# The Economic Value of the Precision Disease Management System for Anthracnose and Botrytis Fruit Rot for the Florida Strawberry Industry

**Ekaterina Vorotnikova, John VanSickle and Borisova Tatiana[1]**
**[1]The authors are (respectively): Graduate Student, Professor, and Assistant Professor, Food and Resource Economics Department, University of Florida**

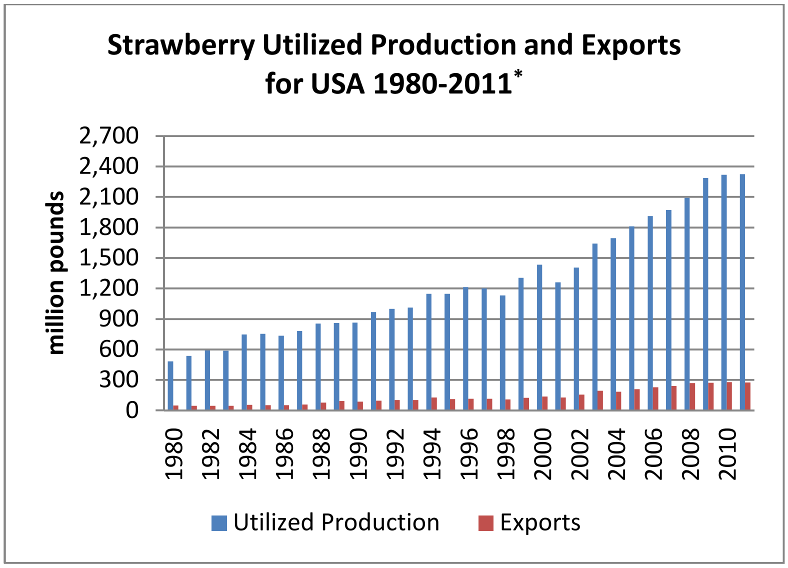
***Selected Paper prepared for presentation at the Southern Agricultural Economics Association Annual Meeting, Birmingham, AL, February 4-7, 2012***

# The Economic Value of the Precision Disease Management System for Anthracnose and Botrytis Fruit Rot for the Florida Strawberry Industry

**Ekaterina Vorotnikova, John VanSickle and Borisova Tatiana[1]**
**[1]The authors are (respectively): Graduate Student, Professor, and Assistant Professor, Food and Resource Economics Department, University of Florida**

## Introduction

The U.S. is the world's largest strawberry producer, accounting for over a quarter of total world strawberry production (Perez et al, 2011). Over the past ten years, U.S. utilized production[1] increased by more than 60% (figure 1). Most of the U.S. production is consumed domestically, and an increasing amount of strawberries are being produced for fresh-market uses (Boriss et al, 2010).



* 2011 values are projected

Source: Perez et al, 2011

Among U.S. states, Florida ranks second for strawberry production (after California). Strawberries are the most significant berry crop produced in Florida, and during the winter season Florida dominates the

---

[1] where utilized production is defined as produced crops that were marketed, and either domestically consumed or exported

national strawberry market. The 2011 Florida winter strawberry crop was estimated at a record 257.4 million pounds, up 33% compared to the previous year, while yields rose by 18 percent to 260 pounds per acre. Harvested acreage in the State was projected at 9,900 acres, which is up 12 percent from 2010 (Perez, 2011). Almost ninety percent of Florida's strawberry acreage is grown around Plant City in Hillsborough County, west central Florida. Strawberries are also grown in the adjacent counties of Pasco, Polk, and Manatee, as well as in the south (Collier, Palm Beach, and Dade counties) and north (Bradford County) areas of the state (Peres, 2010a). The production season in Florida starts in November and continues through May of the following year. The heaviest harvesting occurs between February and March.

Fungal diseases such as Anthracnose and Botrytis fruit rot are considered major challenges for strawberry growers. Even in well-managed fields, losses from fruit rot can exceed 50% when conditions favor disease development (Ellis and Grove, 1982). Fungicides are commonly used by the growers to stem off the development of the diseases. Fungicides are applied once a week, and fungicide cost comprise approximately 7% of pre-harvest variable costs less the interest on variable cost, which represents about $690 per acre (IFAS, 2010). Main problems that are facing strawberry industry are increasing costs of fungicides, building of resistance to the fungicides, and rising public concerns about potential health and environmental effects of fungicide use (Peres, 2010b). Production methods that can reduce fungicide rates without affecting strawberry yields can provide significant economic benefits to Florida strawberry industry.

The objective of this study is to examine the economic benefits associated with precision fungicide application associated with fungus disease management for Florida strawberry producers. In Florida, periods with warm and wet weather create especially favorable conditions for the development and spread of Anthracnose and Botrytis fruit rot, thus increasing the risk of harvest losses. In contrast, given cool and dry conditions, the risk of the disease development is relatively minor. If a weather and disease forecast system is available, growers can potentially reduce fungicide application rates during cool and dry conditions without affecting yields, thus reducing production costs. In this study, we evaluate the economic value of a weather / disease forecast information system, and examine the opportunities to reduce costly fungicide usage by using precision disease management practices.

