A Risk Analysis of precision farming for tomato production

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Abstract

This paper compares precision farming technology with calendar-based approaches in scheduling fungicide applications to manage tomato late blight disease. Two fungicide scheduling strategies were evaluated: calendar-based strategy and BlightPro decision support system based strategy (DSS-based strategy). Using results from 14 years of computer simulation experiments for 25 locations in the United States, we constructed distributions of net return to all costs excluding fungicide cost and application cost (net return per acre) for the calendar-based and DSS-based strategies at each location. These distributions were then compared using three risk management methods: stochastic dominance, stochastic dominance with respect to a function, and stochastic efficiency with respect to a function. Results show that in terms of disease control, the DSS recommended spray schedule is more effective. Depends on the percentage of tomato yield improvement for DSS, the preferred strategy is different. Average net income over fungicide cost and average risk-adjusted net income for the DSS recommended spray schedule is lower for susceptible cultivars and higher for moderately susceptible cultivars and moderately resistant cultivars with no yield improvement for DSS strategy. The value added by DSS ranges from -$17.69 to $48.33 per acre with no tomato yield improvement for DSS strategy. When there are more than 5% yield improvement, DSS strategy is strong preferred strategy by tomato growers. Our research contributes to the literature by providing a method to evaluate the economic benefit of adopting DSS.

Key Words: Stochastic efficiency with respect to a function, precision farming, disease management

Introduction

The United States is the world's second leading producer of tomatoes, after China. Annually, U.S. fresh and processed tomatoes contribute more than $2 billion to cash farm income. California and Florida represent almost two thirds of total U.S. fresh tomato acreage. Ohio, Virginia, Georgia, Tennessee, North Carolina, New Jersey, and Michigan are also major tomato production states. Late blight infection is a persistent problem faced by tomato growers. It is highly contagious, and can be easily dispersed (Wale, Platt, and N. 2008). Every year, a tremendous amount of fungicide is applied to control late blight. Reducing the amount of fungicides applied to control late blight has both environmental and economic benefits. The emergence of precision farming technology can increase farming efficiency and reduce the environmental impact of input usage. However, the decision to adopt precision farming depends on the cost and return of the precision farming technology. In this study, a new potential application of precision agriculture to tomato plant disease control for late blight are examined.

The precision agriculture technology examined in this study is called the BlightPro decision support system (DSS). It uses precision farming technology to recommend precise and timely use of fungicide in accordance with weather conditions and pathogen inoculum. This system could potentially increase farm net returns and reduce risks (Fohner, Fry, and White 1984). The traditional management of late blight depends highly on preventative weekly fungicide application during the planting season (Song et al. 2003). However, late blight epidemics and thus the need for fungicide depends heavily on weather and the source of pathogen inoculum (Fohner, Fry, and White 1984). Consequently, a calendar based schedule may not be the most efficient or cost-effective method of applying fungicide to control late blight.

The efficacy of DSS in disease surpression and fungicide reduction has been an important topic of previous biology and pathology research (Fry, Apple, and Bruhn 1983, Fohner, Fry, and White 1984). Economic research in the area of late blight management is limited (Guenthner, Michael, and Nolte 2001, Johnson et al. 1997). Risk analyses in agriculture have been adopted to a wide range of individual decision making processes taking grower's behavior in face of income uncertainties into consideration (Parcell and Langemeier 1997, Harris and Mapp 1986, Llata et al. 1999, Ritchie et al. 2004, Zacharias and Grube 1984, Musser, Tew, and Epperson 1981, Cochran, Robison, and Lodwick 1985, Greene et al. 1985, Williams et al. 2014). Liu et al. (2017) evaluate the benefit of adopting precision agriculture in managing potato late blight. They identify that the DSS-based strategy was the most effective approach to managing late blight in terms of disease suppression, net return per acre, and risk-adjusted net return. Under high disease pressure circumstances, the economic benefits to potato growers of adopting the precision agriculture technology ranged from \$30 to \$573 per acre. However, risk analysis has not yet been applied in the area of tomato late blight precision farming adoption.

