User Manual for Colorado State University Orchard Disease Tool©

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1. Introduction

1.1 Overview

Welcome to CSU's Orchard Disease Tool! This tool was developed to help peach producers understand the economic viability of treating Cytospora canker (CC), a yield limiting disease responsible for $4-$6 million in damages in Colorado alone according to a study by Larson in 2020). The tool provides users with two different ways to assess the value of different management decisions. One of these allows for detailed analysis. The other provides less flexibility but is simpler to use and includes risk analysis. Due to the complexity of the information analyzed in this model, it is recommended that users start with sections 3 and 4 of this manual, which explain navigation and results, with examples.

Finally, this tool is generic enough that it can characterize any orchard disease by revising the characteristics that we describe in section 6. The code is publicly available at https://github.com/brookefitzgerald/cytospora. We provide license to anyone to use the code for the purpose of developing other tools through this statement, but request that we be given acknowledgement and ask that you notify us about your intentions.

1.2 Purpose of the Manual

The purpose of this manual is to explain how the tool works, provide guidance about using the tool in practice, and to answer common questions.

1.3 Target Audience

Our target audience is producers, academics, and other professionals who want to know how different treatment levels of Cytospora canker and other diseases with similar features impact yield and economic profitability.

1.4 Key Features

The tool has three main features: the simulation explorer, the risk explorer, and this user guide.

The simulation explorer simulates a disease, Cytospora Canker (CC), spreading through an orchard over time and visualizes the results through tables and graphs. Almost every part of the simulation is customizable. This allows the user to explore how farm, disease, and treatment characteristics impact outcomes like returns to treatment, orchard net present value, and yield loss.

The risk explorer module takes in less user input, and relies on more expert judgements, but computes results based on hundreds of simulations, where each simulation accounts for a complex probability scheme representing how the disease spreads. Running the simulation multiple times allows users to consider risk as well as returns.

2. Getting Started

To use the tool, open your web browser of choice and go to http://OrchardDiseaseTool.colostate.edu. The Figure below shows the initial interface that you see when you open the browser. When you click the large green button labeled “Go to app”, you are taken to the risk explorer. You can change to the simulation explorer, or the user guide by clicking the relevant tab on the top of the next screen. (Note: the home site is located at http://bfit.shinyapps.io/cytospora).

2.1 Supported Browsers

This tool supports all browsers, though it was developed using Chrome and will look best on Chrome. It is possible to use the tool on mobile devices, though some functionality (relating to hovering or clicking and dragging) will be lost. It is not recommended.

3. Navigating the Simulation Explorer

The purpose of the Simulation Explorer is to examine the impact of CC management strategies such as pesticide or pruning treatments on yields, disease and economic returns in detail. Basic user information is provided in this first section.

There is a lot of information in this program, so when you click on Simulation Explorer, it takes a short time for the right side of the screen, with results, to appear (Figure 1).

3.1 Program Dashboard

The Simulation Explorer is controlled by a dashboard that provides:

1. a place for users to set important parameters, such as production costs, prices, and how the disease spreads, and three types of output,
2. a map of disease spread, and
3. graphical and tabular results for no treatment and two treatment types set up by the user.

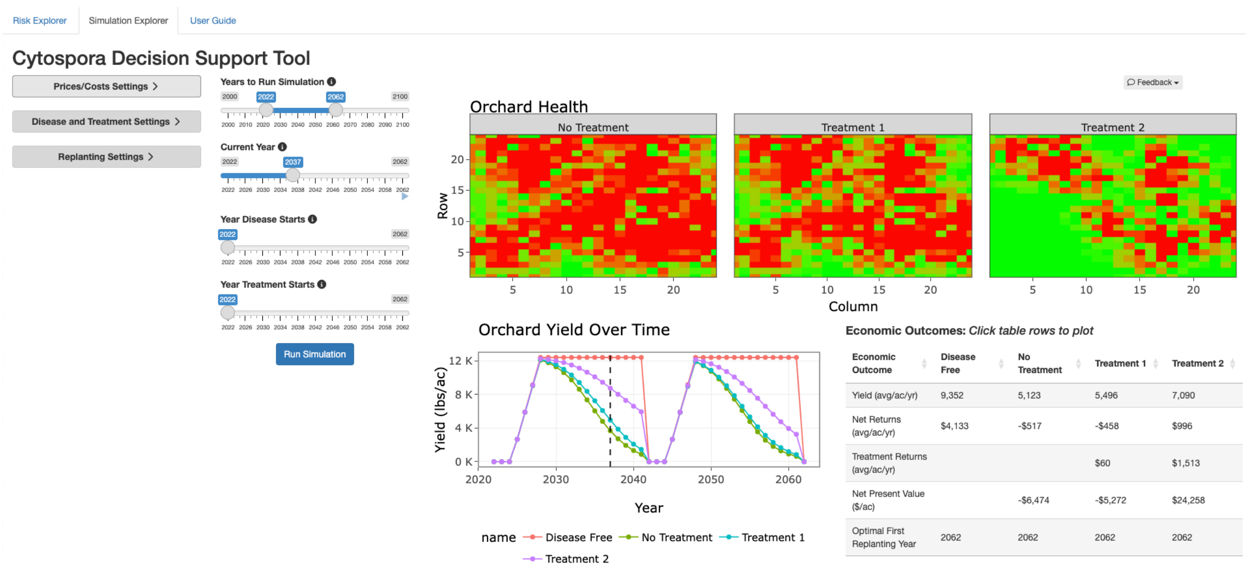


Figure 1: simulation explorer Dashboard

3.2 Program Inputs

The program contains defaults for all parameters, but users are encouraged to provide their own values. Basic production information is provided by clicking one of the three grey buttons on the left.

