The Efficacy of Sticky Trap for Optimal Control the Spread of Tungro Virus Adaptation with a Deterministic SEI Model Stability Analysis

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Abstract

Rice tungro disease (RTD) is caused by the outbreak of green leafhopper (GLH). This research aimed to (1) develop a mathematical model of RTD, (2) investigate the trap design that maximizes the capture efficiency of GLH, and (3) predict the disease incidence using a mathematical model. The study focused on three factors: (1) trap color, including white and yellow; (2) trap shape, including square, triangular, and circular; and (3) an SEI model for RTD. The study was conducted using KDML105. The research began with the development of the mathematical model for RTD, followed by model validation through the analysis of positivity and boundedness of the solution, disease-free equilibrium, epidemic equilibrium, basic reproduction number, and local stability analysis at the disease-free and epidemic equilibrium. The field experiments were conducted using traps ($\bar{X}$=415.45 square centimeter). A total of 18 experimental plots were established, and the traps were deployed for one week. Subsequently, the traps were collected, and the number of captured GLH was recorded. These data were used in rice tungro disease model of this research. The results showed that: (1) the local stability analysis indicated that all eigenvalues of the Jacobian matrix satisfied Re(λ) < 0, confirming that the proposed model is locally asymptotically stable and suitable for disease forecasting; (2) the yellow square trap exhibited the highest capture efficiency $\overline{x_C}$=31 individuals per day; and (3) the yellow square trap achieved the greatest reduction in RTD incidence, decreasing the infection rate by 81.35%.

keywords : Rice tungro disease, Green leafhopper, SEI Model

Introduction

Rice tungro disease is transmitted by the GLH. Suryaningrat et al. (2020) and Suandi et al. (2025) proposed mathematical models to describe the transmission dynamics of RTD. However, these models exhibit inconsistencies with established biological processes, limiting their ability to accurately represent disease transmission under field conditions.

The models which developed by Suandi et al. (2025) and Suryaningrat et al. (2020) classified both rice plants and green leafhopper into two epidemiological compartments: susceptible and infected. In this research, an additional compartment representing the latent exposed stage of rice plants is incorporated to account for the incubation period of the disease (Suranaree University of Technology, 2022). Furthermore, the green leafhopper population is subdivided into nymph and adult stages to better reflect the insect's life cycle and its influence on disease transmission. In addition, Suryaningrat et al. (2020) integrated their epidemiological model with an Integrated Pest Management (IPM) strategy and demonstrated its potential to suppress disease outbreaks. More recently, Yi et al. (2025) reported that green leafhoppers exhibit strong attraction to yellow light, a behavioral characteristic closely associated with host-seeking and plant infestation (Zhang et al., 2025). This finding is consistent with the experimental results of Shi et al. (2020), who demonstrated that green leafhoppers are highly responsive to yellow sticky traps. Moreover, Van de Kamp et al. (2025) showed that green leafhoppers are attracted to objects with distinct angular features, suggesting that such physical characteristics can stimulate landing behavior.

Therefore, this project aims to develop a biologically realistic mathematical model of RTD transmission while simultaneously evaluating the effectiveness of yellow traps as a vector control strategy for improving disease management in agricultural production systems.

Methodology

1) Model development

This study proposes a mathematical model for the transmission dynamics of Rice Tungro Disease incorporating insect traps which formulated as a system of ordinary differential equations :

$$\frac{dS_R}{dt}=\frac{S_R}{N_R}-\alpha S_R(I_{GN}+I_{GA})-\mu_R S_R \quad (1)$$

$$\frac{dE_R}{dt}=\alpha S_R(I_{GN}+I_{GA})-(\beta+\mu_R)E_R \quad (2)$$

$$\frac{dI_R}{dt}=\beta E_R-\mu_R I_R \quad (3)$$

$$\frac{dS_{GN}}{dt}=\Lambda(1-\frac{N_G}{L})N_G-PS_{GN}(E_R+I_R)-(\mu_1+\gamma+C)S_{GN} \quad (4)$$