The intent of this paper is to contribute to the understanding of the economic incentives facing a grower choosing to adopt or not to adopt DSS through the analysis of net income over fungicide cost. The overall objective of this paper is to identify the most risk-efficient fungicide scheduling strategy. More specifically, we evaluate the economic benefits of scheduling fungicide applications between DSS and a 7-day spray schedule, when taking producers' risk aversion level into consideration.

Our analyses require the integration of different models covering DSS, pathology models, and economic components. DSS is used to develop a weather-based spray schedule. The LATEBLIGHT model (Andrade-Piedra et al. 2005), a pathology model, is used to simulate disease severity under different weather scenarios. Net income over fungicide cost distributions are developed for alternative fungicide application schedules from 2000 to 2013 in 25 locations in North Carolina, and New York. Three tomato cultivar resistance levels for late blight (susceptible, moderately susceptible and moderately resistant) are examined in this study. Stochastic dominance (Hadar and Russell 1969) and stochastic dominance with respect to a function (Meyer 1977) are used to compare pairwise late blight management choices between a calendar-based strategy and the DSS-based strategy. Stochastic efficiency with respect to a function (Hardaker et al. 2004, Hardaker and Lien 2010, Meyer, Richardson, and Schumann 2009) is used to identify the risk adjusted value of DSS.

Methods

Late blight creates a highly uncertain decision making environment. Recognizing this, this paper incorporates uncertainty and producers' risk attitudes into the decision making framework. Alternative decisions can be ranked with risk attitudes of each individual (Schumann 2011). In this paper, mutually exclusive alternative fungicide spray decisions faced by tomato growers (i.e., a calendar spray schedule and the DSS recommended spray schedule) are compared. Weather conditions in different years creates a distribution of net income. Computer simulation programs using historical weather data can generate an empirical probability distribution function for net income between alternative spray schedules. The probability distribution functions can then be ranked using stochastic efficiency procedures. Stochastic dominance (Hadar and Russell 1969; Hanoch and Levy 1969; Rothschild and Stiglitz 1970; Meyer 1977), and stochastic efficiency with respect to a function (Hardaker et al. 2004; Meyer, Richardson, and Schumann 2009; Hardaker and Lien 2010) are used to identify risk efficient fungicide application strategies and to compute the certainty equivalent of net income for each spray schedule.

Stochastic dominance and efficiency methods can be adopted to a wide range of individual decision making processes (Quirk and Saposnik 1962; Hadar and Russell 1969). They have been applied to evaluate various alternative decisions, such as beef farms insurance policies (Williams et al. 2014), contract options (Parcell and Langemeier 1997), tillage options (Varner, Epplin, and Strickland 2011), irrigation strategies (Harris and Mapp 1986), growing-finishing gilts diets (Llata et al. 1999), cotton planting acreage (Ritchie et al. 2004), crop rotation and weed control method (Zacharias and Grube 1984), farming machinery selection (Danok, McCarl, and White 1980), postharvest marketing strategies (King and Lybecker 1983), policy impacts (King and Oamek 1983), and integrated pest management strategies (Musser, Tew, and Epperson 1981; Moffitt, Tanigoshi, and Baritelle 1983; Greene et al. 1985; Cochran, Robison, and Lodwick 1985).

First degree stochastic dominance, second degree stochastic dominance, and stochastic dominance with respect to a function are used to identify risk efficient strategies between the DSS recommended spray schedule and a calendar spray schedule. Stochastic dominance with respect to a function requires information pertaining to absolute risk aversion coefficients. According to Raskin and Cochran (1986), this information can be obtained by dividing relative risk aversion coefficients by location specific average net income over fungicide cost. Relative risk aversion levels used for stochastic dominance with respect to a function include slightly risk averse (0-1.0), moderately risk averse (1.0-3.0) and strongly risk averse (3.0-4.0). The equation for transformation of relative risk aversion and absolute risk aversion is shown below.

$$r_a = r_r / w \qquad 1)$$

where r_a stands for absolute risk aversion, r_r stands for relative risk aversion, and w stands for average net income over fungicide cost among both risky alternatives for a specific location.