Prices/Costs Settings >

- Enter annual production costs per acre (after establishment). There is a blue help button with a gear emblem that can be used to help you develop your budget – default $5885
- Enter your average mature tree yield (maximum yield) per acre, with average weather and no diseases or other problems. We make basic assumptions that start yields at zero, then let them climb to the maximum yield in about 5 years. There is a blue icon with a price graphic that lets you draw a line to draw how yields track over the life of the orchard instead of relying on our defaults if you like. – default maximum yield 13,000 lbs
- Enter your net peach price in $/lb (including all handling) – default $1.1
- Enter an inflation rate for prices (since the simulation runs for several decades) – default 0

- Enter an inflation rate for costs (since the simulation runs for several decades) – default 0

Disease and Treatment Settings >

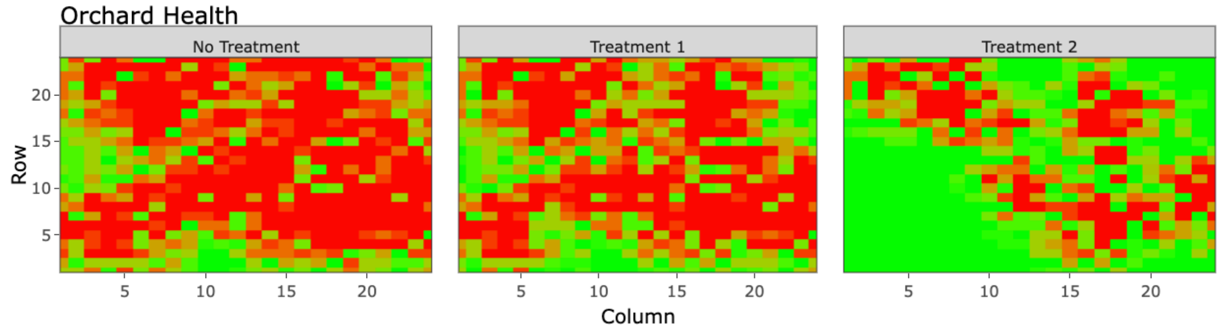
- Enter the number of trees first infected (based on 576 tree/ac density) – default 10
- Indicate how much of the disease in branches is removed through pruning. For a tree with only branch cankers, effective pruning can remove all disease from the tree. Trunk cankers can be treated but not pruned – default = 100%
- Enter how much that treatment 1 (defined by the user) reduces the spread rate. For each treatment, think of some activity like chemical sprays, paints, or a combination of treatments, then indicate how much it will slow the spread of disease here. For example, spraying a particular chemical might slow the spread of the disease by 40% – default 10
- Enter the cost of treatment 1 – default $350
- Enter how much a second treatment reduces the disease spread rate – default 20
- Enter the cost of that second treatment – default $650

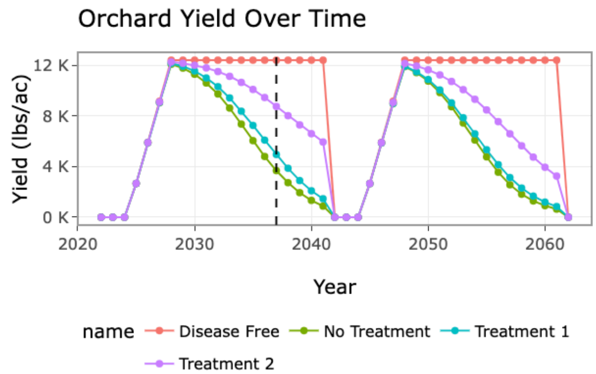
Replanting Settings >

- Indicate what happens to individual trees that die – default -replant orchard every planned replanting cycle number of years (other options include remove dead trees, replant dead trees
- Set your planned orcherd replanting schedule – default every 20 years
- Enter the cost of clearing and replanting ($/acre) – default $5,500

Once production information is supplied, enter the requested information about timing in the slider bars. The first slider indicates the years to run the simulation. The default is set from 2022 to 2062, to account for growing two, twenty-year orchards. The next slider indicates the current year. Try experimenting with it and watch how the graphs and tables change. The last two sliders indicate when the disease started and when treatment started.

3.3 Program Results





Economic Outcomes: *Click table rows to plot*

Economic Outcome	Disease Free	No Treatment	Treatment 1	Treatment 2
Yield (avg/ac/yr)	9,352	5,123	5,496	7,090
Net Returns (avg/ac/yr)	$4,133	-$517	-$458	$996
Treatment Returns (avg/ac/yr)			$60	$1,513
Net Present Value ($/ac)		-$6,474	-$5,272	$24,258
Optimal First Replanting Year	2062	2062	2062	2062

The Simulation Explorer has many powerful features to help users investigate the impact of treatments on the economic health. It is divided into three sections. Three green and red boxes are depicted under the header “Orchard Health.” Think of each box as rows and columns of trees. Each box depicts the number of uninfected trees in green and the number of infected trees in red for the “no treatment” scenario and for the two treatments set up by the user. The graphic is dynamic, showing the growth of the infections as it simulates over the 40-year simulation, and can show the static level of infection for a given year by using the slider bar for the current year. The graphics also depict the tree yield of any section by mousing over the graphic (an image with information will appear).

The second section is a line graph depicting the path of the no-disease, no-treatment, treatment 1 and treatment two scenarios. This graph is linked to both other parts of the output. For example, if you mouse over the orchard health graph, the lines change to depict the yield path of the individual tree that you are hovering over. It also changes if you click on any row in the table. For example, the graphs show the yield paths by default, but will show the net returns if you click on that row in the table.

The third part of the results is a table that shows the average yield per acre, net returns, and treatment returns for the disease free, no-treatment, treatment 1 and treatment two scenarios. It also shows the net present value for no-treatment, treatment 1 and treatment 2, and optimal planting date for the second orchard.

3.4 Using Simulation Explorer, with example

The simulation explorer provides the opportunity look at how many different types of management decisions effect CC and ultimately orchard returns. The primary question that the program is set up to address is to compare the value of treatments compared to no treatment. The program automatically estimates results for a scenario with no disease (Disease Free) and one where disease is introduced and not managed (No Treatment). It also makes estimates for up to two treatments where you define the parameters. Enter the cost of a treatment and its efficacy in the form of how much it slows the spread of the disease. A 10% efficacy for example would mean that this treatment reduced the normal amount that disease might spread in a year by 10%. (e.g. from 20% to 18%).

