

PROJECT DESCRIPTION

PROBLEM, BACKGROUND AND JUSTIFICATION

Problem

In climates with cool and humid weather conditions 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 not tolerated on apple produced for the profitable fresh market. In the US, scab affects the production of apples in all states of the NE-IPM region, Michigan, Virginia, North Carolina and the coastal regions of Oregon and California.

Control of scab with fungicides continues to be the major management tool available to commercial apple growers (MacHardy et al. 2001), with 4-10 applications made during the scab season, depending on the quality of fungicides employed. During the past five decades, apple growers have utilized several classes of scab fungicides, starting in the 1940s with the introduction of the carbamates such as ferbam and progressing to the EBDCs (such as mancozeb) and captan both introduced in the 1950s. The mode of action of the EBDCs and captan, which remain in wide use, is **nonspecific**. Consequently, such fungicides **must** be confined to the surface of the plant tissue to be **protected**. If they were allowed to penetrate the cuticles of leaves and fruits in order to reach the scab pathogen already established inside the host, they would act phytotoxic (Köller 1999).

The nonspecific mode of action inherent to all older conventional protectants has advantages and disadvantages. The most striking **advantage** is that resistance to these fungicides has never become a problem. Disadvantages of the EBDCs and captan have been the continuous toxicological scrutiny by EPA. Captan was granted a Reregistration Eligibility Decision (RED) under FQPA and appears to remain available in the near future. However, a RED is still pending for the EBDCs, and their utility has further been restricted by a recent ban of EBDC use in the production of apples exported to Europe. Furthermore, captan is phytotoxic when applied with mineral oils and the EBDCs are toxic to predatory mites. Both effects are incompatible with the integrated control of mites (Agnello et al. 1999).

An additional important disadvantage of conventional protectants is the inherent lack of post-infection activities (Szkolnik 1981). They must be deposited on plant surfaces **prior** to infection events in order to **prevent penetration** of pathogen spores into the host tissue, and fungicide deposits must be renewed frequently in order to protect new growth and to replenish residues washed off during rain events. In order to be effective, control programs must be started very early, at the growth stage of 'green tip', and then continued with 6-9 applications at weekly intervals. These routine applications of conventional protectants do not comply with the IPM principle of employing pesticides only when needed.

Reliable forecasting models for scab infections have been developed, refined and implemented (MacHardy et al. 2001), and they enable apple growers to **respond** to infection periods **after** they have occurred. Such targeted responses would require highly specific scab fungicides active in a **post-infection** mode of application. The first **post-infection** scab fungicide introduced in the early 1960s was dodine (Syllit). Dodine was accepted rapidly as a new and very convenient tool in the post-infection management of scab (Gilpatrick 1982). Other classes of post-infection fungicides introduced in succession were the benzimidazoles benomyl (benlate)

and thiophanate (Topsin M) in the early 1970s (Gilpatrick 1982), the sterol-demethylation inhibitors (DMIs) fenarimol (Rubigan), myclobutanil (Nova) and triflumizole (Procure) in the late 1980s (Köller et al. 1997), the strobilurins kresoxim-methyl (Sovran) and trifloxystrobin (Flint) in 1999 (Köller et al. 2004) and the anilinopyrimidine (AP) cyprodinil (Vangard), also in 1999, with the AP pyrimethanil (Scala) pending registration (Köller et al. 2005).

As described in greater detail below, populations of *Venturia inaequalis*, the causal agent of apple scab, have developed or will develop **resistance** to all classes of specific post-infection fungicides (Köller 1990; 1994; 1995; 1996; 2001). We define resistance as the sensitivity of a particular orchard population at which a formerly successful fungicide class failed to provide commercially acceptable control of scab (Köller et al. 1997; 1999). We have found over the past 15 years of monitoring sensitivities of *V. inaequalis* populations that outbreaks of resistance were **unexpected** by the growers affected and rarely caused by inadequate management practices (Köller et al. 1997; 1999). We also found that resistance, once established in an orchard, remained stable over several decades (Köller et al. 1997; Köller et al. 2001).