Stochastic efficiency with respect to a function is first used to calculate certainty equivalents, which is the risk adjusted value of net income over fungicide cost. Risky alternatives with higher CEs are preferred to alternatives with lower CEs (Hardaker et al. 2004, Meyer, Richardson, and Schumann 2009, Hardaker and Lien 2010). Stochastic efficiency with respect to a function is also used to identify the utility weighted risk premium (RP) or the value of information provided by DSS. The power utility function[1] was used to calculate the certainty equivalents. Relative risk aversion levels used for stochastic efficiency with respect to a function include 0, 1, 3, and 4.

Given a risk aversion level, the utility weighted risk premium (RP) can be calculated for the DSS spray schedule and the 7-day spray schedule using the following equation:

$$RP_{DSS,Calendar,R_a} = CE_{DSS,R_{a(w)}} - CE_{Calendar,R_{a(w)}} \tag{2}$$

where RP reflects the minimum amount of money ($/acre) that a decision maker is willing to pay for the new technology (Hardaker et al. 2004), which could also be viewed as the value of the information provided by DSS for tomato growers. When RP is positive, the DSS spray schedule is preferred to the 7-day spray schedule.

Data

The DSS field trial was conducted at the Mountain Horticultural Crops Research and Extension Center (MHCREC) in Mills River, NC in 2013 to 2015. In contrast to previous years, two cultivars were used in the trial: Susceptible tomato cultivar Mountain Fresh Plus was used

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[1] The power utility function exhibits decreasing absolute risk aversion and constant relative risk aversion. The functional form of power utility is as follows: $U(x) = \frac{x^{1-r}}{1-r}\ for\ r \neq 1; U(x) = \ln(x)\ for\ r = 1$.

in 2013 - 2015 trial and moderately resistant Legend was used in 2015 trial. Three treatments were set up: a control treatment, a treatment in which plants receive weekly sprays, and a treatment in which plants are sprayed based on recommendations of the DSS. Table 1 shows the tomato marketable weight in the field trial in 2013, 2014, and 2015. The yield improvement by using DSS compared with 7-day improved 7.2% in 2013, 3.7% in 2014, and 14.8% in 2015 for susceptible cultivar. For moderately susceptible cultivar, the yield improvement by using DSS compared with 7-day improved 22.2%.

Data generating process requires the use of DSS (Forbes et al. 2008), the LATEBLIGHT pathology model (Andrade-Piedra et al. 2005), and economic components. Two computer programs, Python^{TM} and SAS ®, are used to obtain the distribution of net income over fungicide cost for both 7-day and DSS spray schedules. The 7-day spray schedule is the most commonly adopted calendar spray schedule for fungicide application by tomato growers. Growers are also assumed to be able to initiate fungicide application based on the DSS recommendation. The Python^{TM} program is used to generate data for disease severity, and the number of fungicide applications by Ian Small and Laura Joseph from the Fry Lab at Cornell University. A SAS® program is then used to add economic components (tomato price, yield, fungicide cost) to construct net income over fungicide cost.

Disease severity and the number of fungicide applications are generated for three different levels of cultivar resistance (susceptible, moderately susceptible, and moderately resistant) in 25 locations from 2000 to 2013 in North Carolina and New York. Two basic components of the simulation programs are DSS (Forbes et al. 2008), and the LATEBLIGHT model (Andrade-Piedra et al. 2005). These components are presented in detail elsewhere (Forbes et al. 2008, Andrade-Piedra et al. 2005) and will not be discussed in detail in this paper.

A description of the generation of disease severity and the number of fungicide applications used in the DSS model is as follows. Historical weather data (rainfall, temperature, and humidity) for 25 locations was used to forecast the incidence of late blight and the number of fungicide applications. The plant growth season is assumed to be from 5/15 to 9/15 in New York and from 3/26 to 7/27 in North Carolina. A fungicide rate of 1.5 pints per acre of Bravo WeatherStik was assumed for each application and cultivar. DSS was used to generate DSS spray schedules for each year. The 7-day and DSS spray schedules were then incorporated into the LATEBLIGHT model (Andrade-Piedra, Hijmans, Juarez, et al. 2005). This model is used to simulate the disease epidemic for schedules involving each resistance category and season. The start time for late blight was randomly selected after the Blitecast forecast reached the severity value of 18.