We use the model with default values as an example.

- Review the input entered by clicking on the grey boxes on the left or using the slider bars.
- Explore the results thoroughly. Examine how yields, net returns, treatment returns and net present value change over time.
- Change the sliders and see how results change.
- There is a black dashed vertical line in the graph that shows the current year. You can hover your mouse over the graph to see exact numbers. Note that in our example, where all values are set to the default, and the current year is set to 2037, the graph shows that disease free yields are higher than any others, followed by the purple line, which is treatment 2, and then treatment 1 and no treatment. In 2037, the disease free yield is 13,000 lbs/ac, the yield for treatment 2 is 8,761 lbs/ac, and the yield for treatment 1 is 4,961 lbs/ac (confirm by hovering mouse over 2037 in the graph).
- Click on the net returns row in the table. The average disease free returns are $4,133 per acre and fall to -517 per acre with no treatment. Using treatment 1 would not be enough to justify its cost, but using treatment 2 increases returns by about $1,500 per acre (going from -517 to 996), and turns a loss into a profit.
- Try clicking on the treatment returns row in the table. You will see again that treatment 2 increases returns by $1,510 per acre per year. You can see in the graph that these gains vary over the life of the orchard, with most of the gains occurring at the end of the rotation cycle.
- Finally, click on the row for net present value. What you see is that if you were to apply no treatment, you would lose over $6000 per acre over the life of two orchards, but that value increases to $24,258 with treatment 2. The graph calculates the net present value starting from each year on the x-axis to the end of orchard’s lifetime. In the first year on the graph (2022), the values are the same as the table. When you hover over the black dashed line at year 2037, you see that after the first 15 years of investment and profit, the net present value from 2037 to year 2062 is still positive with treatment 2 but is very negative with treatment 1 or no treatment.

You can also review the row for optimal planting. For this example, the optimal date is the same as the 20 years that we input in the default. However, this function can result in a shorter time frame if disease is particularly aggressive.

4 Navigating Risk Explorer

The purpose of the risk explorer is to examine the impact of CC management strategies under risk and uncertainty. The user has less control over model assumptions, but gets a more holistic view of what to expect when accounting for uncertainty in several assumptions (such as the number of initially infected trees, efficacy rate of treatments, and the highest possible yield).

4.1 Program Dashboard

The dashboard for this module has three questions:

1. How much should I pay for treatment?
   Compare the net present value of different treatments based on their cost per acre and efficacy.
2. When should I replant?
   Compare the impact on net present value when cankers are present and an orchard is replanted earlier than the 20 years planned.
3. How much do I lose if I don't prune branch cankers?
   Compare the impact on net present value when you miss some of the cankers during annual pruning. If you are interested in the impact of missing treating some of the cankers, try comparing treatments with lower efficacy in the first question.

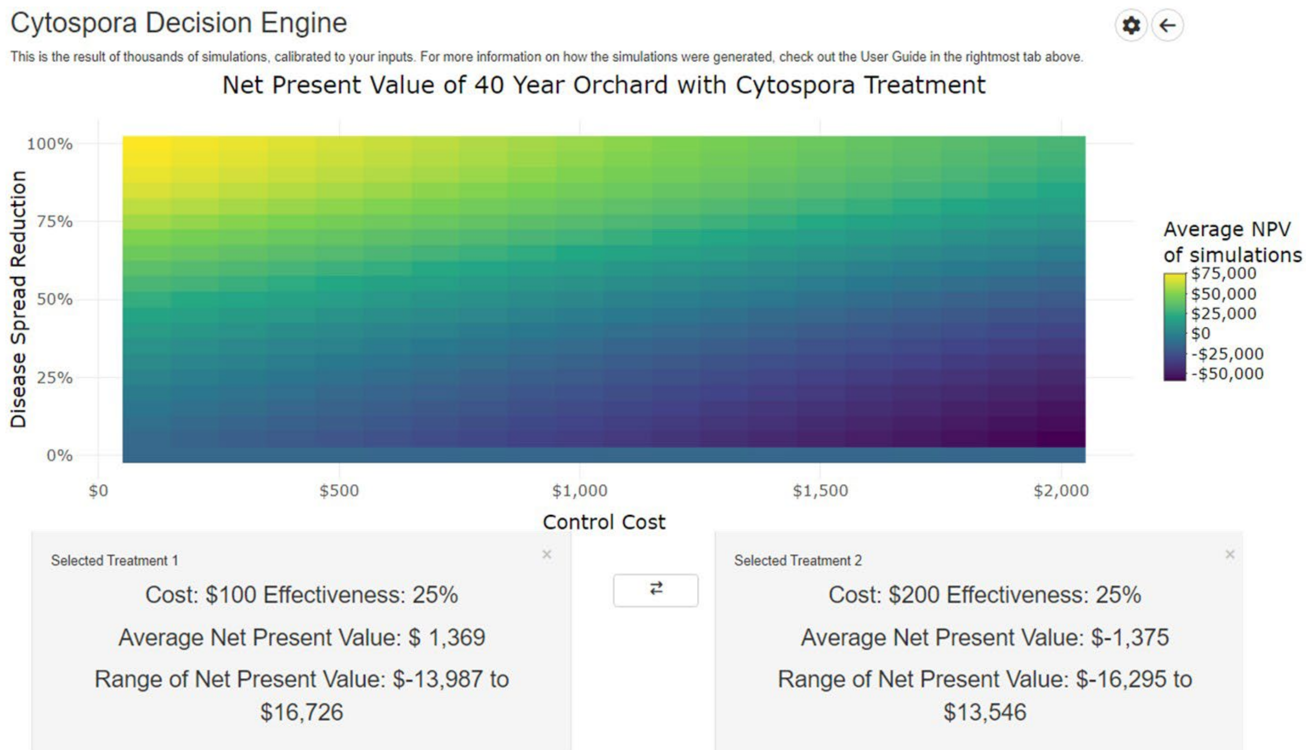
Simply click what you want to know.

