Modelling insect interactions in rice crops on the GAMA platform as a basis for educational VR games

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Abstract

Digital Technology and agriculture are crucial in helping farmers and students understand insect interactions in rice fields and how to apply treatments effectively. An agent-based framework is appropriate for studying the ordinary population of insects interacting on a rice crop, but it is still difficult to adapt for non-computer scientists in more specific application contexts (e.g., various treatment scenarios, insect reproduction, insect resistance, and crop yields), which require integrating particular behaviours for agents. In this paper, we present a built-in model integrated into the GAMA open-source modelling and simulation platform, allowing modellers to easily define the interaction of insects with a detailed presentation of rice field, insect population and treatment decision. In particular, it enables modelling the application of insecticide on paddy fields while understanding its effects. This agent-based model serves as a foundation for creating a comprehensive virtual reality (VR) game that presents scenarios involving pesticide application decisions, interactions between insects, and their impact on crop yields.

Keywords: *Agent-based Modelling, GAMA Platform, Rice Paddies, Insect Interaction, Pesticide Application, Simulation, VR Game.*

1 Introduction

The foundation of Cambodia's economy and culture is rice. Producing about 11.6 million tons of paddy by 2022, it is the primary staple food that sustains the livelihoods of about 3 million farmers and takes up about 75% of the country's agricultural land. [1]. In addition to being essential for food security and exports, rice in Cambodia is also extremely susceptible to outbreaks of pests and diseases, which jeopardise yields and farmer profits. While blast and bacterial leaf blight are among the main diseases, common pests include brown planthoppers, rice bugs, leaf folders, and stem borers. Chemical pesticides are frequently used by farmers for control, but excessive use has resulted in ecological imbalance, resistance, and health issues. In order to guarantee sustainable rice production, integrated pest management (IPM) techniques—such as crop rotation, ecological engineering, biological control, and the use of resistant varieties—are being promoted more and more. Therefore, improving productivity and increasing climate change resilience in Cambodia's rice industry requires more sustainable pest management.[2].

Pesticides are utilised globally to improve crop yields by minimising losses due to all kinds of insect pests (weeds, diseases, insects, etc). However, incorrect application of these chemicals can lead to pesticide resistance and a resurgence of pest populations, non-target organisms that are often beneficial [3]. Therefore, improving the knowledge of farmers on pesticides and their risks remains a condition for better pest management. A simulation on insect interaction in rice crop and application of pesticide is implemented to provide knowledge about the behaviour of insects and the negative and positive impact of pesticides. Insecticides have a negative impact on human health and the environment, which is a concern for the government and consumers. If farmers understand the role of beneficial insects, such as parasitoids and predators, they are likely to reduce pesticide applications. By leveraging these natural enemies to control pest populations, they can enhance rice yields while minimising chemical use.

This research studies a sample of rice field area, where a grid represents one part of the rice crop. The number of grids can change based on the size of the plot. This application is used to build calibrated scientific agent-based models validated in well-documented case studies, ensuring the realism for the development scenarios that participants explore and allowing them to collaborate virtually to explore solutions to sustainability issues. It is a bridge to develop the virtual universes for short modules for workshops with young students or as integral components of the curriculum for high school students.

The aim of this research is to provide a comprehensive understanding of pesticide application in rice fields, exploring both the methods used and the potential consequences. It examines the pesticides commonly employed in rice cultivation, their effectiveness in managing pests, and the practices farmers adopt to maximise their benefits. Additionally, it will address the environmental effects on non-target organisms, soil health, and water quality. It will also discuss the socio-economic implications for farmers and communities, highlighting the balance between pest control and sustainable agricultural practices. Through this exploration, this research seeks to inform farmers about responsible pesticide use and promote strategies that minimise negative outcomes while maintaining crop productivity. All of these are built into an agent-based model for simulation by using the GAMA platform, which is an open-source modelling and simulation platform that allows modellers to easily define the interaction of insects with a detailed presentation of the rice field, insect population and treatment decision.