The precision disease management system examined in this study relies on the model of weather conditions and disease severity estimated by Bulger et al. (1987), Wilson *et al.* (1990), and Mackenzie et al (2009). Specifically, Bulger et al. (1987) used a logit regression analysis to examine the spread of disease as a function of temperature and leaf wetness duration (LWD). Mackenzie et al (2009) identified a combination of temperature and LWD that results in a critical spread of the disease given Florida conditions (referred to as "weather index" below). In a set of production experiments conducted by University of Florida researchers, harvestable yield and disease spread were compared given two fungicide application methods: applications based on the weather index (referred to as "model application" below) and the calendar-based method currently used by most growers (Peres, 2010a). Specifically, the model application method applies fungicides only if the values of weather index indicate high risk of disease development. In contrast, the calendar-based method applies fungicides weekly. The use of the model application in research trials resulted in elimination of a 33% to 50% of the fungicide applications (Mackenzie, Mertely, and Peres, 2009). The weather index is currently used in the web-based disease forecast system available to Florida strawberry growers since the 2009-10 production season (the forecast system can be accessed at http://agroclimate.org/tools/strawberry). The objective of this study was to economically compare the two methods of fungicide applications, and to evaluate the effect each method has on strawberry production, profits and risks. Based on three simulated risk scenarios, the study determines which application method delivers the most profit.

Below, we review the published studies about modeling production risks in agriculture (Section II), describe the data used in this analysis (Section III), present the study methodology (Section IV), and discuss the study results (Section V). The data section discusses the production experiment conducted by University of Florida researchers. The methodology section presents the regression analysis that was utilized to identify the effect of the fungicide application methods and weather on strawberry harvest and the number of the diseased berries. We also discuss modeling production risks given different weather scenarios and fungicide treatment methods. Then economic analysis is used to identify the fungicide method that has the most economic benefit for the grower. Final results demonstrate that a precision disease management system has the potential to produce significantly higher profit in comparison with conventional calendar method of application.

## Modeling production risks in agriculture

Published studies have shown that changes in the use of production inputs (such as fungicides or fertilizers) can influence not only average yield and income, but also income and yield variability. These changes in the income variability are important for the input use decisions of a risk-averse producer. For example, Lambert (1990) developed a model to measure income and risk impacts resulting from reductions in nitrogen rates that were induced by a fertilizer tax. The author showed that reduction in nitrogen use can decrease income variability, influencing the utility of a risk-averse producer. In Lambert's model, input use levels and proportions are influenced by input and output prices, output price variance, output level, marginal products, producers' risk aversion, and the marginal contributions of inputs to yield variance.

Asche et al (2006) also investigated how production risk may influence optimal input levels of a risk-averse producer. The authors compared the input use levels for risk-averse and risk-neutral producers given that the mean and variance of production output as influenced by soil quality, labor, land, fertilizer, pest control, seed and irrigation. The dataset used in the analysis resulted from a survey of small-scale subsistent farmers (213 farmers from 11 villages) in the Tanzanian Kilimanjaro region. It was shown that risk-averse producers chose different input levels compared with risk neutral producers (Asche, 2006).

Ramaswami (1992) showed that for risk-averse producers, the marginal risk premium is positive (negative) if and only if the input is risk-increasing (decreasing). However, if the input is neither risk-increasing nor risk-decreasing, the marginal risk premium can be positive or negative for risk-averse producers. For such a case, Ramaswami derived a sufficient condition on technology which signs the marginal risk premium for the restricted class of concave utility functions with convex marginal utility.

Several studies have also explicitly modeled the effect of weather-related risks on adoption of precision management technologies. For example, Isik and Khanna (2003) examined the impacts of risk preferences and uncertainties about weather and soil conditions on adoption of site-specific technologies. The following steps were used in their analysis: 1) estimate the stochastic production technology and farmers' risk preference parameters jointly, using survey data from farmers; 2) incorporate these risk and technology parameters into a micro-level utility maximization model to determine the impact of risk aversion and uncertainty on adoption decisions for site-specific technologies; and 3) determine the cost-share subsidies needed to induce the technology adoption. The study results demonstrate the advantages of the joint parameter estimation technique for production technology and farmers' utility modeling.

Production decisions under the uncertainty of future weather events are also examined in Dai, Fletcher, and Lee (1993). The authors used the profit maximization framework to analyze crop decisions for corn production.The uncertainty about weather conditions was modeled using a stochastic soil moisture index.To comprise that index they calculated annual estimates for the soil moisture index for a variety of Indiana soil conditions and weather patterns. They also simulated yield response using response functions estimated from long-term experimental data. As an empirical example, nitrogen application rates that maximize farmers' expected returns are developed for 15 different soil and weather conditions in Indiana. The authors then used this information to evaluate the possible economic loss of applying the optimal nitrogen recommendation developed for one soil type to another (Dai, Fletcher, and Lee, 1993).

Similar to Isik and Khana (2003), Dai, Fletcher, and Lee (1993), and Thrikawala et al. (1999), we use the utility maximization model in our analysis to examine producers' choices related to the precision fungicide application, and we also examine the effect of producers' risk preferences on the technology adoption decisions. Weather events are modeled through a weather index, similar to Dai, Fletcher, and Lee (1993). However, unlike Dai, Fletcher, and Lee (1993), we use the index for comparing economic profits between two production technologies (i.e., different fungicide treatments) for a specific soil type.

## Study Area and Data

According to Peres et al. (2005), *C. acutatum* (Anthracnose) likely enters production sites on contaminated nursery plants. It then survives and reproduces on the surface of leaves through secondary reproduction (Leandro et al., 2001). Contamination occurs mainly through splashing water (Ntahimpera et al, 1999). According to Wilson et al. (1990), the optimum temperature for infection for both immature and mature fruit is 25 to $30^{o}$C. In turn, Bortrytis (*B. cinerea*) infection occurs through dead strawberry foliage (Sutton, 1998). The infection starts on the young leaves sporulating as the leaves die. The contamination occurs through wind or water dispersion onto the healthy fruit and petals (Mertely et al., 2002, Sutton, 1998). The open flower, white bud, and senescent flower stages are most susceptible to infection (Henneber and Gilles, 1958). The optimum temperature for flower infection is approximately 20□C (Bulger, 1987).

