too many consumers will inhibit the producers, forming a negative feedback, which in turn affects the ecosystem structure and function, changes the diversity of species, the flow of energy and material cycle, affecting the stability of the ecosystem and ecological service function. Equation for the change in population size of producers is as follows.

$$\frac{dA}{dt} = \alpha_A A \left(1 - \frac{A}{K_A}\right) - \alpha_B \beta_A B - D_A A D \tag{1}$$

In this equation, A means the population of producers,  $\alpha_A$  means the growth rate of producers,  $K_A$  means the environmental carrying capacity of producers,  $\alpha_B$  means the growth rate of insects,  $\beta_A$  means the coefficient of insect damage to plants, B means the population of insects,  $D_A$  means factors influencing herbicides on plant quantity, D means dichotomous variables of herbicides(0,1).

Based on the logistic model, the variation model of plant populations is shown in figure 2.



**Figure 2.** Trends of plant populations

The graph of plant population dynamics on the right shows a gradual downward trend in plant populations, with a gradual decrease in plant numbers over time, which may indicate that plants are facing pressures such as insect predation, competition for resources, or environmental change. Nonetheless, the volatility and rebound in the graph also suggests that there may be a trend towards recovery or stabilization of plant populations at certain points in time.

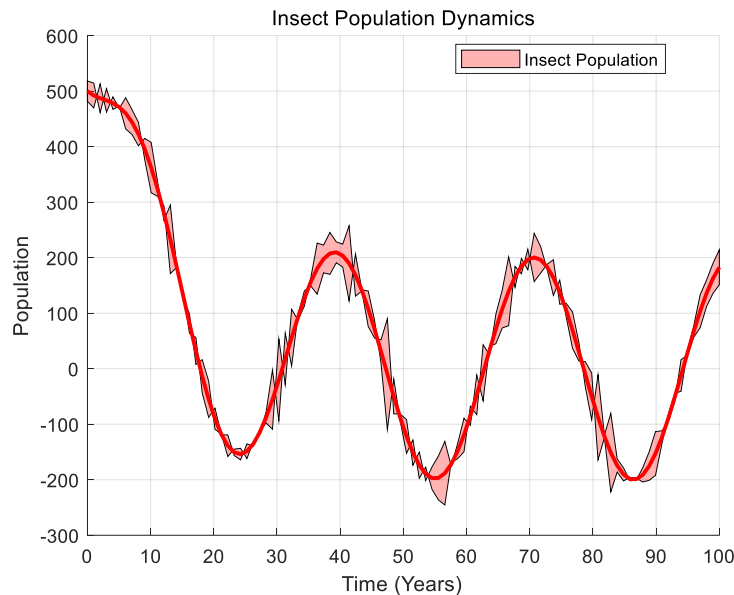
#### 2.3.2. Insect population changes

In agro-ecosystems, changes in insect populations depend mainly on changes in the populations of bats and birds and on the impacts caused by pesticides. When the carrying capacity of the environment is high enough, the rate of increase in insect populations tends to peak gradually. Equation for the change in population size of insects is as follows.

$$\frac{dB}{dt} = \alpha_B B \left(1 - \frac{B}{K_B}\right) + \beta_P A - \delta_i B - \gamma_l B - \eta_b B \tag{2}$$

In this equation,  $A$  means the population of producers,  $\delta_i$  means the natural mortality of insects,  $K_B$  means the environmental carrying capacity of insects,  $\alpha_B$  means the growth rate of insects,  $\beta_P$  means the attraction of plants to insects,  $B$  means the population of insects,  $\gamma_1$  means insect mortality due to pesticides,  $\eta_b$  means the predation coefficient of species 2 on insects.

Based on the logistic model, the variation model is shown in figure 3.