The number of fungicide applications for each schedule were used to compute net income over fungicide cost for each weather scenario. A yield function that relates tomato production to late blight infection is currently not available. Because of this, yield losses are not incorporated into the analysis. Net income over fungicide cost is computed as follows:

$$\begin{aligned} &Net\ income\ over\ fungicide\ cost_{l,y,c,i} \qquad (3)\\ &\quad = Tomato\ \ price_{l,y} * average\ tomato\ yield_{l,y} * (1\\ &\quad + DSS\ Yield\ Improvement\ Percentage_{i})\\ &\quad - (Fungicide\ cost + application\ cost)\\ &\quad * number\ of\ application_{l,y,c,i}\end{aligned}$$

where l stands for the each of the 25 locations; y stands for the specific year; c stands for each cultivar (susceptible, moderately susceptible, and moderately resistant); and i refers to the 7-day or the DSS recommended spray schedule. Based on the field trial result, we assume that the DSS yield improvement percentage includes 5%, 10% and 15%. Tomato prices and average yields from 2000 to 20013 were obtained from USDA National Agricultural Statistics Service. Average yield and price were assumed to be the same among different cultivar resistance levels. As indicated above, Bravo WeatherStik (chlorothalonil) was used for each fungicide application. Application costs are listed in Table 2. Data pertaining to the number of fungicide applications were provided by Ian Small and Laura Joseph from the Fry Lab at Cornell University.

Analysis and Results

The Simulation and Econometrics to Analyze Risk (SIMETAR©) model developed by Richardson, Schumann and Feldman (2006) is used to conduct the stochastic efficiency analysis. Analysis is conducted for 25 locations in North Carolina and New York. Three cultivar resistant levels (susceptible, moderately susceptible, and moderately resistant) for tomatos are examined at each location. Microsoft Visual Basic for Applications (VBA) language was used to facilitate the computations obtained from SIMETAR.

Table 3 shows the summary of statistics for late blight disease rating. Table 4 shows the summary statistics for fungicide applications and tomato revenue with no yield difference between calendar-based and DSS-based strategy. For the susceptible cultivar, DSS requires a higher number of fungicide applications than the 7-day spray schedule, but also exhibits better disease control. For the moderately susceptible cultivars and the moderate resistant cultivars, DSS requires less fungicide applications than the 7-day spray schedule, and has better disease control. These results suggest that the timing of fungicide application is important in controlling late blight. Efficiently applying fungicide helps reduce fungicide applications and allows for more effective control of the disease. The average net income over fungicide cost for DSS is smaller than that for the 7-day spray schedule for the susceptible cultivars, but is relatively higher for the moderately susceptible and moderately resistant cultivars. Table 5 shows the summary statistics for tomato yield and tomato revenue with yield improvement of DSS-based strategy. When there is more than 5% yield improvement for DSS strategy, the tomato yield and net income over fungicide cost increased from the calendar-based strategy.

Table 6 summarize the results of the stochastic dominance analysis with no yield difference between Calendar-based and DSS-based strategy. This tables summarize the percentage of locations that were in the three possible efficient sets: 7-day, DSS, or both. DSS is strongly preferred for moderately susceptible and moderate resistant cultivars based on first degree stochastic dominance, second degree stochastic dominance, and stochastic dominance with respect to a function. Table 7 summaries the percentage of locations preferred DSS in risk efficient set with 5%, 10%, and 15% yield Improvement between Calendar-based and DSS-based strategy. For all cultivars, stochastic dominance with respect to a function shows that all of growers in the 25 locations would prefer the DSS recommended spray schedule over the 7-day spray schedule for all risk aversion levels.

Table 8 summarizes the average certainty equivalents for the 25 locations for each cultivar. Four different relative risk aversion levels were evaluated. DSS generates a lower certainty equivalent for each risk aversion level for susceptible cultivars and a higher certainty equivalent for each risk aversion level for moderately susceptible cultivars and moderately resistant cultivars. The risk premium ranges from -$28 to $48 per acre for the susceptible cultivars, the moderately susceptible cultivars, and the moderately resistant cultivars. Table 9 shows the risk premium of net income over fungicide costs per acre with 5%, 10%, and 15% yield inprovement between Calendar-based and DSS-based Strategy. The risk premium is higher for the DSS based strategy than the calendar based strategy.

