Economics Benefit of Pest Risk Prediction Model: An Agent-Based Model Approach

Huixin Bian and Zhifeng Gao

bian.h@ufl.edu& zfgao@ufl.edu

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1.Abstract

1.1 The background of the tomato and watermelon industry

Watermelons and tomatoes are of great economic significance in Florida (Adkins S, et al 2011), they are highly profitable but costly crop (Vidavski, 2007). In 2017, the output of Florida' tomatoes and watermelons ranked first and second national wide respectively, with a production value of $262 million and $136 million (Freshfromflorida.com 2019). Rapid developed intensive production, which deploys significant resources for research and development, plays a key role in generating these economic benefits. However, intensive production method constantly faces the threat of viral diseases (Navas-Castillo, J, et al 2014), which means labor and a large quantity of chemical inputs are required to protect crops from the various pests and diseases (Vidavski, 2007).

1.2 The impact of whitefly on the tomato and watermelon production

Plant viral diseases are the major pathogen that attack tomatoes and watermelons, of which tomato yellow leaf curl virus (TYLCV), cucurbit leaf crumple virus (CuLCrV) and squash vein yellowing virus (SqVYV) are the most common ones (Camara, M et al., 2013). Tomato yellow leaf curl virus is one of the most destructive plant diseases in the world (Abhary et al., 2007). It spreads very fast and has covered more than 20 countries around the world, causing more damage and encroachment on new area every year (Abhary et al., 2007). The pandemic of devastating TYLCV caused by the dramatic outbreaks of the populations of the major vector- *Bemisia tabaci* (Figure 1.) has a severe impact on tomato production (Antignus 2007). Since the virus was discovered in Florida in 1997, it has caused serious economic damage because of TYLCV and the rise in production costs, the management of TYLCV towards tomatoes is difficult and expensive (Polston & Lapidot). Typically, symptoms in infected tomato plants (Figure 2.) develop 2 to 3 weeks post inoculation (Srinivasan et al., 2012), which is characterized by upward curling of leaves, mottling, often chlorotic leaf margins, leaves are reduced in size and plants are stunted (Polston; Cohen & Lapidot, 2007). If plants are infected at an early stage, they won't bear fruit and growth will be severely hindered (Jane Polston; Wakil et al., 2017; Ghimire 2001). Infected plants have a lower survival rate and produce fruits with reduced market value (Figure 3.). It is common to experience yield losses of up to 100% in affected fields (Rakib et al., 2011; Pan et al., 2012; Wu et al., 2012, Srinivasan et al. 2012). Whitefly is the main vector of these three viruses so that the yield loss of tomatoes and watermelons is directly related to the increase of whitefly populations. (Rakib et al., 2011; Adi et al., 2012). To maintain crop yields, a combination of insecticides to control the whitefly vector in field production has been the most effective approach for chemical practice, in protected production, resistant cultivars have been very effective in reducing losses to TYLCV (Polston & Lapidot). However, growers know neither the whitefly populations nor the potential disease incidence in the upcoming season. It is less likely to precise grasp resistant cultivars, type of production, combination of insecticides and the transplant date which can minimize the risk of high density of whitefly vectors, as they depend on growers' planting habits, planting experience and risk preference. Thus, it is considerably difficult to efficiently adjust the *TYLCV* and whitefly management strategies to reduce the risk and maintain the economic benefit.

Figure 1. Whitefly adult (Schuster et al., 2004)

Figure 2. A tomato plant was infected with tomato yellow leaf curl virus (left), next to a disease-resistant plant developed by UF/IFAS. Once infected with this disease, tomato plants cannot grow normally and cannot be marketed (Jane Polston). Photograph by: Ernest Hiebert

Figure 3. Tomato with symptoms of irregular ripening (Schuster et al., 2004).