4.2 Program Inputs

You have fewer options for inputs in Risk Explorer. Enter the maximum net revenue multiplying your top yield when trees mature by the price you expect to receive, the annual cost to manage an orchard when trees are mature, the cost to replant an orchard and the typical life of that orchard. For the default, we entered were $14,256 (13,000 x 1.1), $5,800, $5,500 and 20 years, respectively.

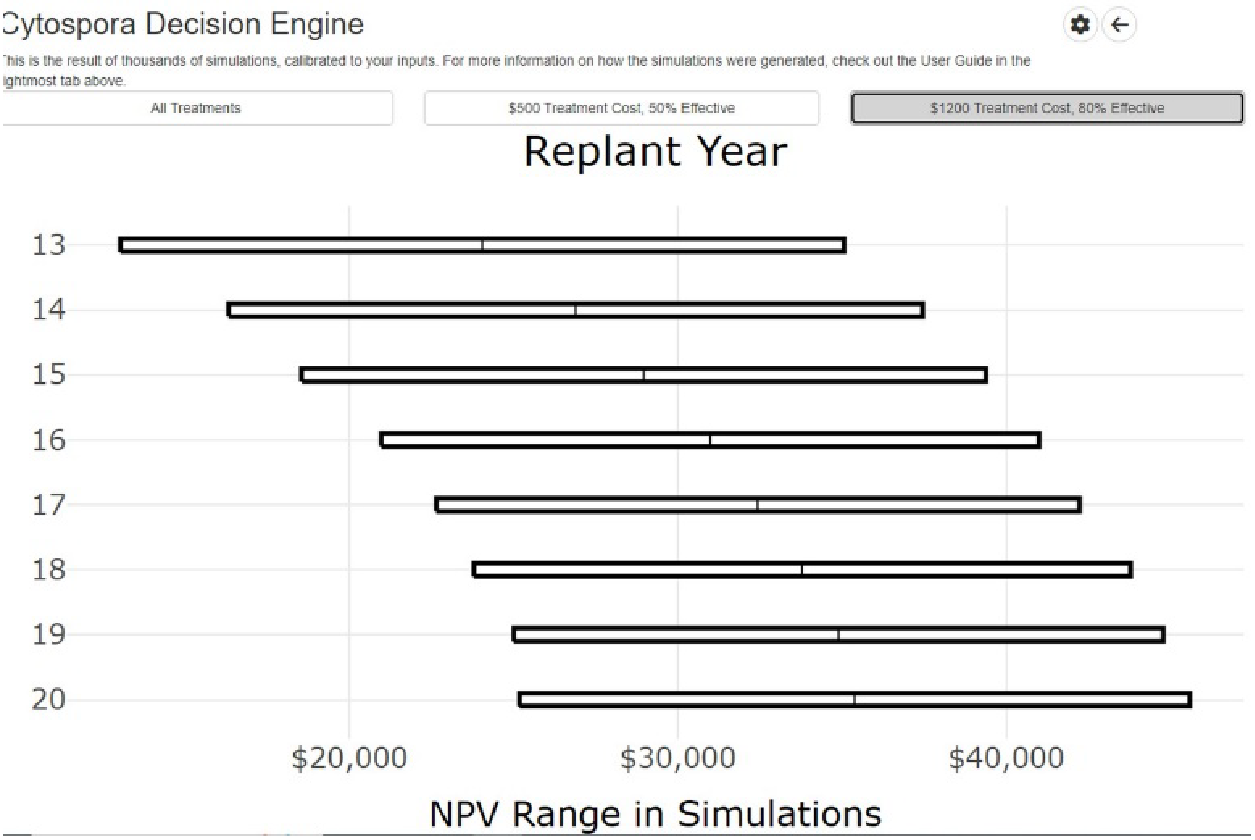
4.3. Program Results

Question 1: How much should I pay for treatment?



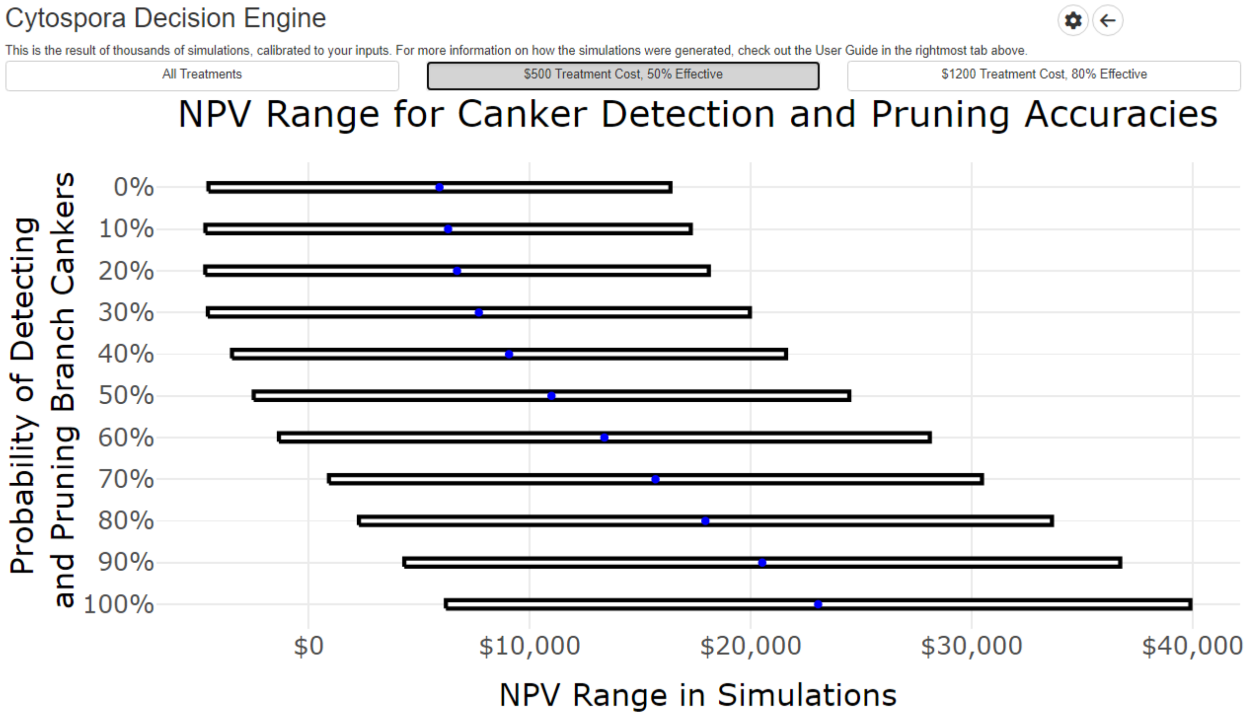
The first graphic in Risk Explorer is set up to determine if up to two treatments are profitable. The risk simulation program is run multiple times with much of the information preprogrammed in with probabilities. The user can still provide some information such as the maximum disease-free yield, price of the produce, and production costs, but other information about the initial number of infected trees and replanting strategy are preprogrammed in so that we can use probabilities for each input instead of exact values. For example, instead of the user having a fixed number of initially infected trees, which now defaults in simulation explorer to 10 per acre, we use a range of 3 to 13 initially infected trees to capture a more realistic setting. Each point also provides a Risk Ranking at the top of the box that appears when a point is highlighted. This is a risk measured known as first degree stochastic dominance (FDSD). When comparing two treatments, the one with the lower number would be preferred when considering risk, even if it has a higher NPV. Since there is a range on returns, it is possible for either strategy to prevail in a given year. However, FDSD accounts for the full range of returns and the score identifies which strategy would have the higher income most of the time.

