A. Grant Data:

Today's Date:
Category: Northeast Regional IPM Competitive Grants Program (RIPM)
Project Title: Site-Specific Management of Resistance (SMOR) in the Control of Apple Scab: Final Phase of Development and Implementation
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States Involved: Maine, New Hampshire, Vermont, Rhode Island, Connecticut, Massachusetts, New York, West Virginia
Grant #:
Year the Grant was Awarded: 2005
Length of the Grant: 3 years
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B. Non-technical Summary:

In climates with cool and humid weather during spring, apple scab caused by *Venturia inaequalis* represents the economically most important disease of apples (MacHardy 1996; MacHardy et al. 2001). Under severe infection conditions, diseased apple trees can be defoliated prematurely, but the economically most important symptoms are scab lesions on apple fruits, which are intolerable for the profitable fresh apple market. While both pre-infection (protectant) and post-infection fungicides are available for control of apple scab, each has advantages and disadvantages. The apple scab fungus will not develop resistance to protectant fungicides, but these are often applied at weekly intervals. Post-infection fungicides are usually applied according to weather conditions and allow growers greater flexibility in practicing IPM, but the pathogen will develop fungicide resistance and when this occurs is unbeknownst to growers and may lead to unanticipated crop losses. Site-specific Management of Resistance (SMOR) tests the apple scab fungus in individual orchard operations for resistance levels to four classes of post-infection fungicides: dodine, the demethylation inhibitors (DMI), the quinone outside inhibitors (QoI) (strobilurins) and the anilino-pyrimidines (AP). Resistance is defined as the sensitivity of an orchard where a formerly successful program failed to provide commercially acceptable control of apple scab (Köller et al. 1997; Köller et al. 1999). SMOR test results are provided to growers with careful and cautious recommendations of how to utilize all post-infection fungicides without the risk of crop losses caused by resistance. All monitoring data and knowledge can be utilized in apple scab management programs once sensitivity levels to all classes of post-infection fungicides have been determined. SMOR will undoubtedly increase the reliability of apple scab management and will slow the development of resistance to classes of modern fungicides. Currently we are able to provide to growers a simple, sensitive orchard test with effective management recommendations based on orchard-specific sensitivities of the apple scab fungus.

C. Introduction:

Domesticated apples (*Malus x domesticus* Borkh) are the most important fruit crop grown in the NE-IPM region, with a value of $260 million in 2003. Apple scab, caused by *V. inaequalis* is the most economically important disease of apples and leads to considerable crop losses in production areas. Under severe infection conditions, diseased apple trees can defoliate prematurely, and from an economic perspective, scab lesions on fruit at harvest are not tolerated in the profitable fresh market venue. Economic losses incurred by apple scab lesions on fruit have increased dramatically over the past decade due to the rapidly declining profitability of apple production for the processing market, which is saturated by low-cost imports of juice concentrate. Fruit with scab lesions at harvest are downgraded from fresh to processing quality, accompanied by a decline in revenues from $0.30 to $0.05 per pound, or from potentially $6000 to $1000 per acre (USDA 2003). The revenue received for processing apples in the US is currently lower than the cost of production.

Apple scab is ubiquitous in the northeastern US and must be managed with 4-10 applications of fungicide per season. Conventional protectant fungicides have been under continuous scrutiny regarding their toxicology and their poor fit into IPM programs. Fungicides with post-infection activity have been developed as an alternative to protectant fungicides, but their potential to develop resistance may render them ineffective in apple scab control. Outbreaks of apple scab caused by resistance to fungicides have become increasingly damaging. In addition, levels of resistance can vary from one location to another making management decisions challenging. Fungicide management programs can be adapted to effectively use classes of fungicides with low 'environmental' risks when the sensitivity level of an orchard is known.

SMOR provides information about the sensitivity of an orchard thereby allowing growers to utilize low risk fungicides without risking unexpected crop loss. The SMOR concept consists of orchard-specific sensitivity tests combined with management recommendations based on the sensitivity of the particular apple scab populations to the low risk fungicide options available-dodine, DMIs, APs and QoIs.

SMOR will significantly enhance environmental quality by promoting the continued use of modern fungicides and at the same time will eliminate wasteful use of fungicides to which apple scab is no longer sensitive. The general concept of SMOR has the potential to have national and international impact on management of pesticide resistance in general, with broad impact on multiple stakeholders. Developing a process to streamline the implementation of SMOR as a service to apple growers constituted the major thrust of this project.

D. Objectives:

I. Final phase of technical development

We have succeeded in developing a unified and simplified sensitivity test for *V. inaequalis* populations causing apple scab. Based upon the analysis of all test results over the past four years, we found that the reproducibility and precision as well as the season-to-season reproducibility of our SMOR test procedure was sufficient to rank orchard sensitivities into four functional categories:

sensitive	good performance is expected
slight shift	good performance is expected under "normal" disease pressure and at high label rates
strong shift	performance must be supplemented
resistant	insufficient contribution to scab management

The practicality of SMOR in conjunction with its impact on management choices has been continuously shared with extension personnel, consultants and growers.