The **economical losses** incurred by **unexpected outbreaks** of resistance have increased dramatically over the past decade. Traditionally, apple production in the NE has served both the fresh and the processing market. During the past five years, however, the profitability of producing apples for the processing market (in particular the 'juice' market) has sharply declined in response to low-cost imports of juice concentrate. A statement made under the 2002 NE PMC "Crop Profile for Apples in Rhode Island" describes these economic constraints: "If adequate pest control products were not available, cider apples would be the only option with values at \$.03 per pound vs. \$.30 - .40 per pound of wholesale apples currently". With a typical yield of 18,000 pounds/acre, the crop value would calculate to: 'Juice apples' = \$540/acre; 'Wholesale apples' = \$6,300/acre. A single fully developed scab lesion will downgrade an apple from "wholesale" to "juice" quality, and thus will decrease its **value** by **90%**. Consequently, unexpected outbreaks of practical resistance to the various classes of 'low-risk' scab fungicides have caused and will cause increasingly severe economical losses. The question is, whether and how growers can be **protected** from such unexpected losses without being forced to abandon the use of **all** modern 'low-risk' fungicides.

Resolving this question would require that apple growers (1) are aware of the level of resistance to **all** post-infection fungicide options in their individual orchards, and that (2) this knowledge would allow them to design 'state of the art' scab management programs without risking unexpected control failures. This rational approach toward fungicide use and resistance management necessitates the development of a novel concept: The '**Site-specific Management Of Resistance**' (**SMOR**). As described below, we have developed a set of tools that will allow us to introduce SMOR into the management of apple scab.

Background

Detection of fungicide resistance. We have measured in *V. inaequalis* populations, over the past 15 years, shifts toward resistance to the DMIs (Köller et al. 1991; 1997; Smith et al. 1991), dodine (Köller et al. 1999), the benzimidazoles (Köller and Wilcox 2001), the strobilurins (Köller et al. 2004) and the APs (Köller et al. 2005). Our results have contributed substantially to the characterization of two **general** routes of resistance development (Köller 1990; 2001). Resistance to fungicides can develop either as the rapid selection of **immune** target site mutants (with benomyl-resistance as the classical example), or as the gradual selection of phenotypes carrying **several** unrelated resistance genes, which individually confer a small degree of resistance (Köller

1990; 2001). However, isolates of the pathogen carrying the majority or all of these genes will respond least sensitive to a new fungicide and will be selected over time. In this scenario of **multigenic** resistance, however, selectable phenotypes remain accessible to inhibition at higher doses of the fungicide. Consequently, **high** application rates will **slow** the speed of their selection and thus, the development of resistance (Köller and Wilcox 1999). The gradual path of multigenic resistance was documented for dodine (Köller et al. 1999), for the DMIs (Köller et al. 1997), the APs (Köller et al. 2005) and the strobilurins during their initial phase of resistance development (Köller et al. 2004). As apparent from this list of case studies, the importance and impact of resistance progressing through a multigenic path was underestimated in the past (Köller 2001).

The detection of multigenic shifts of orchard sensitivities requires (1) a quantitative sensitivity test, (2) tests conducted with a sufficiently large sample size of individual *V. inaequalis* isolates and (3) the establishment of data representing the two sensitivity extremes: **baseline** sensitivities prior to the use of a new fungicide class, and the **threshold** sensitivities constituting the stage of practical resistance (Köller et al. 1997; 1999). Starting in 1998, we have developed such test procedures for the DMIs (Smith et al. 1991; Köller et al. 1997), for dodine (Köller et al. 1999), the benzimidazoles (Köller and Wilcox 2001) and the strobilurins (Olaya and Köller 1999b).

During our monitoring of orchard sensitivities, we realized that many apple growers either **under-** or **overestimated** the resistance status of their orchards, leading either to the **continued use** of fungicides that had reached the status of resistance, or to the **underutilization** of fungicides that could still be used successfully (Köller et al. 1997; 1999). Our results also suggested that the level of resistance was largely orchard-specific, which was expected from the relatively local epidemiology of *V. inaequalis* (MacHardy 1996). However, we also realized that our previous sensitivity tests had to be simplified and unified in order to serve as a viable tool in SMOR. Respective projects were initiated in 2002 and continued during 2003 and 2004. Funding for the pilot studies was provided by the grower-governed NY Apple Research and Development Program.