$$\frac{dI_{GN}}{dt}=PS_{GN}(E_R+I_R)-(\mu_1+\gamma+C)I_{GN} \quad (5)$$

$$\frac{dS_{GA}}{dt}=\gamma S_{GN}+\gamma I_{GN}-PS_{GA}(E_R+I_R)-(\mu_2+C)S_{GA} \quad (6)$$

$$\frac{dI_{GA}}{dt}=PS_{GA}(E_R+I_R)-(\mu_2+C)I_{GA} \quad (7)$$

which constructed by the following assumptions:

1. RTD is exclusively induced by the synergistic interaction between RTBV + RTSV.
2. The population growth of green leafhopper follows a logistic growth model, bounded by a well-defined environmental carrying capacity (L).
3. The critical threshold for a GLH outbreak is strictly defined at a density of 2 vectors/hill.
4. Both infectious nymphs and infectious adults of green leafhopper possess the capacity to transmit the viruses to rice plants.
5. Once a rice plant becomes infected and exhibits symptomatic characteristics, it remains in the infectious/symptomatic state permanently and cannot revert to a susceptible or healthy status.
6. The rates of change governing the population dynamics are entirely deterministic, with no stochastic or random variables integrated into the system.
7. The GLH captured by the traps are removed from the system (C)
8. All parameters are positive.

2) Model validation

1. **Positivity and boundedness of the solutions**

Theorem 1; $S_R, E_R, I_R, S_{GN}, I_{GN}, S_{GA}, I_{GA} > 0$

It is the result of equations (1) to (7) when there are initial conditions according to equation (8) and set Ω is the biological boundary defined by

$$\Omega=\{S_R,E_R,I_R,S_{GN},I_{GN},S_{GA},I_{GA}\in\mathbb{R}^7_+, V_1 \le N_R \le K, V_2 \le N_G \le L\}$$

Where K and L are the limits of the rice and GLH

Method: Lyapunov

$$V=(V_1,V_2)=(S_R+E_R+I_R, S_{GN}+I_{GN}+S_{GA}+I_{GA})$$

The results show that;

$$0\le(V_1,V_2)\le(N_R,N_G)\le(K,L)$$

2. Disease-free equilibrium

Suppose;

$$E^* = (S_R^*, E_R^*, I_R^*, S_{GN}^*, I_{GN}^*, S_{GA}^*, I_{GA}^*)$$

The results show that;

$$E^* = (S_R^*, E_R^*, I_R^*, S_{GN}^*, I_{GN}^*, S_{GA}^*, I_{GA}^*) = (N_R, 0, 0, \frac{(\mu_2 + c)N_G}{\mu_2 + C + \gamma}, 0, \frac{\gamma S_{GN}^*}{\mu_2 + C}, 0)$$

3. Epidemic equilibrium

Suppose;

$$\bar{E} = (\bar{S}_R, \bar{E}_R, \bar{I}_R, \bar{S}_{GN}, \bar{I}_{GN}, \bar{S}_{GA}, \bar{I}_{GA})$$

The results show that:

$$\bar{S}_R = \frac{(\beta + \mu_R)\mu_R \bar{I}_R}{\alpha\beta(\bar{I}_{GN} + \bar{I}_{GA})}$$

$$\bar{E}_R = \frac{\mu_R}{\beta}\bar{I}_R$$

$$\bar{I}_R = \frac{\beta}{\beta + \mu_R}(N_R - \bar{S}_R)$$

$$\bar{S}_{GN} = \frac{\Lambda(1 - \frac{N_G}{L})N_G}{P(\bar{E}_R + \bar{I}_R) + (\mu_1 + \gamma + C)}$$

$$\bar{I}_{GN} = \frac{P(\bar{E}_R + \bar{I}_R)}{\mu_1 + \gamma + C}\bar{S}_{GN}$$