Question 2: When should I replant?



We have assumed that an orchard is replanted every 20 years, which you can change if desired. Many producers that experience a CC outbreak, see their orchards diminish more quickly than usual. This question is designed to help make the decision about the value of replanting. You can indicate whether you want this example for the average cost of treating an orchard, or for a $500/ac or $1,200/ac treatment. This example is for $1,200/ac. In this case, the 20-year orchard is always most valuable.

Question 3: How much do I lose if I don't prune branch cankers?



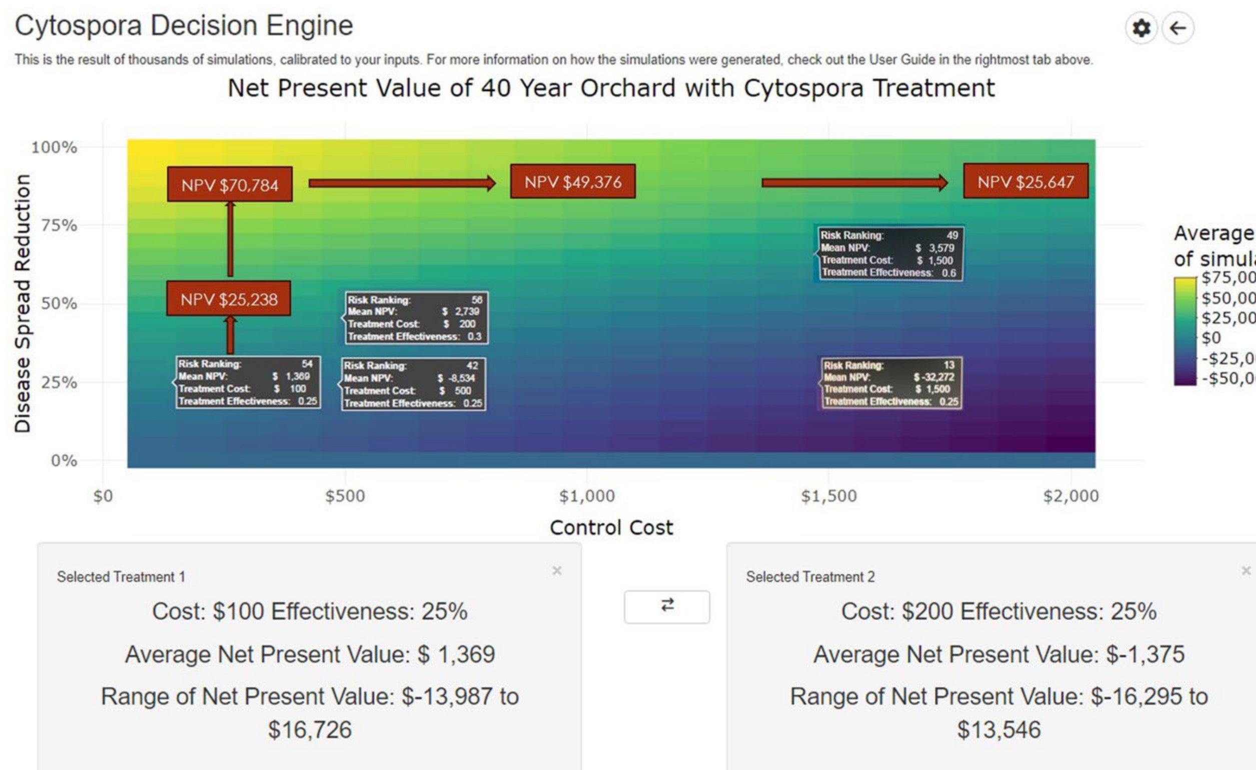
The last question is meant to show how important it is to prune out branch infections. CC can be hard to see, so it can easily be missed, plus targeted pruning of CC is not always an option. What the results graph shows for this question is the economic cost of missing those branches. For example, if a producer were to fail to prune out any branches, his/her net present value for the 40-year scenario could fall from about $24,000, where all branches were pruned, to about $8,000 per acre. If a producer thinks they might miss half of the infected branches, their NPV would fall by about half.

4.4 Using Risk Explorer, with example

The Risk Explorer provides the opportunity look at three common management decisions: 1) Compare the economic returns to different treatments, 2) When to optimally replant an orchard, and 3) The impact of missing some of the disease when pruning.