II. Preparing the ground for broad implementation

Interest in SMOR testing is high with spontaneous requests for testing this year continuing at a level equivalent to previous years. However, growers are reluctant to pay for the service and we have not been able to assess the source of their reluctance. A grower-focused survey could provide us not only with information regarding our previous testing, but also with grower input into how we can improve the testing to make a pay-for-service test both attractive and needs based. Such a survey was proposed in the original grant but has not yet been completed. In addition, a business plan was considered and deemed unnecessary.

E. Approach:

In our test we treat the 50,000 asexually produced conidia suspended from a single apple scab lesion as a single isolate of the pathogen. Distinct scab lesions are cut as discs from diseased leaves, placed individually into open microfuge tubes and stored at room temperature until processing. For processing, stored conidia are suspended in 1 ml water, and 100 µl portions are transferred onto PDA amended with fungicides. Antibiotics are included in the media to inhibit bacterial growth. Germ tube elongation/mycelial growth is measured after 7 days of incubation using video image analysis that allows on-screen colony size measurements and automatic transfer of data to a spreadsheet. Quantitative tests are conducted on all four fungicide classes with myclobutanil (0.1 µg/ml) as a DMI representative, dodine (0.2 µg/ml), pyrimethanil (0.2 µg/ml) as an AP representative and trifloxystrobin (0.2 µg/ml and 0.2 µg/ml + 100 µg/ml SHAM) as a strobilurin representative. Cross-resistance for all members within a fungicide class has been verified (Köller et al. 1991; 1997; 2004; 2005). The two variants of the strobilurin test detect both gradual population responses but also immune target site mutants expected to emerge during the final stage of resistance development (Köller et al. 2004).

Sensitivity data of orchards is analyzed through comparison with baseline and threshold sensitivities. We have assembled these crucial baseline and threshold sensitivity data-bases from results obtained over three years of orchard testing. Statistical comparison of the mean relative growth (*t*-test) and the frequency of isolates designated resistant (chi-square test) with both baseline and threshold sensitivities assigns a sensitivity category to the orchard tested.

F. Progress:

In the final year of the grant, the mechanics of sample intake, processing, testing, data analysis and report distribution have been streamlined. The cost of orchard testing has decreased as a result of greater efficiency that will hopefully translate into a greater interest in pay-for-service testing. The structure of the program ensures that testing can be effectively conducted with fewer staff, providing additional savings. The impact of SMOR testing can readily be assessed now that we have the data to make multiple year comparisons. Familiarity with the service has been publicized in grower publications, through consultants and most extensively through the cooperative extension network. This focus has increased interest in SMOR testing, with increased requests in the year following the conclusion of the grant based on previous year's interest. Growers have responded positively to the information provided to them in the orchard report and the importance of the information in assisting them in making management decisions.

G. Results:

Multi-year SMOR testing has confirmed the consistency of the test and the reliability of management options generated from the test results. Management changes suggested in response to testing results yielded excellent control of scab in subsequent seasons. However, the number of cases has been small requiring additional comparisons to validate the process. We also found that all apple growers with whom we have cooperated employed a uniform scab management program throughout all orchard sites within their production units. Not surprisingly, the sensitivities of three individual orchard sites within a single production unit we tested in 2004 were almost identical suggesting that sensitivity tests conducted in one typical orchard per operation will reflect the status quo throughout the entire operation. In addition, there are instances in which growers have also consolidated operations through orchard purchase. The fungicide use in purchased orchards may have been different from core operations requiring SMOR testing of sensitivities in the acquired orchard.

SMOR testing of a total of 101 commercial orchards throughout the northeast, Ohio and Wisconsin has been completed. With 84 orchards reaching or exceeding the level of practical resistance, this testing confirmed the rapidly declining efficacy of DMIs in the management of apple scab. With respect to dodine, 49 orchards tested sensitive or only slightly shifted relative to resistance levels. This might signal an opportunity to cautiously re-consider dodine as a component of current programs of apple scab management. According to the analysis of SMOR test data, significant quantitative sensitivity shifts were apparent after only a few applications of strobilurins were made. In 2007, one orchard in NY suggested a first case of immunity, a result since confirmed through sequencing of the target site gene (Cox and Köller, unpublished results). These results confirmed the prediction made earlier (Köller et al. 2004) that no more than 20 strobilurin applications in total can lead to target-site immunity. The class of AP fungicides continues to be a challenge. We have related their continuously disappointing scab performances in our DMI-resistant experimental test orchard to an interdependence of isolate sensitivities to both APs and DMIs (Köller et al. 2004), confirming the earlier observation that repeated rounds of resistance can predispose *V. inaequalis* populations to an accelerated speed of resistance development to a class of fungicides introduced later (Köller and Wilcox 2001). Our SMOR test results appear to verify these previous observations. We found that most (but not all) commercial orchards we tested deviated significantly from the baseline sensitivity level we have established for the APs (Köller et al. 2004), even though respective growers had never used this class of fungicides.