$$\bar{S}_{GA} = \frac{\gamma(\bar{S}_{GN} + \bar{I}_{GN})}{P(\bar{E}_R + \bar{I}_R) + (\mu_2 + C)}$$

$$\bar{I}_{GA} = \frac{P(\bar{E}_R + \bar{I}_R)}{\mu_2 + C}\bar{S}_{GA}$$

4. Basic reproduction number

$$R_0 = \sqrt{\frac{\alpha S_R^*}{\mu_R}\left(\frac{PS_{GN}^*}{\mu_1 + \gamma + C} + \frac{PS_{GA}^*}{\mu_2 + C}\right)}$$

5. Local stability of disease-free equilibria

Method: Routh-Hurwitz Stability Criterion

Theorem 2; If $R_0 < 1$, E^* have stability where there is no epidemic

The results show that;

$$\lambda_1 = -(\mu_R - \frac{1}{N_R})$$

$$\lambda_2 = -(\beta + \mu_R)$$

$$\lambda_3 = -\mu_R$$

$$\lambda_{4,5} = -(\mu_1 + \gamma + C)$$

$$\lambda_{6,7} = -(\mu_2 + C)$$

6. Local stability of epidemic equilibria

Method: Routh-Hurwitz Stability Criterion

Theorem 3; If $R_0 > 1$, $\bar{E}$ have stability where there is epidemic

The results show that;

$$\lambda_1 = -\alpha(\bar{I}_{GN} + \bar{I}_{GA}) - \mu_R + \frac{1}{N_R}$$

$$\lambda_2 = -(\beta + \mu_R)$$

$$\lambda_3 = -\mu_R$$

$$\lambda_4 = -P(\bar{E}_R + \bar{I}_R) - (\mu_1 + \gamma + C)$$

$$\lambda_5 = -(\mu_1 + \gamma + C)$$

$$\lambda_6 = -P(\bar{E}_R + \bar{I}_R) - (\mu_2 + C)$$

$$\lambda_7 = -(\mu_2 + C)$$

3) Parameter Configuration

Table 1. Configuration

Parameter	Description	Value	Reference
L	Maximum amount of GLH	1,008	This reseash
Λ	Birth rate of GLH	10	Suandi et al. (2025)
μ_R	The mortality rate of rice	0.003	Suandi et al. (2025)
μ_1	The mortality rate of nymph	0.3	Suandi et al. (2025)
μ_2	The mortality rate of adult	0.12	Suandi et al. (2025)
α	Infection rate of RTD virus	0.008	Suandi et al. (2025)
β	Transition rate from E_R to I_R	0.067	Jonson et al. (2020)

γ	Growth rate of GLH nymph	0.071	Suandi et al. (2025)
P	Feeding rate of GLH on rice	0.008	Suandi et al. (2025)
S_R	Susceptible rice	504	This reseash
E_R	Exposed rice	0	This reseash
I_R	Infected rice	0	This reseash
N_R	Total of rice	504	This reseash
C	GLH in the trap	-	This reseash

Note: C-Value is obtained by installing a trap

4) Trap Formation

Set the diameter of the circular to 23 centimeters (Krahner et al. (2025)), which will be considered for the design of square and triangular traps. The structure of the trap can be shown as shown in **figure 1.**

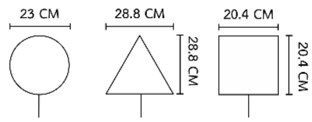

Figure 1. Trap Dimensions

The experiments were divided into two groups: (1) The control group is white trap (2) the experimental group is yellow trap. Then, the test kit code will be set as shown in **figure 2.**

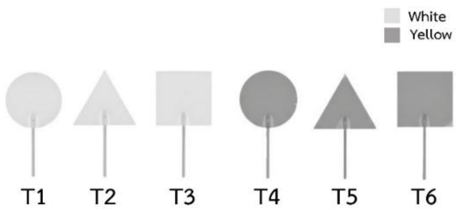

Figure 2. Experimental Trap ID

5) Trap Installation

Experiments conducted internally A total of 18 experimental plots were divided into 3 groups of repetition by randomly embroidering, as shown in **Figure 3.**

Figure 3. Trap Placement Layout

Result and Discussion

1) Rice Tungro Disease Model

Based on the validation of the theoretical model presented in page 3, it can be concluded that the development of the epidemiological model for this research project is capable of forecasting the number of infected rice plants.