We have developed a unified and simplified sensitivity test, and we found that the reproducibility and precision of our new test was sufficient to rank orchard sensitivities into four functional categories (manuscript in preparation). However, the SMOR concept would not only require sensitivity data but also predictions of fungicide **performances** deduced from such orchard-specific sensitivities. This correlation of sensitivities with expected fungicide performances was accomplished through performance trials in our experimental orchards with known levels of resistance and from fungicide performances in commercial orchards (Köller et al. 1999; Köller and Wilcox 1999; Köller et al. 2004; Turechek and Köller 2004; Köller et al. 2005). The four functional categories we have reported to growers are:

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

History of resistance development in New York. Widespread resistance to **dodine** was documented in the early 1970s as the first case of fungicide resistance (Gilpatrick 1982). We showed retroactively that the path of resistance development was multigenic and gradual, and that

practical resistance was reached after approximately 60 dodine applications in total were applied (Köller et al. 1999). In response to spreading resistance, dodine was rapidly replaced by the class of **benzimidazoles**. However, it was found that benzimidazole resistance developed even faster than resistance to dodine (Gilpatrick 1982), and by the early 1980s, benzimidazoles had lost their utility in the management of scab. The course of resistance development was characterized as the rapid selection of immune target site mutants, constituting the first case of monogenic target site resistance (Köller and Wilcox 2001). For several years, most apple growers in New York and elsewhere had to revert back to the management of scab with conventional protectants such as EBDCs or captan.

The new class of **DMIs** introduced in the late 1980s offered a new opportunity. These fungicides provided excellent post-infection activities and allowed the design and implementation of a highly efficacious and integrated 'delayed four-spray program' (Wilcox et al. 1992; Agnello et al. 1999). Our efforts were focused on characterizing the type of resistance to be expected for the DMIs, to **proactively** monitor resistance development to this new class of 'low-risk' fungicides, and to develop and test effective anti-resistance measures. We were able to document that DMI-resistance followed the multigenic route (Smith et al., 1997; Köller et al. 1997), and we could propose a novel high-dose strategy effectively slowing the speed of resistance development (Köller and Wilcox 1999). Although successful, these recommendations did not halt the slow emergence of DMI resistance (Köller et al. 1997; Köller et al. 2005).

In response, the new classes of **strobilurins** and **APs** were introduced in 1999. In the strobilurin case, we initiated a project to proactively **assess the risk** of resistance prior to their commercial introduction. Our risk assessment studies suggested that resistance to the **strobilurins** could be expected to develop as a gradual multigenic shift of population sensitivities (Olaya and Köller 1999a; 1999b), **or** as a target site mutation leading to immunity of respective mutants (Zheng et al. 2000). Our predictions were fully confirmed recently. Following initially multigenic sensitivity shifts, immune target site mutants had emerged after a total of 20-30 strobilurin applications were made in an apple orchard in Germany (Köller et al. 2004). Our current recommendation is to slow the initially multigenic sensitivity shifts by applying the highest label rates (Turechek and Köller 2004), a strategy that **might** also delay the emergence of immune target site mutants (Avila-Adame and Köller, 2002a; 2002b; 2003).

For the class of **AP** fungicides, we observed that orchard sensitivities varied widely **prior** to the **first use** of these fungicides. We were able to demonstrate that orchard sensitivities to the new class of APs were partly correlated with the status of DMI resistance (Köller et al. 2005), a new phenomenon most likely explained by **repeated** rounds of resistance development (Köller and Wilcox 2001; Köller et al. 2005). At our fully DMI-resistant test orchard, the contribution of APs to scab control was lower than for the more economical EBDCs used at their lowest label rates (Köller et al. 2005). Consequently, use of APs could not be recommended in such DMI-resistant orchards. In view of the observed performances, the AP sensitivity at our test site was designated as 'strongly shifted' (= scab control must be supplemented).

Status quo of fungicide resistance. With our new and unified test in hand, we have measured the sensitivities of 17 commercial orchard sites, mostly located in New York but also in Virginia. Many but not all orchards participated in a multi-state RAMP project aimed at comparing 'conventional' with 'soft' insecticide programs. Our sensitivity survey in 2003 and 2004 (Table 1) revealed that after 15 years of DMI use, 71% of the orchards we tested had reached the status of DMI resistance (Table 1). This picture is slightly biased by the fact that four of the

orchards were tested, because growers had experienced unexpected control failures with their DMI programs. However, in all other resistant orchards, DMIs had not been used for several seasons.

Table 1. Sensitivities of *Venturia inaequalis* populations in commercial apple orchards tested in 2003 and 2004.