Is it profitable to treat –
Mathematical computations, including probabilities, have already been preprocessed in Risk Explorer. One graphic is provided with "as-if" results for combinations of costs per acre ranging from 0-$2,000 and efficacy of the treatment to slow disease spread by 0-100%. These are not the producer's returns per se but do show the correct returns when a producer searches on their known cost and efficacy. These results are "as-if" you could achieve the result. That is, you might consider a treatment that costs $300/acre and that reduces spread by 50% based on studies and your own judgement. Highlight that point on the graph with your mouse to determine whether that combination is profitable. Click that position to record the information

below the graph. The fact that the graph has up to 100% efficacy for $300, compared to your 50% estimate, is irrelevant because those levels cannot be achieved. That is, you tell the graph what you can achieve, and the results indicate how much that would earn. Let's look at an example.



Note from the example above that the average Net Present Value (NPV) of a 40-year time frame with two orchard plantings is plotted by color, with yellow representing the highest returns and purple the lowest. Naturally, combinations with high efficacy and low cost in the upper left corner have the highest returns. When you mouse over the graph, a black box will appear like those shown in the graph. If I held the mouse over the value $100 treatment cost and 25% efficacy, the black box indicates that NPV would average $1,300 per acre. If I click that spot, the box below, "Selected Treatment 1" records that value, and let's you know the NPV ranges from -$8,467 to $22,226. That is, since probability is involved, the answer could be anywhere in between. If I move my mouse to the right, the same efficacy with a treatment costing $500 per acre would loves over $8,000. If I move over to $1,500 per acre, I would lose over $32,000 per acre. However, if I could get more efficiency for $100, moving up to 50% or even 90%, I would improve my NPV to over $25,000 and $70,000 respectively. And with 90% efficacy, I could pay $1,500 per acre and still make money.

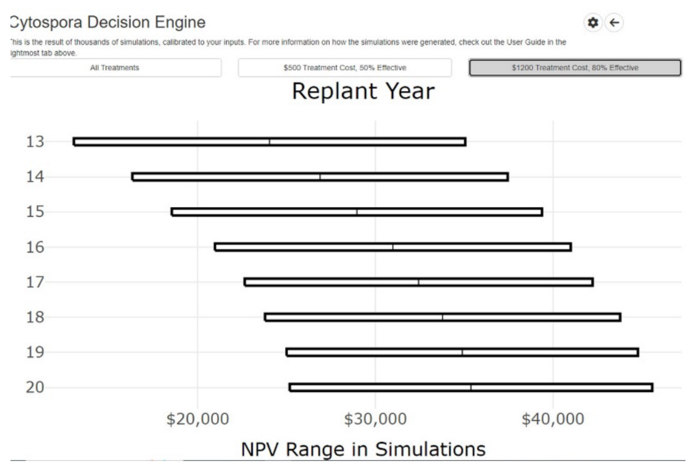
If you click a second time on the graph, the data will be recorded on the right side under the graph. If you click a third time, it will replace your second choice. You can use the arrows between the results boxes to switch the information that stays in box 1 with that which varies with each click in box 2. To remove a selected option, you can click the small x in the upper right corner of the box.

Most producers will know what it costs to apply a treatment but won't know how effective it will be at reducing spread. You might use information from a presentation or article from a study, or advice from a professional or a valued peer. Or, you might use your own experience and judgement. One helpful feature of Risk Explorer is that you can quickly evaluate the impact of your own uncertainty. For example, if you think something costs $300 and is 25% effective, mouse up and down at $300 to see what would happen if efficacy was higher or lower. If you go to the bottom of the range you are more certain about, say 10% for example, and still make money, you know you have some room for error in your decision. If you don't make money and go up in efficacy to increase returns, you can determine for yourself how much you would have to make in order to make a positive return.

When should I replant my Orchard –

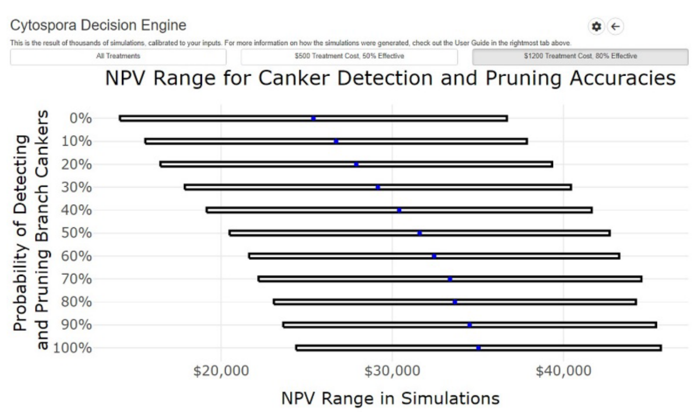
Cystospora can devastate and orchard and present a grower with the question: am I better off to destroy the orchard and replant, or to keep the damaged orchard going until the original intended replanting date. In this example, we intend to replant every 20 years.

This feature helps with that question. A bar is presented for replanting in years 13-20. The center of the bar is the mean NPV and the length of the bar represents the range. In this example, the 20-year orchard makes the most money, so the orchard life should not be shortened. A situation where an orchard is severely damaged might yield a different result.



What is the cost of missing cankers when pruning –

The third feature of Risk Explorer helps growers determine the value of knowing which trees are infected. Cytospora can be difficult to detect. Is it worth learning more about how to do so? Risk Explorer shows the NPV range and mean for different levels of detection. If you detect 100% of the branch infections, and prune accordingly, you would have an NPV of about $35,000 in this example. However, if you miss 50% of the branches with cankers, your NPV falls to