Conclusions

This study used computer generated data from North Carolina and New York to examine the economic benefits of adopting precision farming technology to tomato production. In summary, DSS requires a higher number of fungicide applications for susceptible cultivars, and less fungicide applications for moderately susceptible cultivars and moderately resistant cultivars. For all the cultivars, DSS is more effective in controlling disease than the calendar spray schedule. For the susceptible cultivars, the calendar spray schedule was preferred. Conversely, DSS was the preferred risk strategy for moderately susceptible cultivars and moderately resistant cultivars. Without yield improvement of between the DSS-based strategy and Calendar based strategy, the value of DSS ranged from -$28 to $48 per acre. With yield improvement of between the DSS-based strategy and Calendar based strategy, the value of DSS ranged from $ 496 to $1,687 per acre.

Our research contributes to the literature by providing a method to evaluate the economic benefits of adopting DSS. Knowing the value of the information provided by DSS can help to promote DSS to tomato growers for adoption. This would help improve late blight management actions taken by growers to control the spread of the disease and limit potential loss. The improvement in productivity will help to ensure food security for the growing population.

References

Andrade-Piedra, J. L., R. J. Hijmans, H. S. Juarez, G. A. Forbes, D. Shtienberg, and W. E. Fry. 2005. "Simulation of potato late blight in the Andes. II: Validation of the LATEBLIGHT model." *Phytopathology* 95 (10):1200-1208. doi: 10.1094/phyto-95-1200.

Cochran, M. J., L. J. Robison, and W. Lodwick. 1985. "Improving the efficiency of stochastic dominance techniques using convex set stochastic dominance." *American Journal of Agricultural Economics* 67 (2):289-295. doi: 10.2307/1240681.

Fohner, G. R., W. E. Fry, and G. B. White. 1984. "Computer-simulation raises question about timing protectant fungicide application frequency according to a potato late blight forecast." *Phytopathology* 74 (10):1145-1147. doi: 10.1094/Phyto-74-1145.

Forbes, G. A., W. E. Fry, J. L. Andrade-Piedra, and D. Shtienberg. 2008. "Simulation models for potato late blight management and ecology." *Integrated Management of Diseases Caused by Fungi, Phytoplasma and Bacteria* 3:161-177. doi: 10.1007/978-1-4020-8571-0_8.

Fry, W. E., A. E. Apple, and J. A. Bruhn. 1983. "Evaluation of potato late blight forecasts modified to incorporate host-resistance and fungicide weathering." *Phytopathology* 73 (7):1054-1059. doi: 10.1094/Phyto-73-1054.

Greene, C. R., R. A. Kramer, G. W. Norton, E. G. Rajotte, and R. M. McPherson. 1985. "An economic analysis of soybean integrated pest management." *American Journal of Agricultural Economics* 67 (3):567-572. doi: 10.2307/1241077.

Guenthner, J. F., K. C. Michael, and P. Nolte. 2001. "The economic impact of potato late blight on US growers." *Potato Research* 44 (2):121-125. doi: 10.1007/bf02410098.

Hadar, J., and W. R. Russell. 1969. "Rules for ordering uncertain prospect." *American Economic Review* 59 (1):25-34.

Hardaker, J. B., and G. Lien. 2010. "Stochastic efficiency analysis with risk aversion bounds: a comment." *Australian Journal of Agricultural and Resource Economics* 54 (3):379-383. doi: 10.1111/j.1467-8489.2010.00498.x.

Hardaker, J. B., J. W. Richardson, G. Lien, and K. D. Schumann. 2004. "Stochastic efficiency analysis with risk aversion bounds: a simplified approach." *Australian Journal of Agricultural and Resource Economics* 48 (2):253-270. doi: 10.1111/j.1467-8489.2004.00239.x.

Harris, T. R., and H. P. Mapp. 1986. "A stochastic dominance comparison of water-conserving irrigation strategies." *American Journal of Agricultural Economics* 68 (2):298-305. doi: 10.2307/1241431.