1.3 The background of the Risk predicted model and the importance of the economics analysis of the model

To resist the economic losses caused by whitefly, biological scientists developed risk prediction models (RPM) that can predict the disease and insect pressure in the field such as, whitefly population, the virus incidence of crop and so on. The RPMs quantify how preseason production decisions (e.g., planting date and location, choice of cultivar, IPM practices, etc.), historical disease and insect pressure, and past weather events combined to impact disease risk. Use of the RPM is expected to lead to an overall improvement in management of whitefly-transmitted virus diseases. Usually the assessment of the variables in the RPM is done prior to planting, thus predicted disease pressure for the next season will be obtained. When pressure led by disease and insect are expected to be high, growers can strategize their vegetable production plan by altering their inputs (e.g., choice of variety, planting date, insecticide treatment) until a satisfactory level of risk is achieved.

This paper will conduct an economic analysis to quantify the final benefits of the candidate risk prediction models for growers in different scenarios. Two major scenarios will be simulated, a baseline scenario without the RPM predictions of disease risk and treatment scenarios where production factors are adjusted based on the RPMs prediction of risk. The economic losses suffered by growers of these two scenarios will be compared, the results of the comparison will be referred as future profitability of this tool. The optimal disease and insect management strategy that maximizes the profit will be identified and used for the final selection of RPMs.

1.4 Methodology

Agent-based model, an approach that simulates systems comprised of autonomous and interacting agents, will be applied in our analysis to evaluate the economic impact of the risk prediction model (Macal, C. & North, M. 2010).To test the profitability of risk prediction model, an agent-based model was developed to simulate the *TYLCV* infection of tomato plants and growers' whitefly management strategies when a farmland planted with tomato plants are suffering whitefly infestation (Figure 4.). This simulated system comprises four key elements: whitefly, tomato, grower and economic benefits, the relationship between them are shown as figure 5.

In the absence of any whitefly management, the whitefly follows its own internal cycle of move-reproduction-death. Assuming that the whiteflies have an a% chance of carrying the *TYLCV*, normal tomatoes are b% infected when they are transmitted by the virus-carrying whitefly, then the risk of tomato infection after exposure to whitefly in the simulation was ab‱. Once the tomato was infected, it will develop the symptoms of TYLCV after two to three weeks. There is a positive linear relationship between the number of days until first symptom expression and the percentage of expected -weight per tomato plant.

Tomatoes will lose yield over time while the symptoms of TYLCV appearing, which lead to the loss of final yield and economic benefits eventually. If the whitefly dead, the transmission of the virus was cut off then the yield and economic benefits would be maintained. Applying pesticide is one of the most efficient method to control whitefly, it can lead directly to the death of whitefly, thus indirectly protect the tomato yield from loss.

On the other hand, it also increases the cost to growers of whitefly management, so the effect of pesticides on the economic benefits of growers is two-sided.

In addition to pesticides, other ways to protect tomato from infection are decreasing the susceptibility of tomato b% and the whitefly density, grower will play a role in all three aspects.