In this study, we use data from production experiments conducted at the University of Florida research farm at Gulf Coast Research and Education Center, in Wimauma, Florida. Replicated field trials were conducted during the production seasons of 2006/07, 2007/08, and 2008/09 (Mertely et al., 2009). Bare-root strawberry transplants were planted into fumigated soil in plastic-mulched, raised beds using staggered rows. Treatments were arranged in a randomized complete block design with four blocks (four plots), each in a separate bed (for each treatment) (Mertely, Seijo, and Peres, 2009). Three groups (treatments) were compared: calendar-based applications (once a week conventional application), model-based applications (sprays timed according to the disease forecast system), and a control group (this group received no fungicide applications). Compliance with the fungicide application specifications was insured. Separate independent trials were conducted for Anthracnose and Botrytis diseases (strawberry transplants were inoculated with fungus for the Botrytis production experiments). Trials were conducted using the two strawberry cultivars most popular in Florida, 'Strawberry Festival' (which is more tolerant to Anthracnose and Botrytis) and 'Camarosa' (which is more susceptible to both diseases) (Table 1). The weather data (leaf wetness interval and temperature) was recorded daily.

Table 1. Beginning and Ending Dates for the Production Experiments

| | Season | Beginning of Harvest | End of Harvest |
|---|---|---|---|
| Anthracnose Trials | 06-07 | 11/13/2006 | 3/12/2007 |
| | 07-08 | 11/13/2007 | 3/14/2008 |
| | 08-09 | 11/7/2008 | 3/17/2009 |
| Botrytis Trials | 06-07 | 11/13/2006 | 3/12/2007 |
| | 07-08 | 11/12/2007 | 3/14/2008 |
| | 08-09 | 11/4/2008 | 3/16/2009 |

The model-based fungicide application schedule was based on the study by Bulger *et al.* (1987) and Wilson *et al.* (1990), in which a logistic regression was used to model the proportion of immature and mature strawberry fruit infected by the fungus, *%Inf*, as a function of temperature, *T*, and wetness duration, *W*:

$$ln\frac{\%Inf}{1-\%Inf} = b_0 + b_1\,W + \; b_2\,WT + \; b_3\,WT^2 + b_4\,WT^3 \qquad (1)$$

Denoting the left-hand side of equation (1) as the disease index, or *DI*, the proportion of strawberry fruit infected by the fungus can be specified as:

$$\%Inf = \frac{EXP(DI)}{1 + EXP(DI)} \qquad (2)$$

The value of regression coefficients ($b_0$, $b_1$, $b_2$, $b_3$, and $b_4$) were selected given Florida's production conditions (Mertely, Seijo, and Peres, 2009). Specifically, for Bortrytis experimental trials, the following relationship was used to guide model-based fungicide applications:

$$DI_{Botrytis} = -4.268 \; + \; 0.0294 * W * T \; - \; 0.0901 * W \; - 0.0000235 * W * T^3 (3)$$

The model-based group was sprayed with fungicides when the model predicted that weather conditions should result in 50% of strawberries to be affected by Bortrytis (i.e., $\%Inf_{Botrytis} > 0.499$). The decision on which fungicide to use, Captan or Captevate, was based on the manufacture's specifications. Specifically, the fungicides can be applied at most once every seven days. In addition, Captevate's rate of application is no more than 5.25 pounds per acre per season and no more than 21 pounds per season. Also Captevate is a stronger fungicide, so if conditions are conducive for the development of the disease for several consecutive days, Captevate fungicide is used.

In turn, for Anthracnose trials, model-based was applications were scheduled according to the following disease index model:

$$DI_{Anthracnose} = -3.7 + 0.33 * W - 0.069 * W * T + 0.005 * W * T^2 - 0.000093 * W * T^3 (4)$$

When model (4) predicted that 15% of strawberries were expected to develop disease (i.e., $\%Inf_{\text{Anthracnose}} > 0.1499$), Captan was sprayed. In turn, when model (4) predicted that 50% of strawberries were expected to develop disease (i.e., $\%Inf_{\text{Anthracnose}} > 0.499$), Cabrio, a more powerful fungicide, was used. Manufacturer specifications for fungicide application were also followed, according to which the maximum number of sequential applications for Cabrio was limited to two and maximum rate of its application was 70 oz (4.375 pounds) per acre per season.

The number of days when the weather conditions were conducive for the development of Anthracnose and Bortrytis is summarized in Table 2 given a) % Inf ≥ 15% and b) %Inf ≥ 50%. In turn, the total number of fungicide applications for each of the three treatment groups (calendar-based, model-based, and control group) is summarized in Table 3. Since manufacture's specifications set restrictions on the number of fungicide applications, the number of applications for model-based treatment slightly deviates from the recommendations based on models (3) and (4) (compare values in table 2 with the values in "total number of applications" column in Table 3).

