Leafhoppers and the Spread of Rice Dwarf Virus

Project Module Associated with
2nd Edition, Introduction to Computational Science:
***Modeling and Simulation* by**

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As background for this module, review the introduction to Module 7.14 Control Issues: The Operon.
Project 1 prerequisite: Module 4.3, "Modeling the Spread of SARS— Containing Emerging Disease"
Projects 2-6 prerequisite: Module 11.2, "Agents of Interaction: Steering a Dangerous Course"

Introduction

One of the criteria biologists use to determine if something is alive is that a living thing is made up of one or more cells. Each cell is enclosed by a membranous envelope called the **plasma membrane**. Inside the plasma membranes of organisms, other than bacteria and archaea, there are also internal compartments formed from membranes, suspended in the semiliquid **cytosol**, that provide proper environments and stages for a myriad of cellular functions. One of these compartments is the **nucleus**, which contains the genetic instructions for the cell. In bacteria and archaea, there are no nuclei, and the genetic instructions lie in the cytosol.

You are familiar with the multitude of human diseases, like polio, hepatitis, and colds, that are caused by **viruses**. A virus is essentially a packet of genetic information (DNA or RNA) surrounded by a protein coating. They lack a cellular structure and do not meet other criteria to be classified as living. In fact, viruses are considered parasites of cells, because to replicate they must find a suitable host cell. Once inside the host cell, the viral package can, using some of the host's resources, construct lots of new viruses, which can then invade other host cells. Virally infected cells are damaged and/or killed by the infection, leading to a variety of symptoms in the host.

It surprises some people that, like animals, plants also have their own set of viruses. Plant viruses can cause a variety of disease symptoms including stunting, yellowing, wilting, and necrosis (Hall 2002). Similar to animal viruses, plant viruses attack specific species or perhaps a closely related group of plant species. Rice, for example, is host to a number of virus types. Because rice is such an important food crop, especially in Asia, rice viruses are of special importance. Damage to the rice crop in Asia can have devastating consequences to human health and to the regional economy. Cabauatan et al. reported that during 2006-2007 farmers in southern Vietnam, lost more than 826,000 tons of rice due to viral damage. The farmers took an economic loss, and there was less rice locally available for food.

The viruses that infect rice are of various types, classified by the nucleic acid composition of the core particle. Rice viruses may contain single-stranded RNA, double-stranded RNA, or double-stranded DNA. Virtually all of these viruses are transferred to the host by leaf- or planthoppers. Insects that transfer disease from one plant to another are termed **vectors**. In some cases, the viruses can also be transmitted to the eggs in the female vector, thereby increasing greatly the number of vector organisms. These vectors are widely dispersed, posing a severe threat to rice crops throughout Asia (Sasaya et al. 2014; Hibino 1996; Kitsimoto 1971).

Defenses against Plant Viruses

What defenses are there against plant viruses? One of the most widely used defenses requires human intervention: chemical controls (pesticides). Pesticides are designed to reduce the numbers of or eliminate the vectors. Unfortunately, the success of initial pesticide treatments is short-lived, because vectors develop resistance. Furthermore, pesticides are expensive for farmers, and there are also negative environmental impacts of pesticide application. On the other hand, plants have their own inherent defenses against some of the viruses that attack them.

One of the mechanisms for viral protection inherent to plants is **RNA silencing**. RNA silencing has a number of functions in the plant cell, but one of them is to protect the cell from invading viruses. Most plant viruses are single-stranded RNA viruses (Wang et al 2012).

When the foreign nucleic acid is introduced to the host cell, it prompts a polymerase, using strands of foreign RNA as templates, to produce a complementary strands of double stranded RNA (dsRNA). This dsRNA is cleaved by an RNase enzyme in the nucleus or cytoplasm of the host cell into short strands (22-24 nucleotides) of RNA, called short interfering RNAs (siRNA). One of the strands from an siRNA combines with an enzyme complex, acting as a **guide**. This guide sequence helps this enzyme complex to bind to complementary foreign RNA sequences and cleave them, disrupting the virus's replication. It seems that the initial invasion prompts the host cell to protect itself against other further viral invasions.

Description of Data

The green rice leafhopper, *Nephotetti cincticeps* Uhler, and two other species of green leafhoppers, are vectors for the rice dwarf virus (RDV), which infects rice hills, or clumps of rice stalks. RDV is prevalent in southern Japan. In modeling the dynamics of this infestation, (Nakasuji et al. 1985) considered six categories of rice hill and leafhopper populations:

- healthy rice hills
- latent infected rice hills, where the virus is incubating
- infectious rice hills
- healthy vectors
- latent infected vectors, where the virus is incubating
- infectious vectors

Table 1 lists important parameters and their values, and Table 2 gives initial population numbers. The total number of rice hills does not change.

Parameter	**Value**
coefficient of transmission efficiency (efficiency of a healthy rice hill acquiring virus from an infectious vector)	0.15 (hills/(infectious vector))/day before day 70; 0 otherwise
mean latent period in rice plant	15.0 d
death rate of rice hills with infection as the cause	0
natural birth rate of vectors	0.1
birth rate of infectious vectors	0.07
death rate of vectors	0.033
carrying capacity per rice hill of vectors	50
rate of transovarial transmission (rate at which an infectious vector mother transmits virus to her offspring)	0.84
efficiency of a health vector acquiring virus from an infectious rice hill	$3.1 \cdot 10^{-8}$ (vectors / (infectious hill))/day
mean latent period of virus in vector	12.6 d
duration of a rice cropping season	150 d

Table 1 Parameters and their values (Nakasuji et al1985)

Population	**Initial Number**
healthy rice hills	10^5
latent infected rice hills	0
infectious rice hills	0
healthy vectors	0.95 per rice hill
latent infected vectors	0.00 per rice hill
infectious vectors	0.05 per rice hill

Table 2 Initial population numbers for model (Nakasuji et al1985)

Projects

1. **a.** Develop a system dynamics model for the population dynamics of the rice dwarf virus with vector of the green rice leafhopper.

b. Plot the number of each category of vector versus time.

c. Plot the percent of infectious vectors and the percent of infectious rice hills versus time.

d. Discuss the results.

2. **a.** Develop an agent-based model for the transmission of the rice dwarf virus with vector of the green rice leafhopper.
b. Plot the number of each category of vector versus time.
c. Plot the percent of infectious vectors and the percent of infectious rice hills versus time.
d. Discuss the results.

3. The small brown plant hopper, *Laodelphax striatellus* Fallen, is a vector for the rice stripe virus (RSV). Unlike the rice dwarf virus, the RSV has little effect on the vector's physiology, so that the birth rates for infectious and healthy vectors are the same (Nakasuji et al1985). Repeat Project 2 for this virus-vector combination.

4. Repeat Project 2 for the virus-vector combination in Project 3.

5. The small brown plant hopper, *Laodelphax striatellus*, is a vector for the black streaked dwarf virus (BSDV). Unlike the rice dwarf virus, an infectious vector mother does not transmit the virus to her offspring (i.e., the rate of transovarial transmission is 0), and the birth rates for infectious and healthy vectors are the same (Nakasuji et al1985). Repeat Project 2 for this virus-vector combination.

6. Repeat Project 2 for the virus-vector combination in Project 5.

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