Johnson, D. A., T. F. Cummings, P. B. Hamm, R. C. Rowe, J. S. Miller, R. E. Thornton, G. Q. Pelter, and E. J. Sorensen. 1997. "Potato late blight in the Columbia Basin: An economic analysis of the 1995 epidemic." *Plant Disease* 81 (1):103-106. doi: 10.1094/pdis.1997.81.1.103.

Liu, Y., M. Langemeier, I. Small, L. Joseph, and W. Fry. 2017. "Risk management strategies using precision agriculture technology to manage potato late blight." *Agronomy Journal*. doi: doi: 10.2134/agronj2016.07.0418.

Llata, M. de la, M. Langemeier, S. S. Dritz, M. D. Tokach, R. D. Goodband, J. L. Nelssen, and M. de la Llata. 1999. "Economics of adding fat and increasing lysine:calorie ratio in diets for growing-finishing gilts." *Kansas State University Swine Day 1999. Report of Progress 841*:113-116.

Meyer, J. 1977. "Choice among distributions." *Journal of Economic Theory* 14 (2):326-336. doi: 10.1016/0022-0531(77)90134-x.

Meyer, J., J. W. Richardson, and K. D. Schumann. 2009. "Stochastic efficiency analysis with risk aversion bounds: a correction." *Australian Journal of Agricultural and Resource Economics* 53 (4):521-525. doi: 10.1111/j.1467-8489.2009.00471.x.

Musser, W. N., B. V. Tew, and J. E. Epperson. 1981. "An economic examination of an integrated pest management production system with a contrast between E-V and stochastic dominance analysis." *Southern Journal of Agricultural Economics* 13 (1):119-124.

Parcell, J. L., and M. R. Langemeier. 1997. "Feeder-pig producers and finishers: who should contract?" *Canadian Journal of Agricultural Economics-Revue Canadienne D Agroeconomie* 45 (3):317-327. doi: 10.1111/j.1744-7976.1997.tb00211.x.

Ritchie, J. W., G. Y. Abawi, S. C. Dutta, T. R. Harris, and M. Bange. 2004. "Risk management strategies using seasonal climate forecasting in irrigated cotton production: a tale of stochastic dominance." *Australian Journal of Agricultural and Resource Economics* 48 (1):65-93. doi: 10.1111/j.1467-8489.2004.t01-1-00230.x.

Schumann, K. D. 2011. "Semi-nonparametric test of second degree stochastic dominance with respect to a function." *Journal of Econometrics* 162 (1):71-78. doi: 10.1016/j.jeconom.2009.10.009.

Song, J. Q., J. M. Bradeen, S. K. Naess, J. A. Raasch, S. M. Wielgus, G. T. Haberlach, J. Liu, H. H. Kuang, S. Austin-Phillips, C. R. Buell, J. P. Helgeson, and J. M. Jiang. 2003. "Gene RB cloned from Solanum bulbocastanum confers broad spectrum resistance to potato late blight." *Proceedings of the National Academy of Sciences of the United States of America* 100 (16):9128-9133. doi: 10.1073/pnas.1533501100.

Wale, S., H. W. Platt, and Cattlin N. 2008. *Diseases, pests and disorders of potatoes: a color handbook*. Burlington, MA, USA: Academic Press.

Williams, J. R., A. T. Saffert, G. Barnaby, R. V. Llewelyn, and M. R. Langemeier. 2014. "A risk analysis of adjusted gross revenue-lite on beef farms." *Journal of Agricultural and Applied Economics* 46:227-244.

Zacharias, T. P., and A. H. Grube. 1984. "An economic evaluation of weed control methods used in combination with crop rotation: a stochastic dominance approach." *North Central Journal of Agricultural Economics* 6 (1):113-120. doi: 10.2307/1349306.

Table 1 Tomato Marketable Weight (Tons/A)

	2013	2014	2015	
	Mountain Fresh Plus	**Mountain Fresh Plus**	**Mountain Fresh Plus**	**Legend**
Control	4.835	0	6.15	7.29
7-Day	35.52	2.38	38.61	23.91
DSS	38.07	2.47	44.33	29.22

Table 2. Fungicide application cost in 2013.