Initially, formulas and research were developed by the researcher working on the subject and used as a board game using Microsoft Excel, and subsequently, they were transformed into an agent-based model utilising the Gama platform. This agent-based framework is appropriate for studying the ordinary population of insects interacting on rice crop, but still difficult to adapt for non-computer scientists, to a more specific application context, for example, various treatment scenarios, insect reproduction, insect resistance, and crop yields require integrating particular behaviours for agents.

2 Related Work

A dynamic model along with its discretised system to increase the agricultural crop production using some external efforts in the presence of insects and insecticides. This research model in this paper is based on local governments, farmers, and consumers, and a more detailed evolutionary game analysis model is constructed to provide a reference for subsequent policy optimisation. Mathlab is utilised to simulate the behaviour of stakeholders' participation in pesticide reduction and analyse the impact of changes in the behaviour of different subjects on the pesticide reduction evolutionary game system [4]. This paper reviews recent literature on how pesticides harmfully affect beneficial organisms, such as parasitoid wasps, with the goal of enhancing pest control strategies that integrate both chemical and biological methods for sustainable integrated pest management (IPM) [5].

This study develops a novel geospatial agent-based EAB-BioCon model for the interactions of the emerald ash borer (EAB) with the parasitoid Tetrastichus planipennisi (TP) wasp in order to evaluate the spread of forest infestations. The model is implemented on geospatial data from the City of Oakville, Canada and is composed of EAB Baseline model, representing EAB geospatial dynamics and the EAB-TP model that employs scenarios to measure EAB response to variations in TP-based biological control strategies [6]. Similarly, sugarcane production areas in Brazil have experienced a slower evolution in productivity, and one of the reasons for this is related to the increase in phytosanitary problems, such as the presence of the pests. Therefore, an agent-based model has been developed to simulate the pest population and its dispersal in a one-hectare sugarcane crop field in Pederneiras, São Paulo, Brazil, delimited with the aid of satellite imagery, considering two scenarios: the first without biological control and the second with biological control using the parasites Trichogramma galloi and Cotesia flavipes. This model was developed using the NetLogo 6.3.0 software [7].

3 Implementation of the model

The model has been implemented on the GAMA [1] platform (version 2025-06), dedicated to agent-based modelling (ABM) and simulation. ABM consists of actors, resources, dynamics and interactions (ARDI). The resource consists of rice paddies and rice crops. A rice field is defined as a 10×10 grid in our model, representing the whole configuration. Each cell contains three layers of rice, representing rice crops, which can be damaged or destroyed by pest populations. These pests can devastate the rice crops, leading to a loss in crop yield. The model includes two main actors: farmers and insects. The farmer is responsible for applying treatments, while insects are divided into three main groups: parasitoids, predators, and pests. Parasitoids and predators were introduced to control a rice insect pest. A few introductions of parasitoids from different species of pests related to the target insect have been successful; examples are not common, and none are known in rice [8]. Dynamic models are used to describe objects and their relationships as they change over time. In our model, there are three dynamics included: first, the consumption of pests by parasitoids and predators; second, the movement of insects, such as hunting and fleeing; and third, the farmer's decision on whether to spray or not. There are four interactions in this agent-based model. First, in pest-plant interactions, the model simulates how insects interact with rice plants, including the impact on plant health. Second, insect-insect interactions are actions in which a group of insects, such as parasitoids and predators, eat pests. Third, farmer-insect/plant interactions, farmers' actions, like applying pesticides or adjusting irrigation, can be incorporated as interactions affecting both insects and plants.

[1] https://gama-platform.org/

3.1 Representation of simulation data

Each rice grid consists of three layers, represented by three different colours, and it also has another colour that represents all the layers being lost, which is listed in Table 1. Insects have three groups; the correspondence is shown in Table 2:

Table 1. List of colours used to represent rice health

Layer	Colour	Meaning
3	rgb(0, 112, 48)	Healthy rice
2	rgb(198, 239, 206)	Slightly damage
1	rgb(255, 255, 0)	Heavy damage
0	rgb(88, 57, 39)	Loss all layers

Table 2. List of colours used to represent each group of insects

Type of insect	Colour	Meaning
Pest	red	Harmful insects
Parasitoid	black	Beneficial insects
predator	violet	Beneficial insects

3.2 Data collection

To validate the model and thus the ability of GAMA to simulate insects in rice paddies, we recorded 13 weeks of rice cycles to validate the result. This is important when parameters have been changed so that most of the values in each week will be modified. This data is crucial for analysing the impact of pesticides on insects, both non-target insects and target insects such as pests. Participants are aware of the importance of reducing pesticides in each cycle of rice and the final yield. Furthermore, data from batch simulation was also recorded to analyse the exploration of four parameters which affect the crop yield.