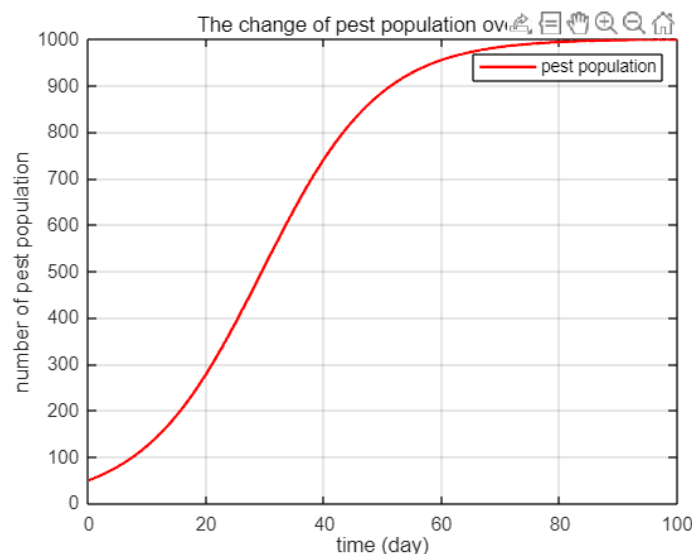
**Figure 3.** Trends of insect populations

From the insect population graph above, the population size of insects experienced periodic fluctuations, showing a clear trend of increase and decrease, which may reflect the interactions between insects and plants in the ecosystem, such as the food resources provided by plants affecting the number of insects, and changes in the number of insects affecting the growth of plants. The shaded area in the figure represents the range of variation in insect population size, showing the volatility and uncertainty of the data.

### 2.3.3. Pest population changes

Pest populations increase, first increasing and then limiting themselves, while inhibiting plant growth, but too many plants inhibit pests, creating a negative feedback.

Based on the logistic model, the variation model is shown in figure 4.



**Figure 4.** Trends in the number of pest populations

Pest population growth patterns over 100 days show initial slow growth, followed by rapid increase, then stabilization as resources limit and competition rises.

### 2.4. Model optimization

The paper use a multi-objective optimization algorithm to go about trying to find the combination that arrives at the optimum for the causes and future predictions of the movement of change in the numbers of multiple populations in an agro-ecosystem. Thus finding the optimal solution by figure 5.

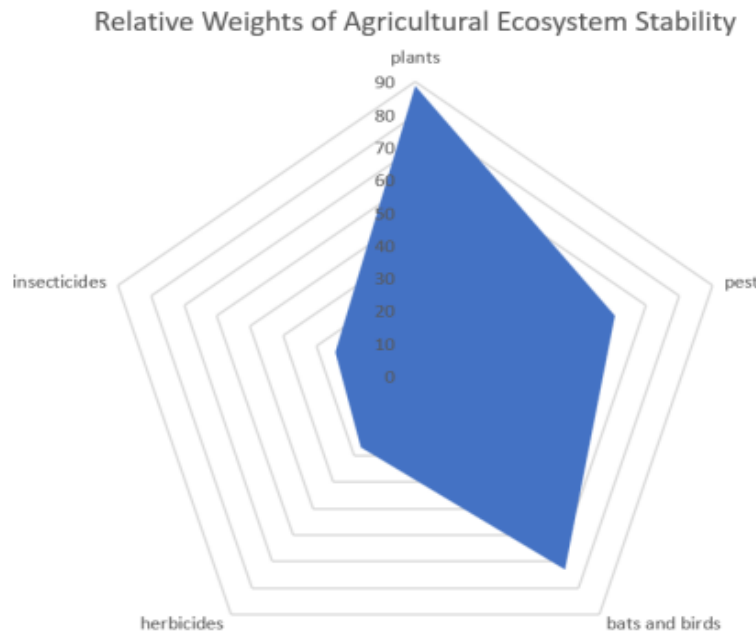


Figure 5. Weight ratio diagram

In agro-ecosystem stability, plants have the highest weightage of nearly 90 points, which indicates that plants have the most important position in maintaining agro-ecosystem stability. Pests also had a high weightage of around 70 points, which indicates that pests also have a significant impact on agro-ecosystem stability and farmers need to control them properly. Bats and birds were weighted around 50 points, which indicates that bats and birds have a role in agro-ecosystems. Herbicides and pesticides have a lower relative weight of about 20-30 points. This indicates that the use of chemicals is not the most important factor in agro-ecosystem stability.