Name	Quantity	Fungicide Cost	Application Cost	Total fungicide application cost
Bravo WeatherStik	1.5 pints	$8.63 /acre/application	$6.58 /acre/application	$15.21 acre/application

*Fungicide price is obtained from local agricultural chemical distributor on Long Island by Dr. M. T. McGrath in April 2013. Application cost ($6.58/acre/application) comes from Lazarus (2013). USDA Prices Paid Indices (Ag Chem & mach) are used to adjust the fungicide price and application cost in 2013 to nominal prices in previous years.

Table 3. Summary statistics for blight disease rating. The number of observations is 316.

	Control				Calendar				DSS			
AUDPC	Mean	S.D	Min	Max	Mean	S.D	Min	Max	Mean	S.D.	Min	Max
Susceptible Cultivars	1688	1900	0	6846	402	973	0	5625	91	278	0	2365
Moderately Susceptible Cultivars	1429	1773	0	6491	243	761	0	6124	225	524	0	3346
Moderately Resistant Cultivars	570	1087	0	4968	16	117	0	1517	26	100	0	1112

Table 4. Summary statistics for fungicide applications and tomato revenue with no yield difference between calendar-based and DSS-based strategy. The number of observations is 316.

Item	Calendar				DSS			
	Mean	S.D	Min	Max	Mean	S.D.	Min	Max
Susceptible Cultivars								
Number of Fungicide Applications	11	0	11	11	13.3	3.3	1.0	21.0
Tomato Yield (cwt/acre)	245.0	85.4	140.0	440.0	245.0	85.4	140.0	440.0
Cost of Fungicide Applications ($/acre)	133.7	19.3	110.7	167.3	161.8	45.8	12.8	286.6
Net Return per Acre ($/acre)	10926	2572	6450	16685	10898	2566	6395	16774
Moderately Susceptible Cultivars								
Number of Fungicide Applications	11	0	11	11	9.2	2.3	1.0	15.0
Tomato Yield (cwt/acre)	245.0	85.4	140.0	440.0	245.0	85.4	140.0	440.0
Cost of Fungicide Applications ($/acre)	133.7	19.3	110.7	167.3	112.2	32.5	12.8	204.7
Net Return per Acre ($/acre)	10926	2572	6450	16685	10948	2571	6464	16789
Moderately Resistant Cultivars								
Number of Fungicide Applications	11	0	11	11	7.1	1.7	1.0	11.0
Tomato Yield (cwt/acre)	245.0	85.4	140.0	440.0	245.0	85.4	140.0	440.0
Cost of Fungicide Applications ($/acre)	133.7	19.3	110.7	167.3	85.8	23.7	12.8	150.1
Net Return per Acre ($/acre)	10926	2572	6450	16685	10974	2574	6491	16804

Table 5 Summary statistics for tomato yield and tomato revenue with yield improvement of DSS-based strategy. The number of observations is 316.

	DSS Yield Improvement Percentage											
	5%				10%				15%			
Item	Mean	S.D	Min	Max	Mean	S.D	Min	Max	Mean	S.D.	Min	Max
Susceptible Cultivars												
Tomato Yield (cwt/acre)	257.3	89.7	147.0	462.0	269.5	93.9	154.0	484.0	281.8	98.2	161.0	506.0
Net Return per Acre ($/acre)	11451	2696	6725	17616	12004	2825	7055	18459	12557	2954	7385	19301
Moderately Susceptible Cultivars												
Tomato Yield (cwt/acre)	257.3	89.7	147.0	462.0	269.5	93.9	154.0	484.0	281.8	98.2	161.0	506.0
Net Return per Acre ($/acre)	11501	2700	6794	17631	12054	2829	7124	18474	12607	2958	7454	19316
Moderately Resistant Cultivars												
Tomato Yield (cwt/acre)	257.3	89.7	147.0	462.0	269.5	93.9	154.0	484.0	281.8	98.2	161.0	506.0
Net Return per Acre ($/acre)	11527	2703	6821	17646	12080	2832	7151	18488	12633	2961	7481	19331

Table 6. Percentage of Locations in Risk Efficient Set with No Yield Difference between Calendar-based and DSS-based Strategy.