Table 2. The Number of Days with Weather Conditions Conducive for the Disease Development

| Disease | Season | 15% Inf | 50% Inf |
|---|---|---:|---:|
| Botrytis | 06-07 | na* | 3 |
| | 07-08 | na* | 8 |
| | 08-09 | na* | 8 |
| Anthracnose | 06-07 | 33 | 1 |
| | 07-08 | 34 | 4 |
| | 08-09 | 13 | 4 |

*na represents measure not applicable to treatment for Botrytis

Table 3. Number of Fungicide Applications for Different Treatment Groups*

| | | Calendar | | | Model | | |
|---|---|---|---|---|---|---|---|
| Disease | Season | Cabrio | Captan | Total # of Applications | Cabrio | Captan | Total # of Applications |
| Anthracnose | 06-07 | 4 | 12 | 16 | 4 | 6 | 10 |
| | 07-08 | 4 | 12 | 16 | 3 | 9 | 12 |
| | 08-09 | 4 | 13 | 17 | 1 | 4 | 5 |
| Botrytis | 06-07 | 4 | 12 | 16 | 1 | 7 | 8 |
| | 07-08 | 4 | 13 | 17 | 2 | 6 | 8 |
| | 08-09 | 4 | 13 | 17 | 1 | 2 | 3 |

* same for both Festival and Camarosa varieties

For the plots with calendar-based applications, model-based applications, and a control group, fruits were harvested twice weekly from December through March, and marketable fruits were counted and weighed. Diseased fruits were also counted for Anthracnose (AFR) and Bortrytis (BFR) incidences. The researchers also counted the number of berries tossed for reasons other than AFR and BFR (i.e., cull).

The production experiment results are summarized in Table 5 There were four plots (F1, F2, F3, F4) for each of the three seasons (2006/07,2007/08, 2008/09) and for each treatment group (Control, Calendar, and Model). The table summarizes the marketable number of the berries (“Number”), marketable weight of berries in grams (“Weight”), the number of berries tossed for other reasons than the disease (“Cull”), the number of berries that contracted Botrytis (“Botrytis”) and Anthracnose (“Anthracnose”). The results are summarized separately for the Camarosa and Festival varieties trials.

Table 5. Aggregated Data

Camarosa

| | Control | Number(#) | Weight(g) | Cull(#) | Bortytis(#) | Anthracnose(#) |
|---|---|---|---|---|---|---|
| Control | F1 | 327 | 6333 | 210 | 23 | 67 |
| | F2 | 279 | 5370 | 141 | 8 | 70 |
| | F3 | 311 | 6065 | 155 | 13 | 49 |
| | F4 | 293 | 5726 | 217 | 17 | 92 |
| | F1 | 39 | 611 | 202 | 0 | 156 |
| | F2 | 86 | 1562 | 258 | 1 | 200 |
| | F3 | 42 | 824 | 218 | 1 | 175 |
| | F4 | 78 | 1312 | 234 | 2 | 136 |
| | F1 | 348 | 7295 | 141 | 1 | 27 |
| | F2 | 406 | 8303 | 188 | 3 | 52 |
| | F3 | 348 | 7493 | 142 | 4 | 49 |
| | F4 | 364 | 7515 | 169 | 2 | 48 |
| | Calender | Number(#) | Weight(g) | Cull(#) | Bortytis(#) | Anthracnose(#) |
| Calendar | F1 | 352 | 7377 | 109 | 7 | 22 |
| | F2 | 370 | 7193 | 108 | 1 | 6 |
| | F3 | 366 | 7208 | 102 | 8 | 13 |
| | F4 | 373 | 7399 | 123 | 2 | 21 |
| | F1 | 156 | 2857 | 117 | 0 | 28 |
| | F2 | 190 | 3826 | 137 | 5 | 61 |
| | F3 | 164 | 3140 | 150 | 1 | 45 |
| | F4 | 186 | 3633 | 139 | 3 | 64 |
| | F1 | 396 | 8013 | 100 | 2 | 4 |
| | F2 | 467 | 9951 | 91 | 0 | 3 |
| | F3 | 398 | 8575 | 106 | 0 | 5 |
| | F4 | 483 | 10243 | 102 | 1 | 6 |
| | Model | Number(#) | Weight(g) | Cull(#) | Bortytis(#) | Anthracnose(#) |
| Model | F1 | 412 | 8379 | 150 | 10 | 12 |
| | F2 | 370 | 7193 | 108 | 1 | 6 |
| | F3 | 430 | 9001 | 119 | 0 | 4 |
| | F4 | 384 | 7982 | 103 | 3 | 15 |
| | F1 | 162 | 2999 | 124 | 2 | 45 |
| | F2 | 158 | 2925 | 179 | 0 | 108 |
| | F3 | 111 | 2149 | 161 | 4 | 94 |
| | F4 | 146 | 2897 | 142 | 1 | 53 |
| | F1 | 376 | 7690 | 94 | 0 | 13 |
| | F2 | 462 | 9413 | 96 | 0 | 3 |
| | F3 | 470 | 10228 | 103 | 1 | 4 |
| | F4 | 396 | 8612 | 161 | 2 | 11 |