Orchard	DMIs	Dodine	Strobilurins	APs
1	strong shift	sensitive	slight shift	sensitive
2	resistant	resistant	slight shift	strong shift
3	resistant	slight shift	sensitive	strong shift
4	resistant	sensitive	slight shift	strong shift
5	resistant	resistant	strong shift	resistant
6	slight shift	sensitive	slight shift	strong shift
7	strong shift	slight shift	slight shift	strong shift
8	resistant	resistant	slight shift	strong shift
9	resistant	sensitive	sensitive	slight shift
10	slight shift	sensitive	slight shift	strong shift
11	strong shift	slight shift	slight shift	strong shift
12	resistant	slight shift	slight shift	slight shift
13A	resistant	resistant	slight shift	resistant
13B	resistant	resistant	strong shift	strong shift
13C	resistant	resistant	strong shift	strong shift
Virginia 1	resistant	slight shift	slight shift	strong shift
Virginia 2	resistant	resistant	slight shift	slight shift

We also found that the incidence of DMI-resistant orchards has surpassed the level of dodine resistance (Table 1). Unfortunately, all orchards diagnosed dodine-resistant were **also** resistant to the DMIs. We concluded that the re-integration of dodine into scab management programs, be it alone or in mixture with DMIs as an attractive alternative (Köller and Wilcox 1999), appears feasible, but only **if** growers are aware of the dodine sensitivity at their candidate orchards. Without that knowledge, many growers would risk to re-introduce dodine into a dodine-resistant environment. We had found previously that dodine resistance remained stable in orchards, where dodine had not been used for 20 years (Köller et al. 1999). In our most recent survey (Table 1), we also found that resistance persisted in orchards **replanted** at sites with resistance problems in the 1970s, and that orchard managers were not aware of the fact.

As apparent from our sensitivity survey, the initially multigenic shifts of orchard sensitivities to the new class of **strobilurins**, as predicted (Köller et al. 2004), have been initiated in the majority of orchards we tested (Table 1). Fortunately, we have not found immune target site mutants thus far (manuscript in preparation). Our survey (Table 1) also showed that AP sensitivities were lower than baseline in all DMI-resistant orchards, even though APs had never been used in any of the orchards tested. Based upon the poor performance of APs in our DMI-resistant experimental orchard (Köller et al. 2005), we had to rate the majority of orchards as “strongly shifted” (good performance must be supplemented). This AP example reflects the complications inherent to the new phenomenon of **multiple** fungicide resistance caused by **repetitive rounds** of resistance development (Köller and Wilcox 2001; Köller and Wilcox 2005).

At present, the integration of APs into scab management programs without knowledge of their sensitivities in particular orchards appears risky, at least in New York but most likely also in other states of the NE-IPM region (Köller and Wilcox 2005).

Challenges and opportunities. The status quo described above for New York and Virginia (and most likely other states) is alarming. Although a total of **nine** post-infection fungicides are available to growers (Syllit, Topsin M, the three DMIs Nova, Procure and Rubigan, the two strobilurins Flint and Sovran, and the two APs Vangard and Scala, the repeated development of resistance has devalued their utility as tools in IPM and resistance management. Unfortunately, new classes of 'low-risk' fungicides with utility in post-infection control of scab are not forthcoming at present.

In order to assist the apple industry, the future IPM program for apple scab with 'low-risk' and post-infection fungicides will have to be guided by two equally important principles:

(1) The speed of resistance development must be slowed down. As we have documented (Köller and Wilcox 1999), the previously prominent anti-resistance strategy of mixing a post-infection fungicide under risk with a conventional protectant is unlikely to accomplish the task. The separation in space of the two mixture components allows resistant isolates to be selected. Consequently, the burden of scab control will shift steadily toward the conventional protectant. When the status of resistance is reached, the protectant applied at a low rate and at a post-infection schedule will fail to control scab. A high-dose strategy has been shown to be effective in slowing the speed of resistance, but this strategy is only applicable to the scenario of multigenic resistance (Köller and Wilcox 1999; Turechek and Köller 2004). It is undisputed, however, that the **useful lifetime** of any particular fungicide class will be prolonged if scab management programs involve **several different** fungicides per season. For example, a total of approximately 60 dodine applications were shown to establish the status of resistance. These 60 applications could be spread over 10 seasons with six applications per season, or over 30 years with two applications per season (Köller et al. 1999).