3.3 Description of the model and parameters used

In this simulation, the parameters have been divided into three different groups such as pesticide, insect, and rice paddy. The pesticide category is used to define user interaction. If it is true, they will interact with this simulation, deciding whether to spray or not; otherwise, it has several scenarios that participants can select the one they prefer, and it will simulate automatically. First, 'None' is an option that no treatment was applied. Second, 'All weeks' is an option that sprays every week except the first and last weeks; the first week marks the start of the rice crop, and spraying in the last week is prohibited to protect the health of the harvesters and consumers. Third, the 'Only 2nd Week' option involves spraying exclusively during the second week, while skipping the first and last weeks, continuing this pattern through week 11.

The insect category is used to define the number of parasitoids and predators. The initial value of the parasitoid will start with 25 as the default, and the initial value of the predator will be 7 as the default. This change will update the population of insects in the rice paddies for the initial simulation.

The first model was built based on a game formula, which we calculated using Microsoft Excel. This initial model serves as a foundation for developing a second, more complex agent-based model. A key aspect of this first implementation is ensuring that the results of the game align with those calculated in Excel. This approach paves the way for the next model, as the complexity of the computations requires a step-by-step process to simplify the calculations.

To calculate each week of this simulation, we first compute the independent variable, followed by the dependent variable that depends on it. Initially, we calculate the dynamic yield, which is first calculated and can be applied in the last computation. Next, according to the Figure 1, the calculation of predators is computed, and then we calculate parasitoids. These calculations increase the population according to the population the week before and the reproduction rate, which depends on whether they eat enough or not. Subsequently, pest and its related variables are calculated. After updating the insect population, the predation rate should also be calculated. The predation rate is the amount of total pests eaten by both predators and parasitoids divided by the total number of pests. It refers to the frequency with which an organism captures and consumes its prey in an ecosystem. Finally, the result is computed to get the remaining field case, potential yield, real yield, and max dynamic yield.

On the other hand, more dynamics have been implemented. It is updated following the first model, which only sticks to the game that is built in MS Excel. The most important parts are the insect's hunting, fleeing and eating, as well as the farmer's decision in many scenarios. Similarly, several parameters have been added for user interaction in the simulation, which you can see in the Table 3. Two types of insect groups, parasitoids and predators, have been implemented using algorithm 1.

Furthermore, four scenarios of this simulation are described in the algorithm 3. It features five functions **sequentialVariableCalculation**, **interactFromParticipant**, **sprayAllTheTime**, **sprayOnceWithinRiceCycle(week_num)**, and **doNotSpray**. The **sequentialVariableCalculation()** function calculates the each week of insect population, and the result of rice yield is mentioned in the Figure 1.

The **interactFromParticipant()** function allows the participant to interact with the simulation by deciding whether to spray or not. This still keeps the first and the last week of the rice cycle, which is our target mentioned above. The **sprayAllTheTime()** function works only *is_interacted* is false, and it will spray every week except for important weeks. The **sprayOnceWithinRiceCycle(week_num)** function runs automatically without interaction from the participant by spraying once within the rice cycle, starting from week 1 to 11. The **doNotSpray()** function indicates that no spray is applied throughout the entire rice cycle, relying on natural enemies such as predators and parasitoids to control the pest population.