Festival

| | Control | Number(#) | Weight(g) | Cull(#) | Bortytis(#) | Anthracnose(#) |
|---|---|---|---|---|---|---|
| Control | F1 | 437 | 7504 | 125 | 7 | 8 |
| | F2 | 518 | 8698 | 151 | 12 | 12 |
| | F3 | 584 | 9892 | 207 | 14 | 25 |
| | F4 | 445 | 7302 | 195 | 20 | 11 |
| | F1 | 133 | 2006 | 351 | 7 | 209 |
| | F2 | 183 | 2788 | 421 | 3 | 208 |
| | F3 | 178 | 2689 | 376 | 2 | 162 |
| | F4 | 168 | 2505 | 384 | 6 | 184 |
| | F1 | 532 | 10162 | 93 | 1 | 1 |
| | F2 | 462 | 8808 | 90 | 3 | 3 |
| | F3 | 543 | 10796 | 114 | 1 | 6 |
| | F4 | 492 | 9803 | 104 | 3 | 0 |
| | Calender | Number(#) | Weight(g) | Cull(#) | Bortytis(#) | Anthracnose(#) |
| Calendar | F1 | 473 | 8440 | 101 | 2 | 2 |
| | F2 | 459 | 8251 | 100 | 1 | 0 |
| | F3 | 522 | 9379 | 106 | 2 | 1 |
| | F4 | 494 | 8859 | 107 | 7 | 14 |
| | F1 | 219 | 3450 | 189 | 2 | 34 |
| | F2 | 224 | 3621 | 230 | 0 | 12 |
| | F3 | 321 | 4976 | 257 | 0 | 23 |
| | F4 | 258 | 4083 | 284 | 2 | 38 |
| | F1 | 486 | 9396 | 98 | 1 | 3 |
| | F2 | 518 | 10144 | 142 | 0 | 2 |
| | F3 | 529 | 10375 | 111 | 0 | 0 |
| | F4 | 547 | 10873 | 67 | 2 | 1 |
| | Model | Number(#) | Weight(g) | Cull(#) | Bortytis(#) | Anthracnose(#) |
| Model | F1 | 515 | 9115 | 79 | 3 | 1 |
| | F2 | 575 | 9760 | 137 | 3 | 3 |
| | F3 | 515 | 9718 | 122 | 2 | 3 |
| | F4 | 558 | 9449 | 153 | 7 | 6 |
| | F1 | 209 | 3379 | 226 | 2 | 50 |
| | F2 | 335 | 5078 | 277 | 6 | 31 |
| | F3 | 237 | 3748 | 217 | 1 | 36 |
| | F4 | 247 | 3640 | 262 | 2 | 39 |
| | F1 | 507 | 10343 | 88 | 0 | 0 |
| | F2 | 511 | 9918 | 77 | 2 | 2 |
| | F3 | 608 | 12134 | 95 | 1 | 5 |
| | F4 | 686 | 13258 | 91 | 0 | 2 |

## Methodology

The objective of the study was to examine the effect of two fumigation methods, calendar-based application (traditional method) and model-based application (using the disease-forecast system) on strawberry production profits. The fumigation methods are not only compared with each other, but also with a "control" option, i.e., a no treatment group.

The farmer's objective is assumed to be to maximize expected profit:

$$\max \pi = p * E[\, h(\xi,\omega) * \,(1 - L(\varphi,\tau) - \, D(W,T,g,e,\eta))] - c(g) - VC \;(5)$$

where $p$ is the sale price, $h$ is yield that depends on two random variables - $\xi$ (year-to-year variability due to external factors like weather) and $w$ (within-year variability, e.g., from one production plot to the next due to different soil characteristics). $D$ is the portion of harvest lost due to the Anthracnose and Botrytis fruit rot, and $L$ is the proportion of the harvest lost due to reasons unrelated to Anthracnose and Botrytis. Disease frequency ($D$, measured as weight of diseased strawberries to the total weight of harvested strawberries, in percent), is a function of leaf wetness ($W$), temperature ($T$) and fungicide application ($g$) and two random variables: $e$ (year-to-year variability) and $\eta$ (variability from plot to plot). $L$ depends on two random variables – $\varphi$ (year-to-year variability, e.g., due to weather events) and $\tau$ (within year variability, e.g., from one production plot to the next). Finally, $c(g)$ is the cost of fungicide and its application, and VC is variable cost associated with the other production inputs. This profit function is based on the assumption that the farmer is a price-taker, i.e., the strawberry market is competitive and sale price $p$ is independent from the grower's actions.

The optimal fungicide application decision, $g*$, is given as (marginal cost of the fungicide is equal to its marginal value):

$$\frac{\partial\, c(g)}{\partial\, g} = -p * E[\ h(\xi,\omega) * \frac{\partial\, D(W,T,g,e,\eta)}{\partial\, g}] \qquad (6)$$

Perfect disease / weather forecast information can allow the farmer to make fungicide application decisions given a specific value of the random variable $e$ (i.e., the year-to-year variability affecting disease frequency):

$$\max \pi = p * E[\, h(\xi,\omega) * \left(1 - L(\varphi,\tau) - D(W,T,g,e,\eta)\right) |_{e=e_i}\, ] - c(g) - VC \qquad (7)$$

We denote the optimal fungicide level that solves the equation (7) as $g**$. The objective of this study is to examine whether the fungicide application decisions made with disease / weather forecast should result in higher profits, as compared to the decisions made without additional weather/disease information:

$$H_0\colon E_e\left[E[\pi(g^{**})]\, |_{e=e_i}\right] > E[\pi(g^{*})] \qquad (8)$$

To test the hypothesis (8), we will use simulation methods to examine the marketable yields, costs, and returns for calendar-based and model-based fungicide application. Such simulations require assigning specific distributions for the random variables influencing marketable yield. These distributions are developed based on the results of the production experiments, as discussed below. Simetar© software (Richardson et al., 2004) is used to conduct all simulations and data analysis. Simetar© is a simulation language written for risk analysts to provide a transparent method for analyzing data, simulating the effects of risk, and presenting results in the user friendly environment of Microsoft® Excel (Richardson, 2008). It is an add-in software for Microsoft® Excel spreadsheets, which was developed specifically to conduct farm-level risk analysis. It allows simulating random variables, conducting statistical analyses and tests, econometric modeling and forecasting. The method was previously used for production risk and budget analysis in Archer and Reicosky (2009), Van Sickle et al. (2009), Prato (2008), and Liu (2007).