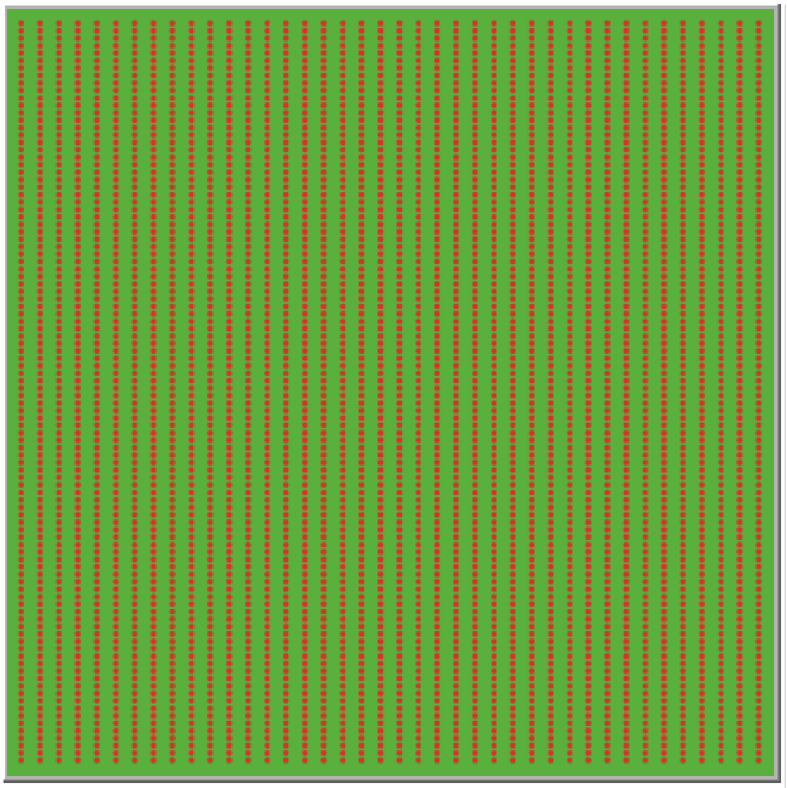


Figure 4. Simulated one-acre tomato field with 4000 tomato plants

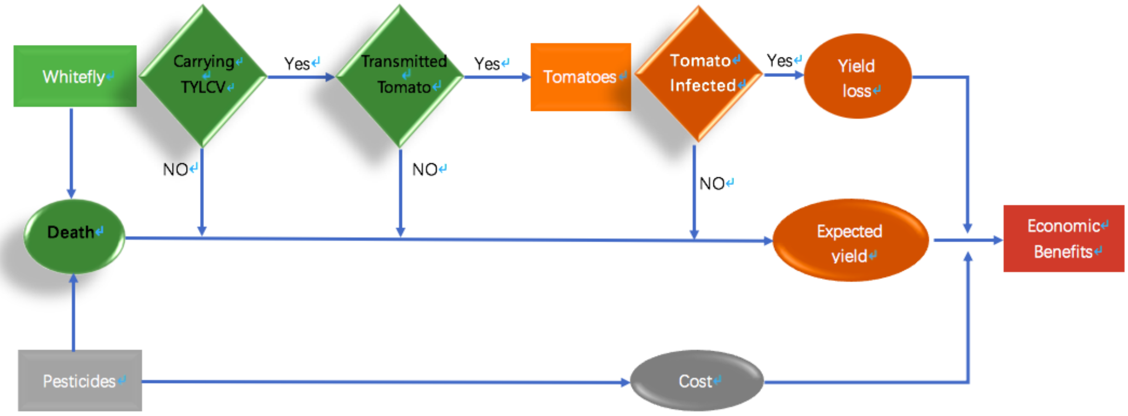


Figure 5. The diagram of agent-based model

1.4.1 Whitefly

Whitefly density depends on initial population n, reproduction rate $r\%$, hatchability h, fecundity m and longevity γ days in simulation. Assuming that there are n whiteflies which are assigned random age, the oviposition period is from day 15 to day 25, suppose the random ages do not exceed their oviposition period, then there would be $nr\%$ whiteflies (regarded as female),each of them laying m eggs per day between their age of 15 to age of 25, and then the first generation whiteflies will die at their age of γ. The 2nd generation whiteflies maximize density would be $10mnr\%$ and so on to the nth generation which will grow exponentially.

1.4.2 Tomato

At the beginning of simulation, each tomato agent is assigned a unit-expected-yield w_e referring to different tomato cultivars, which follows a normal distribution with the mean u and standard deviation sd. The summation of unit-expected-yield of total tomato agents is the total expected yield $y_e = \sum w_e$. Total expected yield indicates the yield can be harvested without whitefly infestation. When a tomato agent is infected with the *TYLCV*, there is a positive linear relationship between the number of days until first symptom expression and the percentage of unit- expected -yield $k\%, k\% = \alpha + \beta \cdot days$ (Wakil et al., 2017). The unit-yield is the actual yield of a single tomato agent in the harvesting with whitefly infestation, $w_a = w_e \cdot k\%$. The summation of unit-yield of total tomato agents is the total yield $y_a = \sum w_a$.