4 Experimental results

The experiment was divided into two main categories derived from an 11 factorial combinations scenario. First, user interaction in

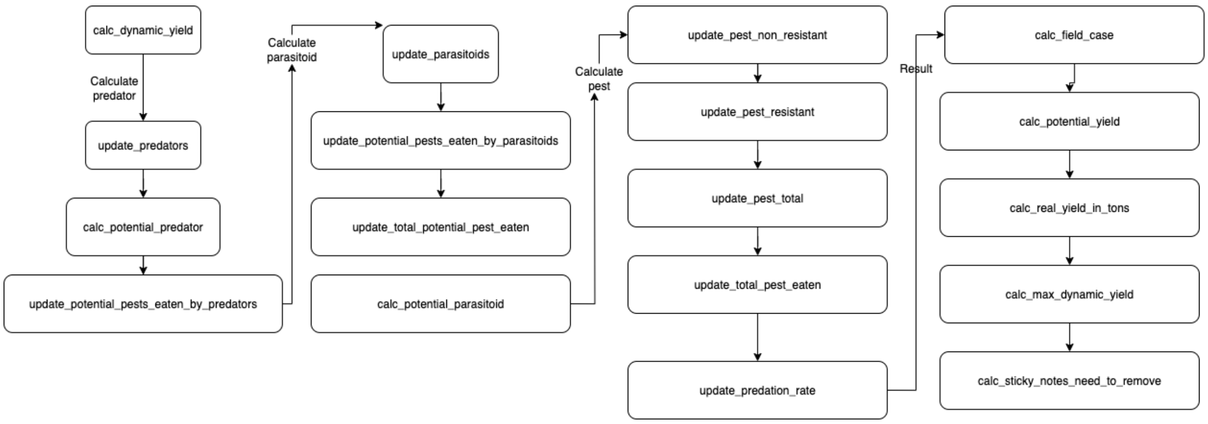


Figure 1. Step to calculate each week of rice paddies

Algorithm 1 Hunting

function HUNTING
  if $goal = nil$ **then**
    $lstPest \leftarrow Pest\ where(!dead(each)\ and\ each.shape\ distance\_to\ self.shape < perception\_radius\ )$
    if $length(lstPest) > 0$ **then**
      $agent\ a \leftarrow first(lstPest\ short\ (each.shape\ distance\_to\ self.shape))$
      if $a = nil$ **then**
        $a \leftarrow any(Pest\ where(!dead(each)))$
      else
        $speed \leftarrow 2.5\#km/\#day$
        $goal \leftarrow a.location$
      end if
    end if
  else if $self.location\ distance\_to\ goal < 0.5$ **then**
    $pestToDie \leftarrow Pests\ where\ (!dead(each)\ and\ each.location\ distance\_to\ goal < 0.5)$
    $remainToEat \leftarrow length(Pest\ where(!dead(each) - pests\_total)$
    if $remainToEat > 0$ **then**
      $pestToDie \leftarrow remainToEat\ among\ PestToDie$
      ask pestToDie do die
    end if
    $goal \leftarrow nil$
    $speed \leftarrow 1.6\#km/\#day$
  end if
end function

Algorithm 2 Fleeing

```
function FLEEING
    if length(Predators) where(each distance_to self < perception_radius) > 0 or length(Parasitoids) where(each distance_to self < perception_radius) > 0 then
        speed ← 2.0#km/#day
        is_chased ← true
        color ← #lime
        if goal = nil then
            agent a ← any(Pests !dead(each) and !Insect(each).is_chased)
            if a ≠ nil & !dead(a) then
                if flip(0.5) then
                    goal ← a.location
                else
                    goal ← any_location_in(cell.shape)
                end if
            else
                goal ← any_location_in(cell.shape)
            end if
        end if
    end if
    if goal ≠ nil & self.location distance_to goal < 0.5 then
        goal ← nil
    end if
    if length(Predators) where (each distance_to self ≤ perception_radius) = 0 and length(Parasitoids) where (each distance_to self ≤ perception_radius) = 0 then
        is_chased ← false
        color ← #red
        speed ← 1.6#km/#day
    end if
end function
```

Algorithm 3 Farmer decision function

```
function FARMER_DECISION
    do sequentialVariableCalculation()
    if is_interacted then
        do interactFromParticipant()
    else if ALL_WEEK then
        do sprayAllTheTime()
    else if ONCE_PER_CYCLE then
        do sprayOnceWithinRiceCycle(week_num)
    else if NONE then
        do doNotSpray()
    end if
end function
```