## Results

To simulate and compare farmers' costs and returns for calendar-based and model-based fungicide application, we used production experiment results (see Table 5). We identified systematic effects of weather and fungicide application method on strawberry yield, as well as random effects of weather, soil characteristics, and other uncertain factors. This section describes the analytical procedure as well as the results.

### Experimental Trial Results for the Two Strawberry Varieties

As the first step in the analysis, we examined whether experimental trial results for the two strawberry varieties could be combined. Specifically, for each fungicide treatment group in Anthracnose and Botrytis experiments, two-tailed T tests (at 95% confidence intervals) were used to examine whether the means of each category (marketable number, weight, cull, botrytis, and anthracnose) are the same for two strawberry varieties across the three growing seasons 2006/07, 2007/08, and 2008/09:

**H0**: the means are the same for the two strawberry varieties;
**H1**: the means are different for the two strawberry varieties.

The analysis shows that the null hypothesis cannot be rejected for all the categories tested (marketable number, weight, cull) and all treatments (model-based, calendar-based, and control). These results were consistent for both Botrytis and Anthracnose production experiments for both Camarosa and Festival varieties.

Further, F tests were used to examine if the variance of each category (marketable number, weight, cull, botrytis, and anthracnose) is the same for the two strawberry varieties:

**H0**: the variances are the same for the two strawberry varieties;
**H1**: the variances are different for the two strawberry varieties.

When the F-test was used to compare the control and calendar-based fungicide treatments, the null-hypothesis could not be rejected. In contrast, for model-based fungicide treatment, the test results were mixed. In Botrytis production experiments, the null hypothesis was not rejected for two categories: marketable number and number of Botrytis instances. However, in Anthracnose production experiments (for season 2008/09), the null hypothesis was rejected for weight and cull categories, implying that the data for the two varieties are drawn from different distributions and cannot be combined. Based on the test results, the data for the two strawberry varieties were analyzed separately.

## Experimental Trial Results for Different Fungicide Treatment Groups

The mean and variance tests (at 95% confidence interval) were conducted to compare experimental trial results for Control and Calendar, Control and Model, and Calendar and Model fungicide treatments groups. We compared results for the market weight, market number, cull, and the number of Botrytis and Anthracnose berries. These tests were conducted separately for each strawberry variety.

The test results show that for the Control and Calendar-based treatments, the null hypothesis of the same variance was rejected for cull, number of botrytis berries, and number of anthracnose berries categories. This result was consistent for both Camarosa and Festival varieties. In addition, for Camarosa variety, T-test showed that the hypothesis of the same means was rejected for cull and the number of anthracnose berries categories.  For Festival variety, the hypothesis of the same means was rejected for the number of berries affected by Botrytis. Based on these test results, we conclude that there is a significant difference between the Control and Calendar-based treatments. This result confirms our expectations, since Control group was not sprayed with any fungicide.

When Control and Model treatments were compared for the Camarosa variety, the null hypothesis that the variance is the same was rejected for the number of Botrytis instances. In addition, based on T-test, the hypothesis of the same means was rejected for cull and the number of anthracnose affected berries. Between the two tests, there is enough evidence to suggest that the Control and Model treatments have different effect on the disease in the crop. In turn, for Festival variety, the hypothesis that the means are the same could not be rejected at 95% confidence interval for any of the categories. However, the hypothesis of similar variances was rejected for cull, number of berries affected by botrytis, and number of berries affected by anthracnose categories.  Considering the results of the two tests together, we concluded that there is difference in the Control and Model treatments for both strawberry varieties. This result confirms expectations that the precision disease management system used for Model-based treatment leads to different production outcomes as compared with the Control group (which received no treatment).

Finally, when Model-based and Calendar-based groups were compared, the Null hypothesis that variances were equal was rejected for all categories (marketable number, weight, cull, number of berries affected by botrytis, and number of berries affected by anthracnose). The hypothesis that the means are the same could not be rejected at 95% confidence interval. These results were consistent for both varieties of strawberries: Camarosa and Festival.

The test results are summarized in Table 5. Overall, the variance of experimental trial results appears to be different across control, calendar, and model plots for both Camarosa and Festival varieties. In addition, for the Festival variety, model- or calendar-based fungicide application results in statistically higher yields, and statistically lower number of discarded berries (compared with the control treatment).

Table 5. Means and Variance Tests Results

| Variance (F-test)<br>95% Conf. Interval | Camarosa | | Festival | |
|---|---|---|---|---|
| | Categories that showed to be statistically | | Categories that showed to be statistically | |
| | Different | The Same | Different | The Same |
| Control VS Calendar | Cull, Anthracnose, and Botrytis | Marketable Number and Weight | Cull, Anthracnose, and Botrytis | Marketable Number and Weight |
| Control VS Model | Botrytis | Marketable Number, Weight, Cull, and Anthracnose | Cull, Anthracnose, and Botrytis | Marketable Number and Weight |
| Model VS Calendar | all | none | all | none |

| Mean (T-test)<br>95% Conf. Interval | Camarosa | | Festival | |
|---|---|---|---|---|
| | Categories that showed to be statistically | | Categories that showed to be statistically | |
| | Different | The Same | Different | The Same |
| Control VS Calendar | Cull and Anthracnose | Marketable Number, Weight, and Botrytis | Botrytis | Marketable Number, Weight, Cull and Anthracnose |
| Control VS Model | Cull and Anthracnose | Marketable Number, Weight, and Botrytis | none | all |
| Model VS Calendar | none | all | none | all |