(2) Growers must be protected from unexpected losses caused by resistance. This task can only be accomplished by SMOR, the site-specific management of resistance aimed at employing all classes of efficacious 'low-risk' fungicides at a particular site. To be successful, SMOR must not only **measure** the sensitivities to all available fungicide options but also reliably **predict** fungicide performances deduced from their sensitivities. Although our current experience was limited in scope, the results are encouraging. **All** control failures coincided with the diagnosis of 'resistance' to the fungicides used, and **management changes** based upon orchard-specific sensitivities yielded excellent levels of scab control during the next following seasons (manuscript in preparation).

Implementation of SMOR as the major objective of our proposed project will allow apple growers to assess the sensitivity status of *V. inaequalis* in their individual orchards and then to design 'tailor-made' IPM programs without risking unexpected economical losses. Successful implementation of SMOR will require:

(1) A final **technical development phase** to refine the important questions of sampling and shipment of diseased apple leaves and, perhaps most importantly, to insure the safety and success of management recommendations based upon measured orchard sensitivities to **all** current 'low-risk' options.

(2) Promoting the **awareness** of current **problems** with resistance (= unexpected yet severe economical losses) and conveying the **benefits** offered by SMOR. This task will be crucial to a

broad implementation of the SMOR service, because the cost for the service will have to be covered by the growers requesting the service and will necessitate the establishment of a fee structure to make this crucial service available to growers on demand.

Both tasks comprise the Objectives of the project proposed here.

Justification

With increasing cases of unexpected outbreaks of apple scab in well-managed orchards, which are most often caused by fungicide resistance, growers must be provided with tools to adequately assess the sensitivities to all fungicide options in their orchards to make fully informed and economically sustainable management decisions. In the past, sensitivity tests and the development of anti-resistance strategies were focused on **single classes** of fungicides. It became clear, however, that general tactics of proactive resistance management must not only involve one particular fungicide class but rather the **entire** arsenal of efficacious options. Only full knowledge of **all options** considered effective at a particular orchard site will protect growers from unexpected and increasingly costly crop losses and will, at the same time, prolong the **useful lifetime** of our modern 'low-risk' fungicides.

The task can only be accomplished by testing the sensitivities of *V. inaequalis* populations to **all** available fungicide classes **at-site**, followed by recommendations of effective management options deduced from the **site-specific spectrum** of fungicide sensitivities. The **combination** of sensitivity tests with management recommendations constitutes the principles of our novel **SMOR** concept, the site-specific management of resistance.

Our long-term work on the detection and management of fungicide resistance, which involved **all** modern 'low-risk' fungicides, culminated in the opportunity to implement a SMOR service. As described in detail elsewhere, we have developed a unified sensitivity test, and we have found that our predictions of fungicide performances deduced from orchard sensitivities were accurate and reliable. We concluded that our work has reached the **proof-of-principle** stage and justifies moving to the **implementation** phase. Broad implementation of SMOR will require: Optimization of several technical aspects with importance to SMOR, verification of its predictive value and preparing the ground for broadly implementing SMOR as a service offered to growers.

The need for SMOR in the management of apple scab with 'low-risk' fungicides has been emphasized as a research priority in the NE-IPM region:

- (1) The current 'New England Apple Pest Management Strategic Plan' lists, under 'Apple Scab': "Cost effective resistance monitoring tools".
- (2) The Northeastern IPM Center lists, under "Fruit IPM Working Group Priorities": "Resistance monitoring for fungicides in apples."
- (3) Under the 2003-2004 list of New York-IPM **Stakeholder** Research Priorities, 'Fungicide resistance management and monitoring for apple scab and powdery mildew' was entered as a 'top research priority'. Stakeholder interest is also evident by the continuous funding of our pilot projects by the NY Apple Research and Development Program, a funding source governed by growers.

In addition to our focus on the management of apple scab, the **general** need for managing pesticide resistance has received renewed attention as a priority of future IPM research:

- (1) The 2003 'National Roadmap for IPM' states in its introduction: "Pest management systems are subject to constant change and must respond to a variety of pressures. For example, growers require access to a diverse array of pesticides because numerous pest species have developed resistance." Under seven examples of IPM 'research needs', the roadmap lists: "Develop new

diagnostic tools, particularly for plant diseases and for detection of pesticide resistance in pest populations, including weeds.”

(2) In a 2003 symposium organized by the Council for Agricultural Science and Technology (CAST) and entitled ‘Management of Pest Resistance: Strategies Using Crop Management, Biotechnology and Pesticides’, it was concluded that proactive resistance management will be required to prolong the useful lifetime of valuable ‘low-risk’ pesticides and to protect crop producers from unexpected economical losses (CAST 2004; Köller 2004).