The production loss is the deviation between total expected yield and total yield, $y_l = y_e - y_a$.

1.4.3 Growers

Four whitefly control strategies in the simulation were considered representative of growers: resistance cultivars, planting date, green house and pesticides, which intend to decrease the susceptibility of tomato b% and the whitefly density n.

Strategy1: Select planting date.

Selection of planting time is important to control the incidence of TYLCV. If whitefly population is more at the beginning of the crop or within a month after transplanting, the incidence and transmission of disease are higher (Rashid et al.,2008).The risk-predict-model forecast relative risk of whitefly injury for the grower's location across all possible planting dates of the current year. The prediction tool will grade the risk and provide the appropriate planting time period for the growers. To simulate this situation, a mild initial whitefly density will be applied in the model, which would relieve pressure on whitefly in the early stages of transplanting of simulated farmland system. It is consistent with the thought of avoiding the peak of whitefly outbreaks in reality.

Strategy2: Greenhouse

In open field, plants are exposed to infection by TYLCV, which led to severe epidemics of the disease (Antignus 2007). The greenhouse isolates the host tomato from the whiteflies that attracted by it from other fields. In simulation, breeding is the sole source of whitefly population growth in greenhouse, whereas in open field, more randomly assigned age whiteflies n'were added to the population besides reproduction at each time step. In open field, the 2_{nd} generation whiteflies maximize density would be $km(n+100n')r$ h% and so on to the n_{th} generation.

Strategy3: Resistance cultivars

In the view of a tomato grower, resistance to TYLCV, in contrast with susceptibility, is expounded by the absence of, or mild, disease symptoms, and acceptable yield (Gorovits & Czosnek, 2007; Mugit, & Akanda, 2007). Disease resistance is represented by a lower susceptibility to infection. As mentioned above, normal tomatoes are $b\%$ infected when they are transmitted by the virus-carrying whitefly, then susceptibility rate of resistance cultivars will be reduced to $b'\% \, (b' < b)$. Therefore, the risk of resistance cultivars tomato infection after exposure to whitefly in the simulation was ab'‱ which is less than ab‱.

Strategy4: Insecticides

Applying insecticides can be effective in lessening economic losses of tomato caused by TYLCV (Polston & Lapidot, 2007). A variety of insecticides have been used to control whitefly populations including chlorinated hydrocarbons, organophosphates, neonicotinoids, pyridine-azomethines, and pyrethroids (Polston & Lapidot, 2007). In addition, other chemical approaches such as oil, insecticidal soap and insect growth regulators are also applied in tomato production (Polston & Lapidot, 2007). These chemical practices are simulated as pesticides with different efficiency (from 0 to 100%) which is the main whitefly control method in the simulated farmland system.

In the figure 6 below, there are three thresholds from low to high of whitefly density, corresponding to growers' decision under different situations. Growers' decisions are consisting of choosing different efficiency pesticides and doing nothing. For example:If hkmnr% < 50, apply pesticide A with efficiency 52%, whitefly population = hkmnr% × 48%. If 50<hkmnr% < 200, apply pesticide B with efficiency 66%, whitefly population = hkmnr% × 34%. If 200<hkmnr% < 500, apply pesticide C with efficiency 86%, whitefly population = hkmnr% × 14%. If hkmnr% > 500, apply pesticide D with efficiency 95%, whitefly population = hkmnr% × 5%.

Considering growers are reasonable, they would switch to a higher efficiency pesticide or keep the previous decision when the risk index exceeds a certain target threshold value. The grower decisions' choice relies on the growers' preferences of risky. The extreme risk loving would choose doing nothing whatever the whitefly risk is and the extreme risk averse would choose the most effective insecticide in any case.