Table 3. List of parameters used in experiment

Parameter	Category	Value (default)	Note
rice_field_width	Rice Paddy	10	width of rice paddy
rice_field_height	Rice Paddy	10	height of rice paddy
number_of_parasitoid	Insect	25	This will affect and update both the number of parasitoid and potential parasitoid
number_of_predator	Insect	7	This will affect and update both the number of predator and potential predator
interactive	Pesticide	True	
spray_decision	Pesticide	None	Enable only interactive is false

Table 4. Apply pesticide once during the rice cycle (tons/ha)

Week	1	2	3	4	5	6	7	8	9	10	11
Result	0.0	4.02	3.99	3.93	3.83	3.73	3.65	3.65	3.65	3.65	3.65

the simulation. This depends on the participant's decision that they can input like the Figure 2. Second, without interaction from participants, we chose the important scenarios such as no treatment, all-week treatment, and only the second week. Moreover, the result will be shown in a graph and the rice grid user interface (UI). For various scenario experiments, a batch experiment has been implemented with four experiments into one UI for comparing the results, for example, spray only the 2nd week, only the 1st week, only the 3rd week and no spray.

4.1 Interaction from player

The interaction from the player, the result relies on the behaviour of the player who decides to spray or not for each week of rice cycles. Therefore, various scenarios will be presented in this section. For example, the participant decides to spray in the sixth week of the rice cycle, and the result is illustrated as a graph in Figure 3. It is seen that in the second week the pest population stood at 200 and dramatically decreased to just under 60. In the sixth week, pesticides have been applied while the population hit to bottom, indicating that natural enemies can control pest populations. Inversely, this treatment will affect the next week of the rice cycle, as natural enemy such as parasitoids and predator drop their population. It has been concluded that the treatment in the sixth week does not affect rice yield. As a result, rice yield is only just above 3.5 tons with a maximum of 5 tons per hectare.

This is not a good spray based on what was mentioned, so if we spray in the previous week, which is the fifth week what will happen?. According to Figure 4, it is seen that crop yield is just under 4, with the exact amount 3.83, which was recorded. This amount is slightly different from the amount chosen to spray on the sixth week. The reason is that even though we do not spray, it will not affect to the pest population and crop yield because natural enemies can control the pest population by eating them. Reducing pesticide use this week is crucial, as it has no impact on crop yield, lowers pesticide costs, and helps prevent health issues. Taking into account this scenario, the application of the pesticide in the fourth week was experimented.

Regarding the pest population, it consistently remained at 200 in the second week and rose to approximately 220 in week 4. Subsequently, after insecticide was applied, the pest population plummeted to 80 in week 5 and continued to decline through the end of the week. As a result, the crop yield reached 3.93 tons/ha. What happens if a pesticide is applied in the third week?