### Experimental Trial Results for Strawberry Marketable Weight

For Anthracnose experimental trials and for each strawberry variety, regression analysis was used to examine the relationship between the marketable weight of berries (as dependent variable) and weather and fungicide treatment method (Table 6). We expect that the regression analysis will confirm that the calendar-based treatment and the model-based treatment result in higher strawberry yields (as compared with the control group). We also expect that the model-based treatment results in higher yields than the calendar-based treatment. Weather conditions are modeled based on Wilson's weather index, and we expect it to have a negative effect on yield. However, weather conditions can also have a positive effect on yields, since it takes sun and water for the crop to grow. In turn, to capture the differences in the weather and disease risks at different stages of plant growth, we introduce a "weather intensity measure", WIntnsty1. For each production season and each experimental plot, the values of this variable are obtained as follows. For each day when the Wilson weather index indicates conditions conducive for the disease, we recorded the number of the weeks left in the season. Then we summed up these values over the entire season. Larger values of WIntnsty1 indicate that the days with unfavorable weather conditions occurred earlier in the season, and/or that there were greater number of such days, and we expect that the effect of this variable on yield should be negative.

Table 6. Independent variables used in regression analysis for Strawberry Marketable Weight

| Variable | Description | Expected effect on the dependent variable, which is marketable yield |
|---|---|---|
| Cal | Dummy Variable (Short for Calendar), indicating the experimental plots treated with calendar-based method (i.e., weekly schedule). | positive |
| Mod | Dummy Variable (Short for Model), indicating the experimental plots treated with the model-based method (i.e., precision disease management) . | positive and greater than that for Cal (expecting that model-based treatment performs better than the calendar-based treatment). |
| Weather | Cumulated number of days that are conducive for the development of the decease according to the Wilson weather index for the entire season (%Inf > 0.15, Table 2). | negative |
| WIntnsty1 | "Weather intensity" | negative |

The results of the regression analysis are presented in Table 7. The results were consistent for the two strawberry varieties, and the effects of all the variables on strawberry yield matched the expectations. The only exception is variable WIntnsty1, which appears to have a positive effect on yield. However, this effect is much smaller in absolute terms than the significant and negative effect of variable Weather.

Tables 7. Regression Analysis Results for the Weight of the Marketable Berries

| | *Festival Variety* | | *Camarosa Variety* | |
|---|---|---|---|---|
| | Beta | S.E. | Beta | S.E. |
| Intercept | 5713.25 | 654.52 | 3914.89 | 527.933 |
| Cal | 741.16 | 342.72 | 1750.5 | 276.435 |
| Mod | 1382.25 | 342.72 | 1754.917 | 276.435 |
| Weather | -792.9 | 40.77 | -698.645 | 32.885 |
| Wintnsty1 | 83.165 | 5.533 | 72.89 | 4.463 |
| | $R^2 =$ 0.939; $\bar{R}^2 = 0.931$ | | $R^2 =$ 0.951; $\bar{R}^2 = 0.945$ | |

In the Festival variety regression, the coefficient for Model dummy variable, Mod, is significantly higher than that of Calendar dummy. In fact, the value of the coefficient for Mod variable is almost double (1.87

times) that of Cal. This result implies that plots with model-based fungicide treatment yielded 641.09 grams more of marketable strawberries than calendar-based treated plots.

For the Camarosa variety regression model, the coefficients for Cal and Mod are nearly the same, with Model's coefficient being about 4 gramss more than that of Calendar's. Thus, this result also favors the model treatment application system, especially since model treatment results in fewer numbers of applications with fungicide (on average 44% less in fungicide use). Therefore, this application system can be considered as low cost without penalty to yield.

## Conclusion

The objective of this study was to examine the economic benefits associated with precision fungicide application system for Florida strawberry production. Given the weather and disease forecast system developed by the University of Florida researchers (Peres, 2010a , strawberry growers can potentially 1) reduce fungicide application rates during cool and dry conditions without affecting yields, thus reducing production costs; or 2) apply fungicide at the precise time of high disease pressure during warm and wet weather, therefore, decreasing disease development and spread, and increasing the yields and profits.

The data from three-year strawberry production experiments were examined using regression analysis techniques. Strawberry harvests given the traditional (calendar-based) and the precision (forecast model-based) fungicide treatment were compared with the control group with no fungicide applications. The effects of climatic conditions on strawberry yields, as well as the differences between the two popular strawberry varieties – Festival and Camarosa, were explored.

Production experiments data showed that for the three seasons (2006-07, 2007-08, 2008-09), Model based treatment required on average 44% less fungicide applications as compared with the Calendar based treatment (38%, 25%, and 71%, respectively for each season). Furthermore, the regression analysis showed that the two strawberry varieties responded differently to the changes in the fungicide treatments. For Festival variety (which is more resistant to Anthracnose and Botrytis fungus diseases), strawberry harvest for the Model based treatment was about 1.87 times higher, and the fungicide used was on average 44% lower as compared with the Calendar based treatment. In other words, the precision (model-based) fungicide application can potentially save Florida strawberry producers 44% of fungicide cost, while increasing the yield and revenues by 87%.

In turn, for Camarosa variety (which is less resistant to the fungi), the fungicide use was also on average about 44% lower given Model-based treatment (as compared with the Calendar based treatment). The difference in yields between the two treatments was insignificant (only 0.2%). Hence, given Camarosa variety, strawberry growers who opt for the Model based treatment (vs traditional treatment) can expect the same yields, but lower fungicide use and production costs.

Overall, the precision (Model-based) application system is a viable fungicide management system that can provide economic benefits to Florida strawberry producers by reducing their fungicide use and costs, and potentially, increasing the yields.