In reality, the management of whitefly and TYLCV includes an adherence with the timetable for insecticidal applications (Schuster et al., 2004). Generally, it is suitable to apply the systemic nicotinoid insecticide imidacloprid (Admire Pro) to seedlings 7–10 days prior to transplanting (Schuster et al., 2004). Tomato seedlings are usually treated again at transplanting with a soil application of imidacloprid or in the planthouse a with flupyradifurone (Schuster et al., 2004). Different chemical classes of pesticides would be applied after about 3 weeks as the effects of the transplant treatment diminish (Schuster et al., 2004). The graph 1 below shows the growers' pesticides application timeline， the horizontal axis are from ten days prior transplanting to the end of a whole planting cycle (suppose planning cycle is 100 days), in the model, the pesticide using decisions discussed above will be repeated at each insecticide's application point-in-time. The timing of pesticides application is dynamic and varies with different growers' habit.

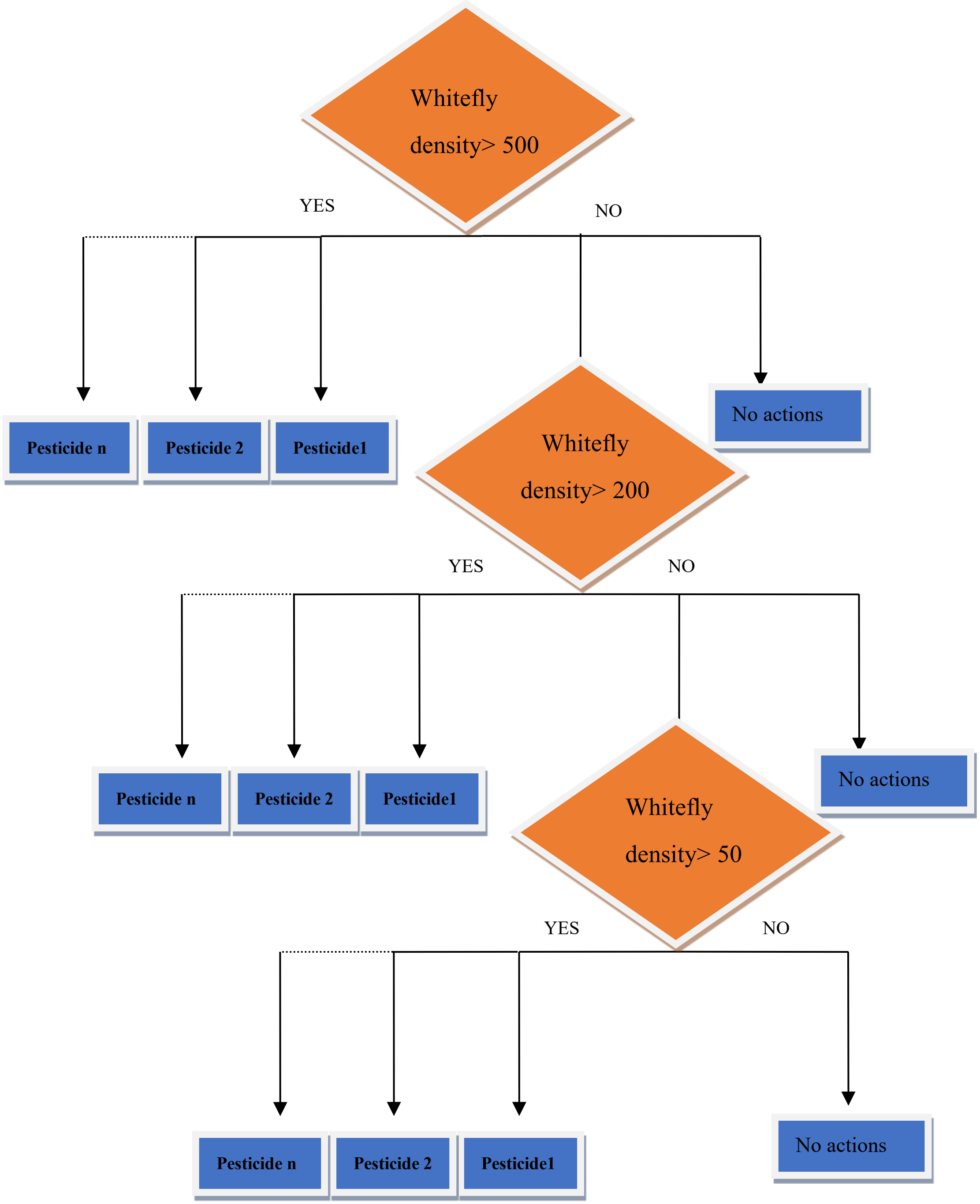
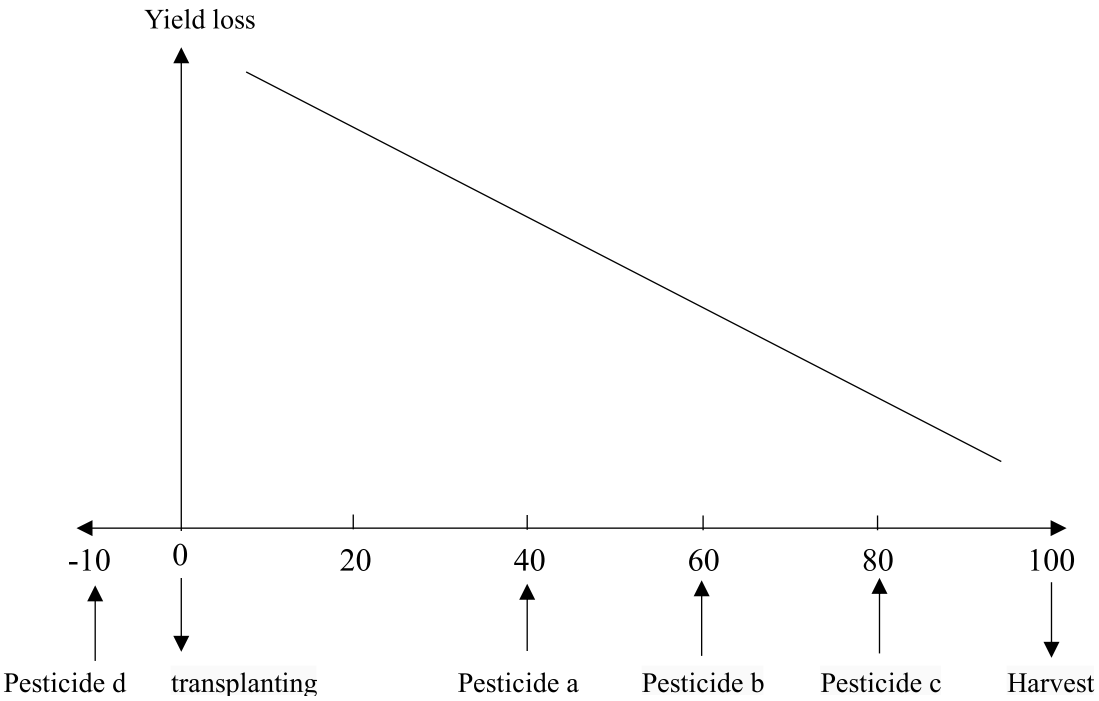


Figure 6 Diagram of pesticide using decision



Graph 1. Tomato infection and pesticides application timeline

1.44 Economic components

In economic analysis, economic components are derived from simulated different TYLCV and whitefly management strategies and the yield outcome. profit = revenue- total cost, $\pi = R - TC$. Revenue equals prices of tomato times total yield $R = p_t \times y_a$. Total cost includes the cost of the pesticide and the cost of the tomato seed or seedling $TC = C_P + C_S$. The cost of the pesticide is equal to the sum of every kind of pesticide cost which equals to unit price of the pesticide times the number of times it is used$C_P = \sum_{i=1}^{n} p_i \times \tau$. The cost of the tomato seed or seedling will vary depending on whether it is a resistance cultivar. Therefore, the performance of candidate RPMs can be conducted by comparing the profitability $\pi = p_t \times y_a - \sum_{i=1}^{n} p_i \times \tau - C_S$ under baseline and different treatment scenarios which will be discussed in the next section.

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