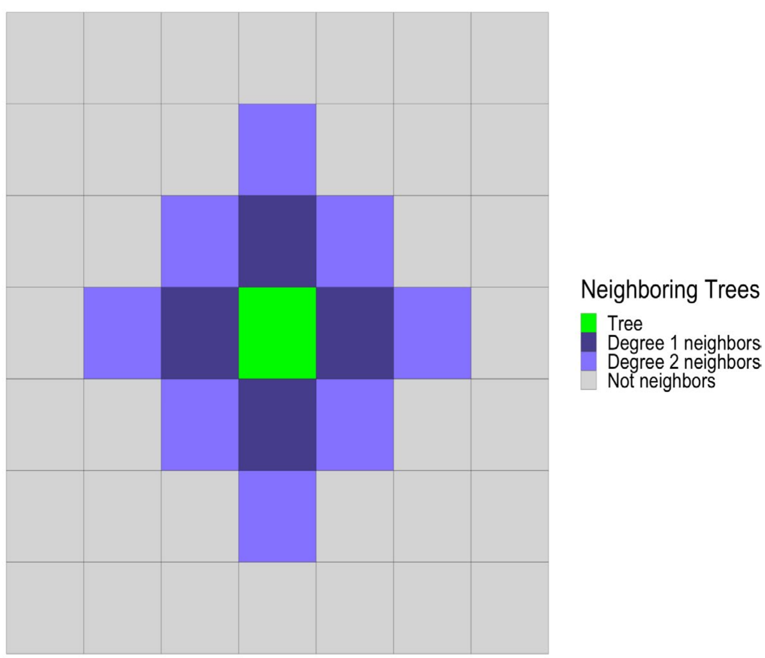
about $32,000; and it falls to about $28,000 if you miss all cankers. A way to think about this is that if you could improve your ability to detect cankers from 50% to 100%, it would mean about $3,000 more NPV per acre.

5. Methods and Assumptions for Simulations

5.1 Disease infections

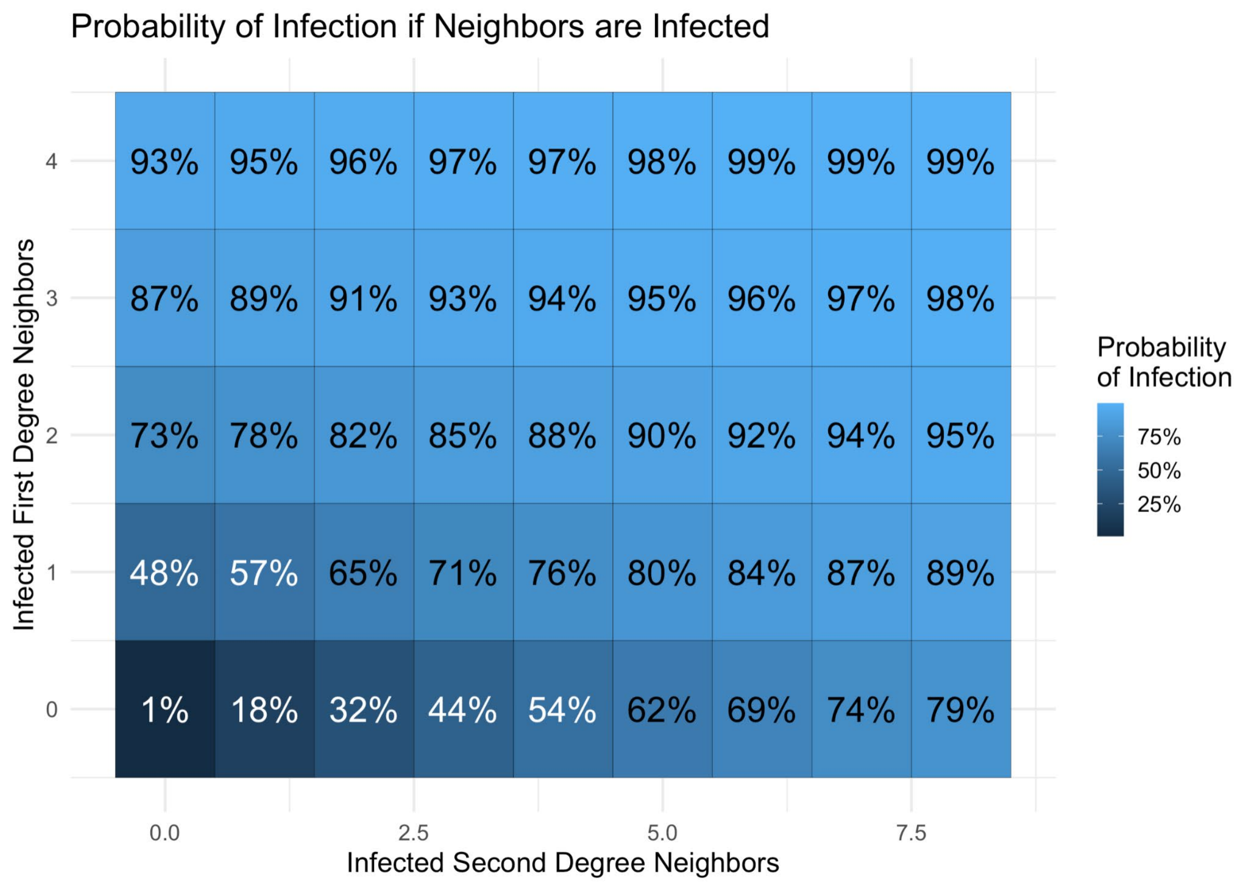
The disease spreads in the following way: starting the first year the disease starts, an **initial number of trees are infected** in the orchard. The infection in the tree can be in the branches or in the trunk. If the infection is in the branches (⅔ of infections), the infection can be pruned out of the tree, removing the infection entirely. The **detection probability** is likelihood that the infection in the branches will be removed in the first three years that the tree is infected. After three years, any infection in the branches is assumed to always be detectable and pruned out. For some branch infections, the canker is very close to the trunk and pruning it leads to pruning an entire scaffold. This happens 1% of the time and causes the yield of that tree to be 33% lower than it would have been otherwise.

Any tree within two rows or columns of an infected tree can become infected. As more surrounding trees are infected, the probability of infection grows. Specifically, the probability of spread is a function of the top/bottom/left/right neighbors (call them degree one neighbors, or n1) and any degree one neighbors of those neighbors (call them degree two neighbors, or n2). The neighbors are visualized in the figure below. Each tree has four first degree neighbors and eight second degree neighbors.