This scenario is similar to the above; after

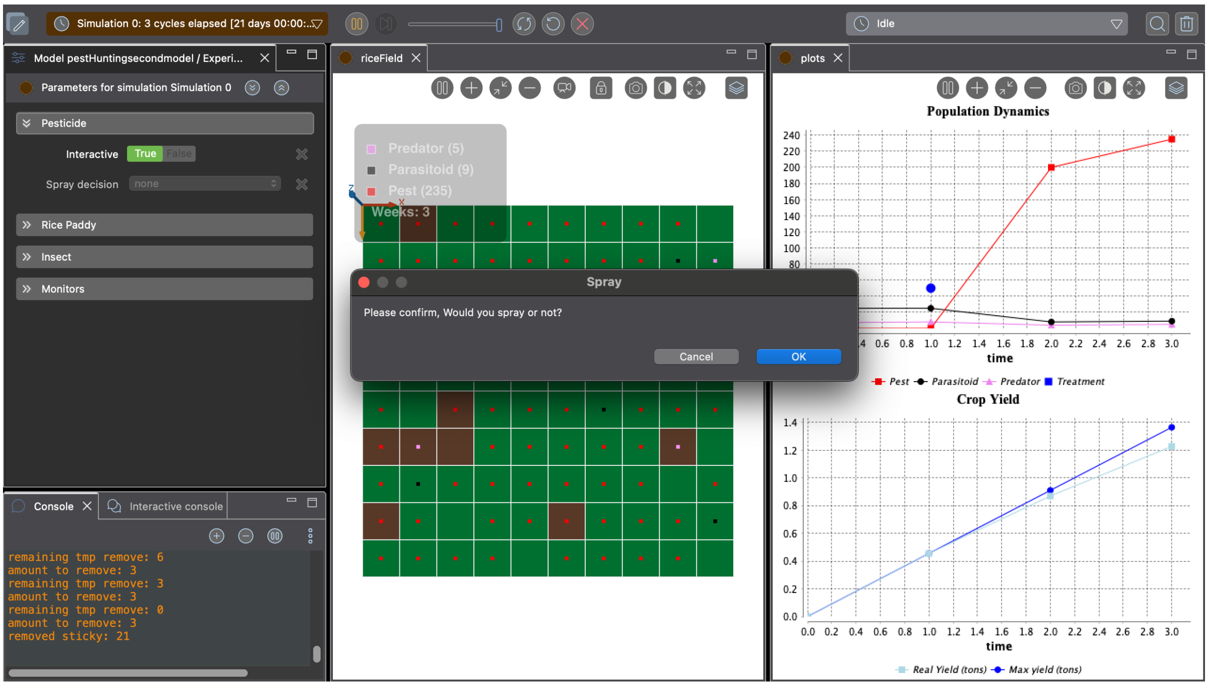
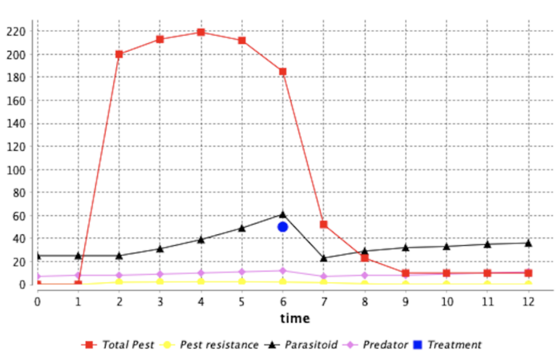
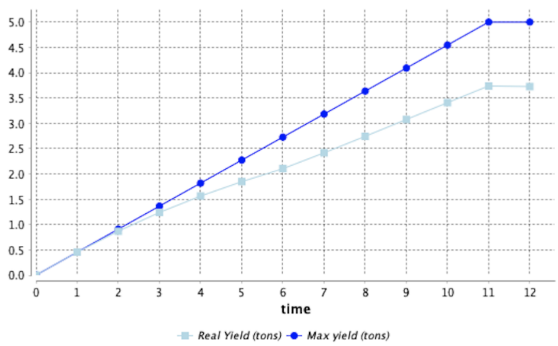