### 2.5. Results

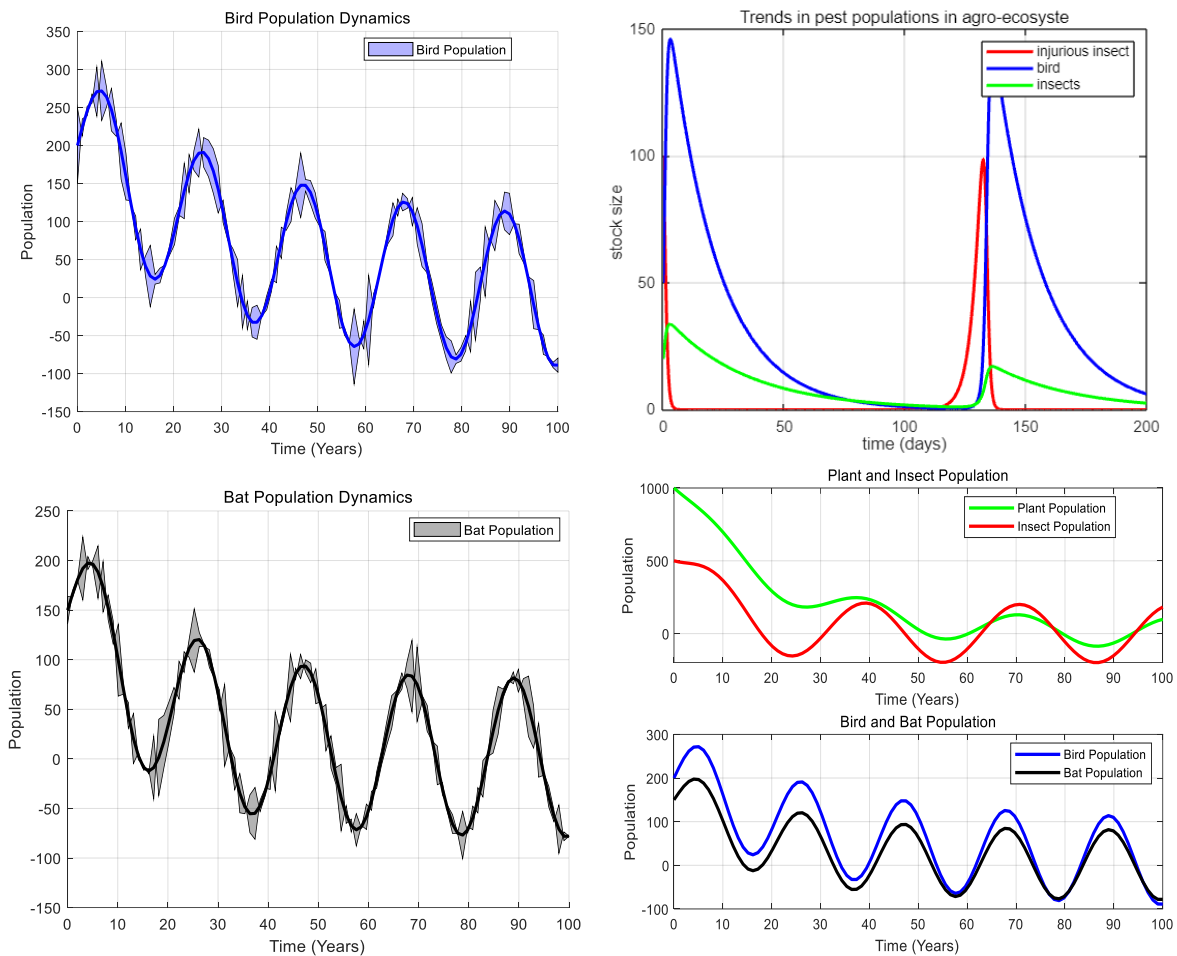
In order to maintain the stability and health of the agro-ecosystem, we can appropriately adopt plant protection techniques, such as organic agriculture, which can not only greatly reduce the amount of pesticides and fertilizers, but also control pests and diseases well. By reducing the use of pesticides, thus improving the safety of agricultural ecosystem agricultural production, reducing its impact on the surrounding environment, and finally promoting the stable development of ecological agriculture.