The project identifies also with **all** defined NE-IPM Program Priorities. **Stakeholders** have requested resistance monitoring and management as a research priority. The project indirectly promotes **non-pesticidal tactics** by developing and implementing a method by which the use of low-risk fungicides can be sustained in the management of apple scab. **Multi-State involvement** is warranted by the collaborative effort between New York (Cornell University), New England States (University of Massachusetts) and the southern tier of the NE-IPM region (West Virginia University). The results, however, will undoubtedly be applicable throughout other apple-growing regions such as Michigan, Wisconsin, Virginia and North Carolina, and thus are expected to have impact on **multiple regions**. Furthermore, the general concept of SMOR as a novel concept might, quite possibly, have national and international impact on the management of pesticide resistance in general, with potentially broad impact on **multiple stakeholders**.

All base priorities of the NE Grants Program are addressed in our project:

Environmental stewardship and risk management: If successful, SMOR will significantly enhance environmental quality by promoting the continued use of modern low-risk fungicides and, at the same time, will eliminate wasteful use of fungicides to which apple scab is no longer sensitive. Importance and value of the crop or cropping system to the region: Apples are the most important fruit crop in the Northeast IPM region, with 93,000 acres under production in 2003, generating a crop value of \$260 Million (USDA 2004). New York leads in the relative importance of the apple industry (45,000 acres, \$150 Million value). Importance of the pest or pest complex to the crop or cropping system: Apple scab is the most important and consistently threatening apple disease throughout the entire NE-IPM region. Fully effective management of the disease relies on fungicides, but unexpected outbreaks of scab caused by fungicide resistance can diminish the crop’s value by 90%. Likelihood of implementation: As described above, the merits of SMOR - sensitivity tests **combined** with the recommendation of management options - has been validated in our pilot studies. Preparing the ground for the broad implementation of SMOR as a service to apple growers constitutes the major thrust of the proposed project.

OBJECTIVES:

A. Final phase of technical development: The relative **precision** of our sensitivity test and its utility in the **prediction** of fungicide performances constitute the **two pillars** of our SMOR concept. Our pilot studies have validated the reliability of management decisions deduced from orchard-specific sensitivities of scab populations to modern ‘low-risk’ fungicides. However, prior to the broad implementation of SMOR, a final phase of technical development is required to optimize the technical aspects of the service. Our goals under this ‘technical’ objective are as follows:

(1) Fine-tuning the sampling protocol, including selection of sampling sites, shipment of diseased apple leaves, establishing the number of orchard blocks to be tested per production unit,

communication of results to participating growers, and evaluating the time after which the tests should be repeated.

(2) Verifying the reliability of management recommendations derived from orchard-specific sensitivities to all classes of modern low-risk fungicides.

B. Preparing the ground for broad implementation of SMOR: Although the stakeholders have prioritized management of fungicide resistance in the control of apple scab as one of their research priorities, the broad implementation of SMOR will only be successful, if apple growers are willing to cover the costs for the service. The inevitable 'fee-for-service' approach mandates that the benefits of the service must be disseminated and advertised. Therefore, the goals under this 'implementation' objective are as follows:

(1) Broad dissemination of information and results to growers, consultants and cooperative extension educators.

(2) A targeted survey of apple growers subsequent to our initial dissemination of SMOR information and results to test the response of growers regarding the value they assign to the service.

(3) Design of a business plan to establish the infrastructure for a first example of SMOR as a service.

APPROACH AND PROCEDURES:

Our original sensitivity tests accommodated the characteristics of the DMIs, a class of inhibitors most active at the stage of mycelial expansion but relatively inactive as spore germination inhibitors (Smith et al. 1991; Köller et al. 1997). We found that the same test was applicable to both dodine (Köller et al. 1999) and the benzimidazoles (Köller and Wilcox 2001), allowing us to include these fungicides in the monitoring of orchard sensitivities. The test involved growth of mycelial colonies from single conidia first, and then a test determining the sensitivities of these clonal mycelia. Because the mycelial growth of *V. inaequalis* colonies is very slow, the test required a minimum of 12 weeks to yield results. For the strobilurins, we had to further modify and complicate the test (Olaya and Köller 1999b). We calculated that the costs for establishing the sensitivity of a particular orchard population to all fungicide options amounted to approximately \$3,000 direct costs per orchard. Such costs were justified in a 'research mode', but they were prohibitive in establishing SMOR as a service.