Figure 2. Pop-up dialogue to ask for spraying decision

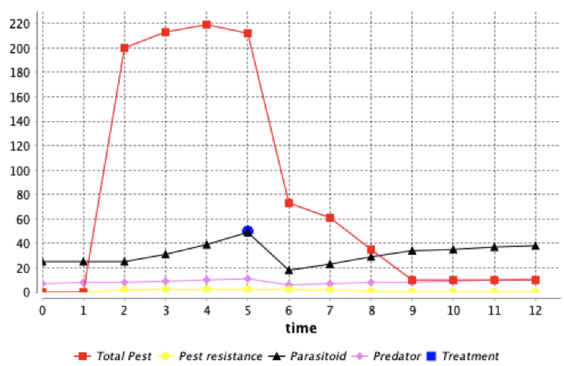


(a) Population dynamics

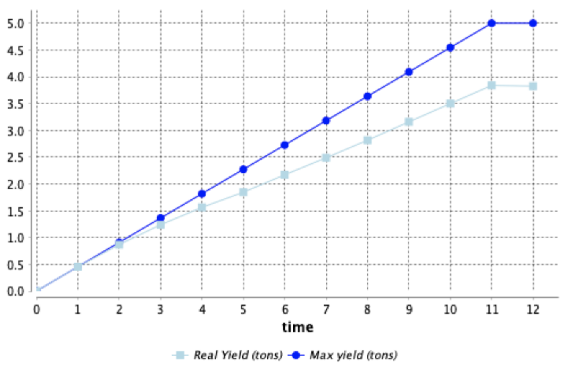


(b) Crop yield

Figure 3. Result spray on the sixth week

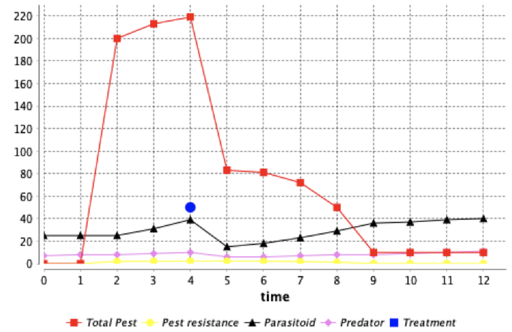


(a) Population dynamics

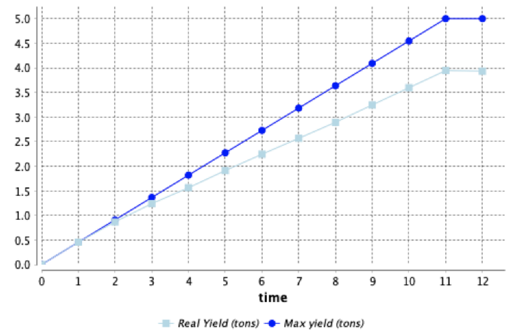


(b) Crop yield

Figure 4. Result spray on the fifth week

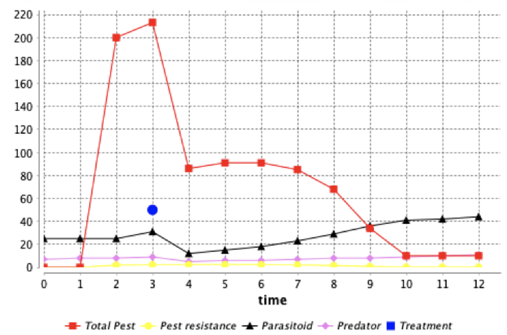


(a) Population dynamics

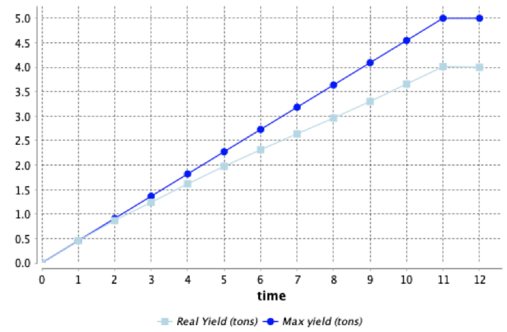


(b) Crop yield

Figure 5. Result spray on the fourth week

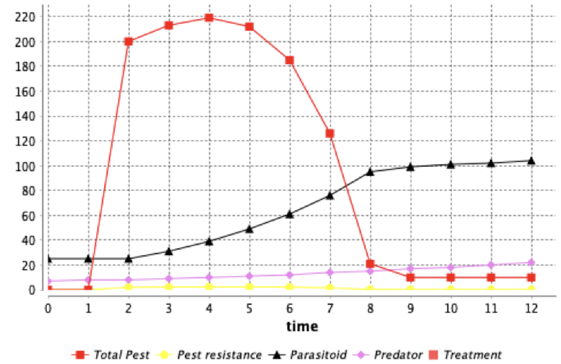


(a) Population dynamics

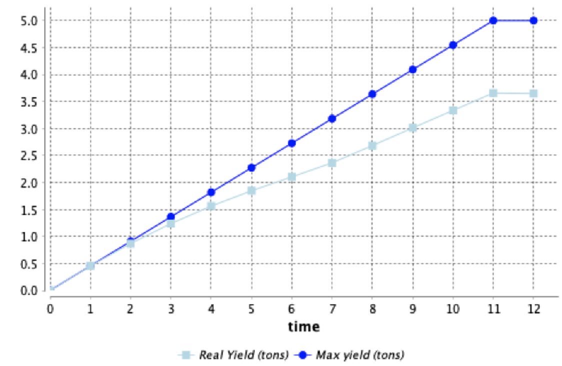


(b) Crop yield

Figure 6. Spray only third week



(a) Population dynamics



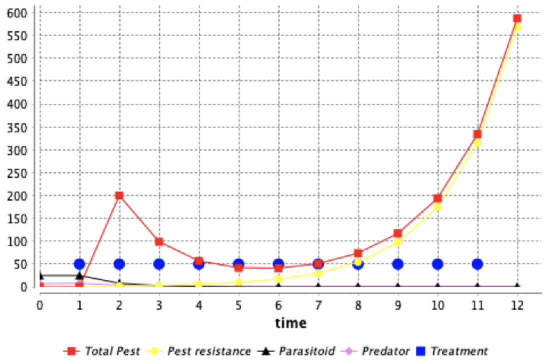
(b) Crop yield

Figure 7. No treatment

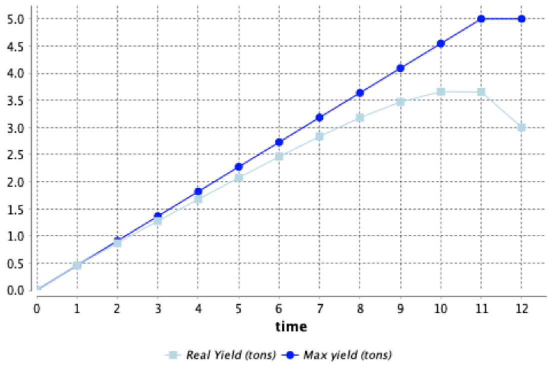
spraying at week 3, the pest population declines to the bottom from week 4 until the crop yield. As a result, rice yield obtained 3.99 tons/ha. In conclusion, early-season spraying (Week 3) significantly reduces pest population growth compared to mid- or late-season spraying. Delayed spraying interventions (Week 6 and beyond) result in greater yield losses due to established pest populations. For more results, refer to the section on spraying once per rice cycle.

4.2 No treatment scenario

No treatment for all weeks is a good scenario, because natural enemies can control the pest population. According to Figure 7, it is observed that as the number of natural enemies slightly increases, the pest population rises to just under 220 in week 4 before decreasing significantly. This indicates that traditional farming practices that utilise beneficial insects for pest control are effective. Consequently, the rice yield is 3.65 tonnes per hectare.