## 3. Ecosystems after the introduction of new species

In this section, the paper consider the re-emergence of species. That is, as time passes and marginal habitats mature, some native species will re-enter the agro-ecosystem, affecting the populations and ecological balance of existing species. The paper construct models to analyze how these species interact with other species in the current ecosystem and thus affect the dynamics of the agro-ecosystem.

### 3.1. Analysis of population changes

#### 3.1.1. Population changes of pests, birds, bats, and insects



**Figure 6.** Population changes of pests, birds and insects

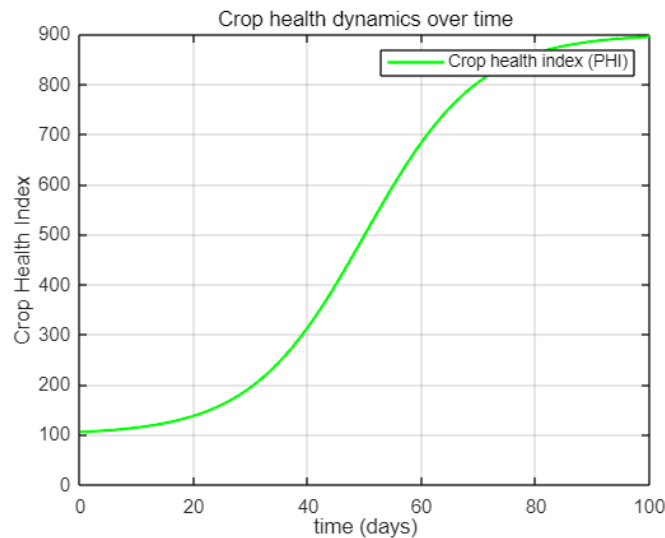
As shown in figure 6, in agro-ecosystems, interactions between pests, birds and bats (as one of the predators), and insects (which may act as predators or competitors of the pests) affect changes in their respective populations.

Pests are reduced as a direct result of predation by birds, bats and insects. At the same time, insects compete with pests for the same food resources, limiting the growth of pests. In turn, a decrease in the number of pests may lead to a decrease in the food supply for birds, which affects their reproduction and survival, and may lead to a decrease in the number of birds. In the case of insects, if the insects are successful in feeding on pests, they will increase in number because of the availability of food. If insects compete with pests for food resources, a decrease in the number of pests provides more resources for the insects, leading to an increase in their numbers.

In this predator-prey model, the population sizes of pests, birds, bats, and insects typically fluctuate around some equilibrium. This equilibrium is determined by a combination of factors such as predation rates, natural mortality, resource availability, and environmental carrying capacity. By understanding and managing these interactions, pests can be controlled more effectively and the health of agro-ecosystems protected.

### 3.2. Crop health status after the introduction of bats and birds

After data access and its quantitative processing, we can get the following visual representation in figure 7:

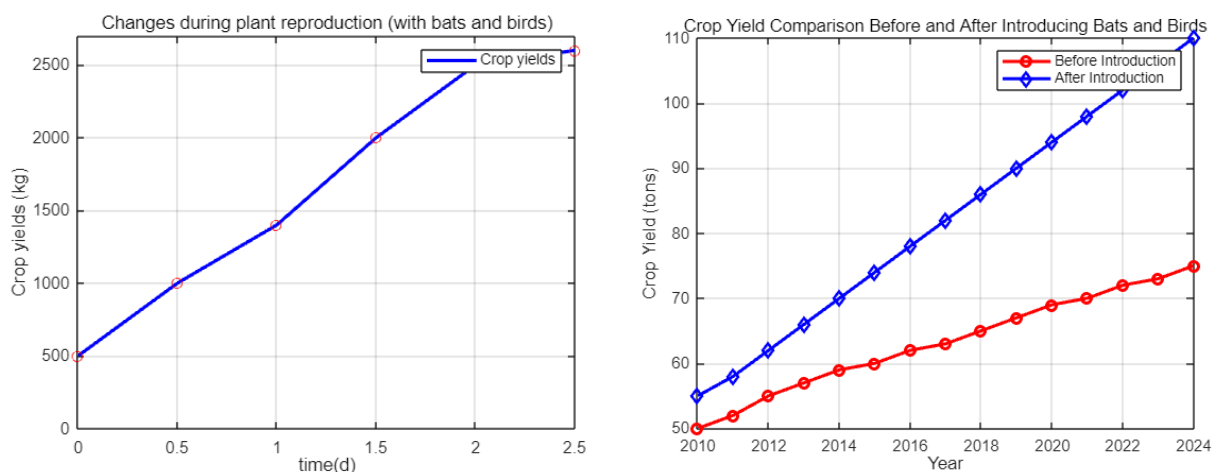


**Figure 7.** Crop health map

We can observe that the health status of crops is showing a continuous increase, which is in line with our literature [11] findings. This is due to the fact that bats and birds act as natural predators of pests and can effectively reduce their population. This predation can significantly reduce the damage caused by pests to crops, thus protecting the healthy state of crops. If bats and birds are present in sufficient numbers and their predation is efficient, they can quickly reduce pest populations and prevent them from reaching levels that pose a threat to crops. In healthy ecosystems, predator-prey interactions naturally regulate pest populations and maintain ecological balance, thereby protecting crops from excessive damage. Of course, ecosystems with high biodiversity are often more stable and resistant to pest outbreaks because multiple predators can work together to control pest populations.

### 3.3. Yield analysis of crops after the introduction of bats and birds

After the introduction of bats and birds, not only the health of the crops has improved, but also the yield has increased steadily.



**Figure 8.** Crop yield chart

As shown in figure 8, bats and birds are effective in reducing pest populations by acting as natural predators of pests. Reduced pest populations mean less damage to crops, which improves the growing environment and health of crops. As pest populations are kept under control, farmers may use fewer pesticides. This not only reduces the cost of agricultural production, but also reduces pollution of the environment and favors the natural growth of crops. At the same time, the introduction of bats and birds helps maintain the balance of the farmland ecosystem. A healthy ecosystem better supports crop growth and improves crop resistance and resilience.

The elevated health of crops means they are able to utilize photosynthesis more efficiently, which increases biomass and yields. And bat and bird droppings act as natural fertilizers, increasing soil fertility and providing essential nutrients for crop growth.

Not to be overlooked, healthy growing crops tend to be of better quality, which can further increase the market value of the crop. While the introduction of bats and birds may require an initial investment, in the long run, this method of bio-control can lead to sustained yield increases and ecological benefits. This method of biological control is a sustainable agricultural practice that can help improve the efficiency and sustainability of agricultural production.

#### 4. Conclusion

The paper shows that introducing bats, birds, and insects as natural pest predators significantly suppresses pest populations. These predators reduce pest reproduction and overall numbers, minimizing crop damage. Their presence keeps pest levels low, creating a healthier growing environment for crops. This biological control method also reduces reliance on chemical pesticides, lessening environmental impact and the risk of pests developing pesticide resistance.

For crops, the introduction of bats, birds and insects has had a positive impact. As a result of reduced pest populations, there is less damage to crops, which improves the quality of growth and yields. Healthy crops are able to photosynthesize more efficiently, increasing biomass and ultimately leading to a steady increase in yield. In addition, this increased biodiversity helps maintain the balance of the farmland ecosystem, improving soil fertility and the natural resistance of the crop, making it more resilient in the face of other environmental stresses as well. In the long run, this biological control strategy not only improves the sustainability of agricultural production, but also potentially enhances the quality and market competitiveness of crops.

In the future, we can reduce pest populations by introducing natural enemies such as bats; Improve soil health and crop health index by organic fertilizer and crop rotation. Increasing different crop types promotes plant reproduction and ecological diversity and stability, thus achieving harmony between man and nature.

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