The **technical development** of our simplified and unified **sensitivity test** aimed at the implementation of SMOR has been pursued during 2002-2004 (Köller et al. 2004; 2005; unpublished). In our redesigned test, we treat the approximately 50,000 asexually produced conidia suspended from a single scab lesion as a single 'isolate' of the pathogen. Distinct scab lesions are cut as discs from diseased leaves, placed individually into open Eppendorff tubes and stored at room temperature until processing. We found that conidia stored on dried leaf disks can be processed for >6 months. For processing, conidia are suspended in 1 ml water, and 100 μ l portions are transferred to PDA amended with fungicides. Germ tube elongation/mycelial growth is measured after 7 days of incubation via image analysis. This shortened period of growth allows quantitative tests for all four fungicides. We have verified cross-resistance for all members within a fungicide class (Köller et al. 1991; 1997; 2004; 2005) and employ myclobutanil (0.1 μ g/ml) as a DMI representative, dodine (0.2 μ g/ml), pyrimethanil (0.2 μ g/ml) as an AP representative and

trifloxystrobin (0.02 µg/ml and 0.2 µg/ml + 100µg/ml SHAM) as a strobilurin representative. The strobilurin test consists of two variants in order to 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). Quantitative sensitivity data are recorded as relative growth (RG) at the discriminatory doses employed, according to the method established in our program (Smith et al., 1991; Köller et al. 1991; 1997; 1999; 2004; 2005). All agar media contain antibiotics to eliminate the growth of bacterial contaminants. However, fungal contaminants (mostly epiphytic yeasts) are always present. We found that they do not restrict the test in >80% of the samples, because they leave sufficient surface areas where the small *V. inaequalis* colonies can be measured. Colonies of other fungi with morphological resemblance to *V. inaequalis* have never been observed. Colony growth after 7 days of incubation is measured via an imaging system allowing on-screen colony size measurements and automatic transfer of data into a spreadsheet.

As in the past, we analyze sensitivity data of distinct orchards through comparison with **baseline** and **threshold** sensitivities. **Baseline** sensitivities are defined as the sensitivities of *V. inaequalis* populations never treated with fungicides (Smith et al. 1991; Köller et al. 1991; 1997; Olaya et al. 1999b; Köller et al. 2004; 2005). We have assembled these crucial baseline data by testing several baseline populations over a three-year period collected from several wild-type sites, mostly in New York but also in Pennsylvania. Statistical data analysis of these baseline populations allowed us to combine all data to a baseline composite for all four fungicides tested. We also have assembled composite **threshold** sensitivities (= the sensitivity at which a fungicide can no longer be expected to provide economically acceptable scab control) for the DMIs and dodine (Köller et al. 1997; 1999) and adjusted them to the new test procedure. In order to rank orchard sensitivities, we statistically compare the mean relative growth (*t*-test) and the frequency of isolates designated 'resistant' (chi-square test) with both baseline and threshold sensitivities, according to the statistical methods we have employed previously (Köller et al. 1997; 1999). This analysis assigns a sensitivity category to the orchard tested (**sensitive, slight shift, strong shift, resistant**). The predicted performance of a fungicide falling into one of the measured categories was derived from numerous performance trials in experimental (and commercial) orchards with known sensitivities to the fungicides involved (Köller and Wilcox 1999; Köller et al. 1999; Köller et al. 2004; Turechek and Köller 2004; Köller et al. 2005). Both steps - measurements of sensitivities and predictions of fungicide performances - constitute the two components of SMOR. An example of our analysis is illustrated in Table 2 for the DMIs. All sensitivity designations listed in Table 1 were derived from similar data analyses. The performance predictions are specific to the fungicide (classes) tested, as deduced from numerous performance trials.

The year-to-year precision of our new test was evaluated by measuring sensitivities of five orchard populations in both 2003 and 2004 (manuscript in preparation). As expected, we found that the two quantitative parameters, mean RG and frequency of resistant isolates, varied slightly from year to year. However, we also found that these variations did **not** alter the rankings into the four sensitivity categories with relevance to SMOR.

In addition to developing a simplified and unified protocol, we have continuously lowered the **cost** of the test. We found that a sample size of 20-25 isolates tested per orchard rendered sufficient precision, confirming our earlier size analysis (Smith et al. 1991). In order to adjust for too heavily contaminated samples, we subject conidia from 30 distinct lesions to the analysis of sensitivities. With five fungicides tested per isolate and a non-treated control, the analysis consists of 180 individual measurements (= 180 petri dishes).