Item	7-Day	DSS	Both
Susceptible Cultivars			
FSD	28.0%	0.0%	72.0%
SSD	64.0%	16.0%	20.0%
SDRF			
Slightly Risk Averse	92.0%	8.0%	0.0%
Moderately Risk Averse	92.0%	8.0%	0.0%
Strongly Risk Averse	84.0%	8.0%	8.0%
Moderately Susceptible Cultivars			
FSD	4.0%	32.0%	64.0%
SSD	8.0%	84.0%	8.0%
SDRF			
Slightly Risk Averse	16.0%	84.0%	0.0%
Moderately Risk Averse	16.0%	84.0%	0.0%
Strongly Risk Averse	16.0%	84.0%	0.0%
Moderately Resistant Cultivars			
FSD	0.0%	100.0%	0.0%
SSD	0.0%	100.0%	0.0%
SDRF			
Slightly Risk Averse	0.0%	100.0%	0.0%
Moderately Risk Averse	0.0%	100.0%	0.0%
Strongly Risk Averse	0.0%	100.0%	0.0%

Table 7. Percentage of Locations Preferred DSS in Risk Efficient Set with Yield Improvement between Calendar-based and DSS-based Strategy.

	DSS		
Item	5%	10%	15%
Susceptible Cultivars			
FSD	100.0%	100.0%	100.0%
SSD	100.0%	100.0%	100.0%
SDRF			
Slightly Risk Averse	100.0%	100.0%	100.0%
Moderately Risk Averse	100.0%	100.0%	100.0%
Strongly Risk Averse	100.0%	100.0%	100.0%
Moderately Susceptible Cultivars			
FSD	100.0%	100.0%	100.0%
SSD	100.0%	100.0%	100.0%
SDRF			
Slightly Risk Averse	100.0%	100.0%	100.0%
Moderately Risk Averse	100.0%	100.0%	100.0%
Strongly Risk Averse	100.0%	100.0%	100.0%
Moderately Resistant Cultivars			
FSD	100.0%	100.0%	100.0%
SSD	100.0%	100.0%	100.0%
SDRF			
Slightly Risk Averse	100.0%	100.0%	100.0%
Moderately Risk Averse	100.0%	100.0%	100.0%
Strongly Risk Averse	100.0%	100.0%	100.0%

Table 8. Certainty Equivalent of Net Income over Fungicide Costs per Acre with No Yield Difference between Calendar-based and DSS-based Strategy.

Item	Spray Schedule		Risk Premium
	7-Day	DSS	DSS over 7-Day
Susceptible Cultivars			
r=0	$10,974	$10,946	$(28)
r=1	$10,855	$10,827	$(28)
r=3	$10,636	$10,608	$(28)
r=4	$10,536	$10,508	$(28)
Moderately Susceptible Cultivars			
r=0	$10,974	$10,995	$21
r=1	$10,855	$10,876	$21
r=3	$10,637	$10,658	$21
r=4	$10,536	$10,558	$22
Moderately Resistant Cultivars			
r=0	$10,974	$11,022	$48
r=1	$10,855	$10,903	$48
r=3	$10,637	$10,684	$48
r=4	$10,537	$10,584	$48

Note: r is the relative risk aversion coefficient. A power utility function is assumed.

Table 9. Risk Premium of Net Income over Fungicide Costs per Acre with Yield Inprovement between Calendar-based and DSS-based Strategy.

	Risk Premium DSS over 7-Day		
Item	5%	10%	15%
Susceptible Cultivars			
r=0	$527	$1,082	$1,638
r=1	$518	$1,065	$1,611
r=3	$503	$1,034	$1,564
r=4	$496	$1,020	$1,543
Moderately Susceptible Cultivars			
r=0	$576	$1,132	$1,687
r=1	$568	$1,114	$1,661
r=3	$552	$1,083	$1,614
r=4	$545	$1,069	$1,593
Moderately Resistant Cultivars			
r=0	$603	$1,158	$1,714
r=1	$594	$1,141	$1,687
r=3	$578	$1,109	$1,640
r=4	$571	$1,095	$1,619