The probability of infection grows with the number of infected first and second degree neighbors according to the following equation, visualized in the figure below.

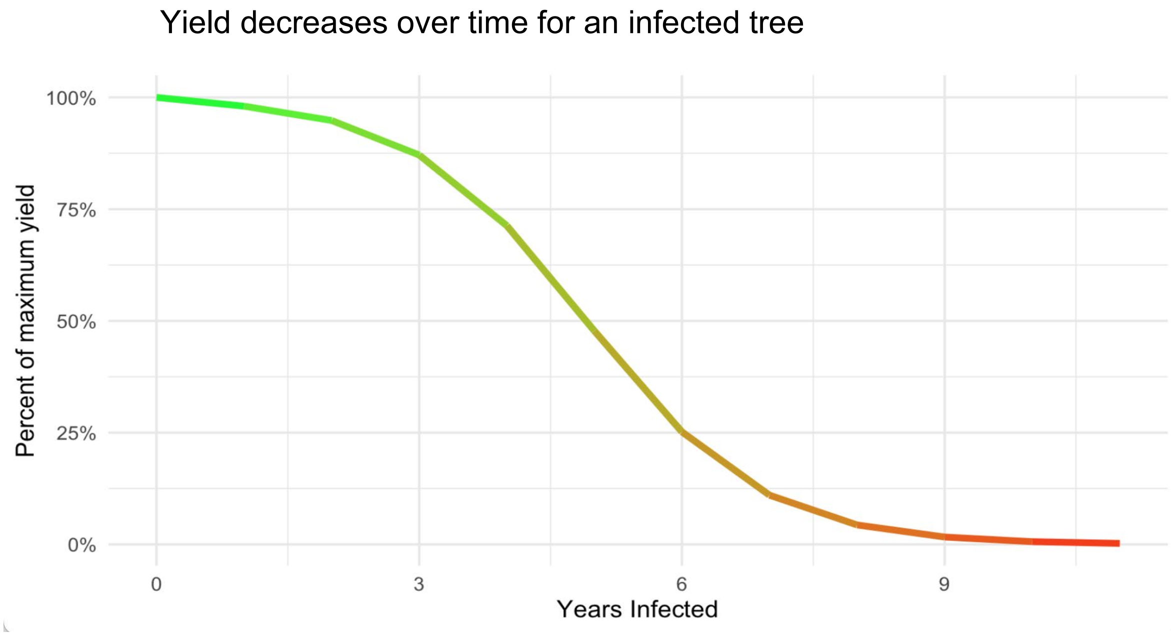
f(n1_infected, n2_infected) = 1.01 - exp(-(0.6437658*n1_infected + 0.1881593*n2_infected))



Note that this does not allow the canker to become more infective over time, though the joint probability of overall infection does increase over time for trees with infected neighbors.

5.2 Yield Impacts

If the infection is in the trunk (⅓ of infections), the infection cannot be removed. For trunk and undetected, unremoved branch infections, the disease grows linearly each year, reaching it's maximum in year 10. As shown in the graph below, the yield of each infected tree decreases as the disease grows. The tree has no effective yield if it has been infected for 10 years or more with Cytospora (see figure below).



5.3 Management Efficacy

Any tree with at least one infected neighbor can be infected the next year. To reduce disease spread, a producer can apply treatment that decreases the likelihood of spread. Each treatment has a **cost** and **effectiveness**. The cost of the treatment is a constant cost incurred every year that the treatment is active, and the effectiveness is measured by the percent reduction in disease spread that occurs because of the treatment. If a treatment is 20% effective, it reduces (multiplies) the probability of spread to 0.8, or one minus the effectiveness.

The simulation explorer allows the user to select two treatments with different costs and effectiveness to compare the economic outcome of both. The **Year Disease Starts** is the year that the orchard is initially infected. **Year Treatment Starts** is the year that the two treatments start being applied to reduce the spread of the disease.

5.4 Additional Assumptions in Risk Explorer

In addition to the assumptions above, the Risk Explorer runs 100 simulations for all 36,960 combinations of four parameters: replant year, treatment cost, treatment effectiveness, and canker detection and pruning probability.

Each of the 100 simulations are different for three reasons:

1. Different maximum healthy yields – default between 18 and 24 with an average 22.5 lbs/yr
2. Different initial infection rates – default between 1%-5% with average 3% of trees infected.
3. Different runs of the model. A 50% chance of a tree becoming infected will sometimes infect the tree and sometimes won't. When/where trees are infected can lead to different results, as you can see if you run the simulation explorer multiple times.

The range of net present values in each of the Risk Explorer modules comes from the mean and standard deviation of the net present values across all the simulations. For example, in the treatment cost/effectiveness module the net present values across all canker pruning efficacies and a selected replant year are averaged together for a given cost and effectiveness. The selected replant year can be changed in the orchard information dropdown menu. In the replant year module, the net present values are averaged across all treatment cost, treatment effectiveness, and canker pruning accuracy parameters.

6. Troubleshooting

6.1 Common Issues and Solutions

Risk Simulator is slow to load because there is a great deal of information. If it does not load, close the program and try again.

6.2 Contacting Support

For any support questions that are not answered in this manual, please fill out a feedback form https://forms.gle/4xAttrdxB3Z3GZaq9 detailing your question or problem and we will get back to you as soon as possible. This feedback form is also available in the app in the button labeled "Feedback" in the upper right hand side of the simulation explorer tab.

7. Updates and Maintenance

We will conduct yearly updates to the app. These updates will include improving the simulations given any scientific advances, maintaining current functionality, and potentially adding additional functionality if time allows. Since these updates will be conducted offline and published when finished, we do not expect there to be more than a few minutes of downtime. If the app is ever down for longer than a few minutes, please contact support using the form link above.

8. Legal Information

We license this software under the GNU General Public License v3.0. This generally allows for modification and/or distribution of the software with the condition that the source be disclosed.

For the full text of the license document, please visit the code repository website https://github.com/brookefitzgerald/cytospora/blob/main/LICENSE.