In future, we plan to expand this analysis and examine the effects of alternative fungicide treatments on the average profits of Florida strawberry producers, as well as the profit variability. The effect of the degree of the growers' risk aversion on the choices of the fungicide treatments will also be analyzed.

**References**

Archer, D.W. and D.C. Reicosky. 2009. Economic Performance of Alternative Tillage Systems in the Northern Corn Belt. Agronomy Journal 101(2):296-304.

Asche F., Guttormsen, A.G. and K.H. Roll, 2006. Modelling Production Risk in Small Scale Subsistence Agriculture, International Association of Agricultural Economists 2006 Annual Meeting, August 12-18, 2006, Queensland, Australia.

Boriss H., Brunke H., Kreith M., and M. Geisler, 2010. Commodity Strawberry Profile, Agricltural Marketing Resource Center. Available at http://www.agmrc.org/commodities__products/fruits/strawberries/commodity_strawberry_profile.cfm

Bulger M.A., Ellis M.A., and L.V. Madden, 1987. Influence of Temperature and Wetness Duration on Infection of Strawberry Flowers by *Botrytis cinerea* and Disease Incidence of Fruit Originating from Infected Flowers, Phytopathology, 77:1225-1230.

Dai, Q., J.J. Fletcher and J.G. Lee, 1993. Incoroporating Stochastic Variables in Crop Response Models: Implications for Fertilization Decisions, American Journal of Agricultural Economics, 75: 377 – 86.

Ellis M.A. and G.G. Grove, 1982. Fruit rots cause losses in Ohio strawberries, Ohio Re. Res. Dev., 67: 3-4.

Henneber G.L., and G.L. Gilles, 1958. Epidemiologie de *Botrytis cinerea* Pers. Sur frasiers, Meded. Landbouwhogesch. Opzoekingsstn Staat. Gent 23: 864-888,

IFAS, 2010. Interactive Strawberry Budget. Plant City, 2008-2009 Season. Available at http://www.fred.ifas.ufl.edu/iatpc/files/strawberries09I.xls

Isik M. and M. Khanna, 2003. Stochastic Technology, Risk Preferences, and Adoption of Site-Specific Technologies. American Journal of Agricultural Economics, 85(2): 305-317.

Lambert, D.K., 1990. Risk Considerations in the Reduction of Nitrogen Fertilizer Use in Agricultural Production, Western Journal of Agricultural Economics, 15: 234- 44.

MacKenzie S.J., Mertely J.C., and N.A. Peres, 2009. The Curative and Protectant Activity of Fungicides for Control of Crown Rot Caused by *Colletotrichum gloeosporioides*. Plant Disease, 93: 815-820.

Mertely, J.C., Seijo, T.E., and Peres, N.A. 2009. Effect of Pre- and Post-Plant Fungicide and Fertilizer Treatments on Infection by *Colletotrichum acutatum*, Plant Survival, and Yield of Annual Strawberry in Florida. Plant Health Progress.

Ntahimpera, N., Wilson, L.L., Ellis, M.A., Madden, L.V., 1999. Comparison of Rain Effects on Splash Dispersal of Three Colletotrichum Species Infecting Strawberry. Phytopathology 89 (7), 555–563.

Peres N. A., Fraisse C.W., Van Sickle J., Borisova T., Gleason M., Schnabel G., Ellis M., Louws F., and G. Wilkerson, 2010a. Precision Decision Management for Sustainable Strawberry Production in the Eastern U.S., USDA. Available at http://www.reeis.usda.gov/web/crisprojectpages/222314.html

Peres N.A., Seijo T. E. and W.W. Turechek, 2010b. Pre- and Post-Inoculation Activity of a Protectant and a Systemic Fungicide for Control of Anthracnose Fruit Rot of Strawberry under Different Wetness Durations. Crop Protection, 29: 1105-1110.

Peres, N. A., L. W. Timmer, J. E. Adaskaveg, and J. C. Correll. 2005. Life styles of Colletotrichum acutatum. Plant Disease 89: 784-796.

Perez A., Platter K. and K. Baldwin, 2011. Fruit and Tree Nuts Outlook, USDA Economic Research Service: FTS-347.

Ramaswami, B., 1992. Production Risk and Optimal Input Decisions, American Journal of Agricultural Economics, 74: 860-69.

Richardson, J. W., K. D. Schumann, and P. A. Feldman, 2004. Simetar: Simulation for Excel to Analyze Risk. Dept. of Agricultural Economics, Texas A&M University, College Station, TX, January 2004.

Sutton, J.C., 1998. “Botrytis fruit rot (Gray Mold) and Blossom Blight”, Compendium of Strawberry Diseases. ed. J.L. Maas. 2nd Edition. APS Press: 28-31.

Thrikawala, S., A. Weersink, G. Kachnoski and G. Fox, 1999. Economic Feasibility of Variable Rate Technology for Nitrogen on Corn, American Journal of Agricultural Economics, 81: 914-27.

VanSickle J.J., S. Smith and E. McAvoy, 2009. Production Budget for Tomatoes in Southwest Florida, EDIS Publication: FE 818.

Wilson L.L., Madden L.V. and M.A. Ellis, 1990. Influence of Temperature and Wetness Duration on Infection of Immature and Mature Strawberry Fruit by *Colletotrichum acutatum*, Phytopathology, 80: 111-116.

Wu J., and K. Segerson, 1995. The Impact of Policies and Land Characteristics on Potential Groundwater Pollution in Wisconsin, American Journal of Agricultural Economics, 77: 1033-47.