(a) Population dynamics



(b) Crop yield

Figure 8. Spray every week

4.3 Spray every week

Apply treatment every week; Figure 8; will be harmful to all insects, including good and bad insects. The pests develop resistance to pesticides and reproduce rapidly, damaging the crop, which results in a yield of only 3 tons per hectare. Not only is it unhelpful, but it is also harmful to human health.

4.4 Spray once per rice cycle

Applying pesticide once during the rice cycle is a notice scenario that we considered. As shown in Table 4, applying the spray in the second week yields the best result of 4.02 tons per hectare, as this coincides with the week pests enter the rice paddy. For more details about this scenario, refer to Interaction from Participants.

5 Conclusion

This model is designed to provide various scenarios for a VR game aimed at educating high school students and farmers. Initially, a game was defined in Microsoft Excel to lay the groundwork for developing an agent-based model. Subsequently, an agent-based model was constructed to expand on this idea and experiment with different scenarios. After different scenarios were implemented, we found that a farmer has their own rice field, so 4 different rice fields with different spray actions were implemented to compare the results. This will provide four different players to interact in game play for the next implementation in VR. The objective is to help farmers understand the underlying mechanisms and key messages, such as the fact that a high level of pesticides is not the optimal scenario. In the near future, the shapefile will include or be loaded into our agent-based model to simulate a real environment and get more accurate results.

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