H. Impacts:

Unexpected outbreaks of fruit scab impact apple production economically. These outbreaks result from the increasing severity of resistance to fungicides leading to fewer choices for growers in managing orchards. Reversion to exclusive use of protectants is an option, but fits poorly into IPM programs and excludes the use of fungicides with low 'environmental' risks. These "low risk" fungicides have a specific mode of action and thereby reduce the amount of material used per acre. SMOR allows growers to design management programs that include "low risk" fungicides and are specific to their orchards without risking revenue losses caused by resistance. In addition, testing will reduce the use of ineffective fungicides in areas where resistance is documented.

Economic losses incurred from unexpected outbreaks of resistance have increased as sensitivity to fungicides diminishes. One lesion will downgrade an apple from wholesale to juice quality. Where the value of wholesale apples would be valued at $6000, a comparable juice crop would yield only $1000, leading to an economic loss of $5000. Site-specific management of orchards will lead to greater mitigation of unexpected crop losses. In all the 101 orchards tested over the length of the grant, the sensitivity analysis provided improved management decisions resulting in enhanced control.

In one orchard, management practices for subsequent seasons were modified based on SMOR tests, resulting in excellent control of apple scab in subsequent seasons. The choice of which fungicide to use was selected with IPM principals in mind. Not only were low risk fungicides used in the spray program but these fungicides were also known to be effective in this particular orchard setting.

Continuous contact with growers, consultants, and cooperative extension personnel is maintained through publications and websites. Articles have appeared in newsletters in New York, Massachusetts, and West Virginia, such as *Fruit Fax,* the *Northeastern NY Fruit Newsletter,* the *Hudson Valley Fruit Newsletter, Scaffolds,* and *Fruit Notes.* Results of SMOR have also been presented at regional fruit worker meetings of extension educators and faculty, including the Canadian, New York, and New England Fruit Pest Management Conference, the Great Lakes Fruit Workers Annual Conference, the Cumberland-Shenandoah Fruit Workers Conference, and the New York Winter Fruit Schools in the Hudson Valley, and Northeastern New York, the New England Fruit Meeting and Trade Show, and the Mid-Atlantic Fruit and Vegetable Convention.

I. Appendices:

Printed fact sheets or other publications

Scaffolds: www.nysaes.cornell.edu/ent/scafolds/
Scaffolds subscription level: 300 units
Scaffolds website unique sessions: approximately 4000 per month

Cooley, D. 2006. Second Opinion on Scab Inoculum Reduction. Scaffolds Vol. 15 No. 1.
Köller, W. 2007a. Apple Scab and Post-Infection Fungicides, Part I. Scaffolds Vol. 16 No. 3.
Köller, W. 2007b. Apple Scab and Post-Infection Fungicides, Part II. Scaffolds Vol. 16 No. 7.
Köller, W. 2007c. Apple Scab and Post-Infection Fungicides, Part III. Scaffolds Vol. 16 No. 9.
Köller, W. and Parker, D. M. 2006. Apple Scab and Fungicide Resistance. Scaffolds Vol. 15 No. 10.
Köller, W. and Rosenberger, D. 2005. Managing Scab Resistance to Fungicides. Scaffolds Vol. 14 No. 2.
Köller, W. and Parker, D. m. 2005. Testing Scab Resistance to Fungicides: SMOR as a Service. Scaffolds Vol. 14 No. 8.
Rosenberger, D. and Köller, W. Revising Scab Control Strategies for 2004. Scaffolds Vol. 13 No. 1.

Köller, W., Wilcox, W.F., and Parker, D.M. 2005. Sensitivities of *Venturia inaequalis* populations to anilinopyrimidines and their contribution to scab management in New York. Plant Dis. 89:357-365
Cox, K. D., Russo, N. L., Parker, D. M., Villani, S. M., and Köller, W. 2008. QoI qualitive resistance and CYP51A upstream anomalies in NY populations of the apple scab pathogen *Venturia inaequalis*. Phytopathology: in press.

Web pages and url's

Tree Fruit and Berry Pathology: http://www.nysaes.cornell.edu/pp/extension/tfabp/smor.htm

J. References:

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Köller, W., Parker, D. M., Turecheck, W. W., Avila-Adame, C., and Cronshaw, K. 2004. A two-phase resistance response of *Venturia inaequalis* populations to the QoI fungicides kresoxim-methyl and trifloxystrobin. Plant Dis. 88: 537-544.
Köller, W., Wilcox, W. F., and Parker, D. M. 2005. Sensitivities of *Venturia inaequalis populations* to anilinopyrimidines and their contribution to scab management in New York. Plant Dis.: in press.
MacHardy, W. E. 1996. Apple Scab - Biology, Epidemiology, and Management. APS Press, St. Paul, 545 pp.
MacHardy, W. E., Gadoury, D. M., and Gessler, C. 2001. Parasitic and biological fitness of *Venturia inaequalis*: Relationship to disease management strategies. Plant Dis. 85:1036-1051.
USDA. 2003. Non-citrus fruits and nuts. – Final Estimates 1997-2002, edited by S. G. N. S. – (03).