2) Summary of Green Leafhopper Capture Quantities

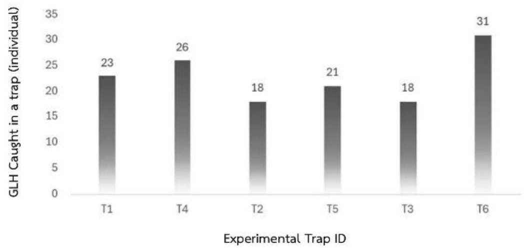

Figure 4. The amount of GLH in a trap

From **figure 4.** T4 can catch 13.04 percent more GLH than T1, while in the triangular trap, T5 can catch 16.67 percent more GLH than T2, and in the quad trap, T6 can catch 72.22 percent more GLH than T3

At the same time, it was found that in each trap, Yellow trap was able to trap more GLH than white trap. Therefore, the results of the experimental trap (Yellow) installation will be predicted in the model to illustrate the number of rice plants infected with rice tungro disease.

3) Determination of Optimal Policies for Controlling Rice Tungro Disease Infection

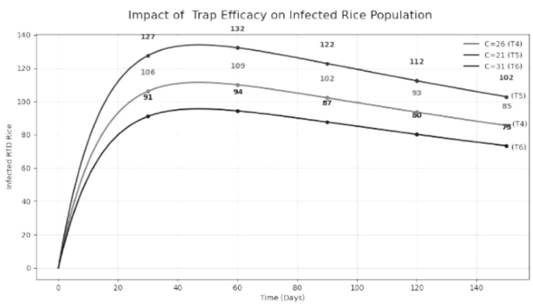

Figure 5. The forecast of infected RTD After the trap is installed

From **figure 5.** it is found that the highest number of infected RTD is the policy of installing the yellow triangle (T5) is followed by the yellow circular trap installation policy (T4) and the lowest infected rice is the policy of installing a yellow square trap (T6).

Conclusions

The model of this research project was further developed by the researchers, who refined the disease transmission mechanism by adding the exposed stage of rice. However, regarding the GLH vector population, this research classified the vector (GLH) into two life stages: nymph and adult. This classification ensures that the model comprehensively reflects the overall outbreak dynamics within the actual ecosystem. Moreover, the model validation confirm the validity of the disease outbreak model developed for this research project. From the experiments, it was found that the yellow square traps achieved the highest average capture rate of GLH at 31 vectors/day. Meanwhile, the yellow circular traps captured an average of 26 vectors/day, and the triangular traps captured the lowest average at 21 vectors/day. This variation reflects the efficiency of the yellow square traps in maximizing GLH capture, leading to the developed mathematical model for Rice Tungro Disease outbreaks was applied in conjunction with trap-installation policies. The model was utilized to forecast the rate of change in the infected rice population under different trap-installation policies to analyze which type of trap exhibits the highest efficiency in capturing green leafhoppers, thereby leading to a significant reduction in infected rice plants. Since the severity of GLH outbreaks directly correlates with the occurrence of Rice Tungro Disease in rice crops, it was found that the installation of yellow circular, triangular, and square traps could reduce the percentage of remaining infected rice plants to 21.63%, 26.19%, and 18.65%, respectively. Consequently, it can be concluded that implementing a policy with square yellow traps is the most effective in reducing the occurrence of infected RTD.

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