Table 2. SMOR analysis of orchard sensitivities to myclobutanil (=DMI fungicides)

Orchard	n	Mean RG	P_{base}	P_{thres}	F_{res} (%)	P_{base}	P_{thres}
Baseline	185	25.2			1.1		
Threshold	194	64.6	hs		49.5	hs	
Orchard A	38	28.6	0.13	hs	0.0	0.52	hs
Orchard B	33	37.9	hs	hs	12.1	hs	hs
Orchard C	55	50.1	hs	hs	25.5	hs	hs
Orchard D	53	59.5	hs	0.72	50.9	hs	0.85

hs; $P \leq 0.001$ RG; relative growth at 0.1 $\mu\text{g/ml}$ F_{res} (%); frequency of resistant isolates (RG>60).

Diagnosis:

sensitive	both mean RG and F are not different from baseline
slight shift	mean RG or F is different from baseline but both are different from threshold
strong shift	both mean RG and F are different from both baseline and threshold
resistant	either mean RG or F (or both) are not different from (or above) threshold

Predicted Performances:

- Sensitive: Good scab control can be expected.
- Slight shift: Good scab control can be expected, but application rates must be **higher** than their lowest label rates.
- Strong shift: Contribution to scab control can be expected at highest label rates, but protectants in mixture **must** also be used at a **high rate**, and spray intervals longer than 9 days **must** be avoided.
- Resistant: DMIs will control powdery mildew and rust, but scab control **must** be provided by another fungicide in mixture.

The preparation of 180 petri dishes per orchard tested and the measurement of growth on these plates remain labor-intensive. We found that both the timing of the test during the season (mid June to mid August) is ideally suited for work conducted by prebaccalaureate students pursuing a major in biology. These students start their work in early May, leaving 4 weeks of preparing agar media to be used later in sensitivity tests conducted from early June to late August. The Petri dishes prepared in advance are stored in a cold-room and are stable throughout the subsequent testing period. The technical demands of the work are simple enough to allow for minimal 'training on the job' in all steps involved. The work requires two students per test unit, plus general supervision of the technical part and the analysis and reporting of data. We tested 30 orchards with one test unit in 2004. Minor adjustments made in the future will increase the number processed per test unit to 35.

Our **cost analysis** for 2004 calculated to \$15,000 for labor and \$4,000 for materials and supplies, translating into **real** costs of \$550 per orchard tested. This direct cost does not include indirect costs such as fringe benefits, accounting, laboratory space and amortization of equipment. Automation of several manual steps would decrease costs, but respective incentives would require capital investment such as automatic media dispensers. This would only be justified by a larger than expected demand for the SMOR test. We also realize that sensitivity tests based on real-time PCR would greatly reduce costs. Unfortunately, the molecular mechanisms responsible for **quantitative differences** of isolate sensitivities remain unknown for all four fungicides under question here, only the target site mutations leading to benzimidazole and strobilurin immunity would be accessible to this modern technique (Köller and Wilcox 2001; Köller et al. 2004). This

knowledge would be of very restricted value to apple growers. Therefore, the **bioassay** approach we have developed and tested recently will remain the only option for the foreseeable future. We will employ this test throughout the project (and beyond).

Objective A: Final phase of technical development

Sampling and shipment of diseased apple leaves: The sensitivity test requires sampling of scab-infected apple leaves. In order to be most effective, the SMOR service would call for sensitivity tests **prior** to costly control failures caused by unexpected resistance. According to our decade-long experience, locating 30 scab-diseased leaves in a well-managed orchard is not practical. In recognition of this limitation, we have asked participating growers to leave several trees at opposite corners of an orchard block unsprayed until the first scab symptoms on cluster leaves develop (Köller and Wilcox 1999). After sampling diseased leaves, these 'corner trees' are included in the management program.

The sampling strategy was successful in our cooperation with several growers (Köller and Wilcox 1999; manuscript in preparation), and we have not experienced grower resentment toward allowing first scab symptoms to develop in a very small segment of their orchard blocks. Unfortunately, we also experienced that the 'corner tree' guidelines were not always conveyed to the personnel responsible for spraying pesticides. We expect, however, that compliance by growers with self-interest in our SMOR service will be high. We will also recommend to 'clearly flag' the trees to be left unsprayed.

Alternatives to unsprayed corner trees as sources for diseased leaves exist. We found that unsprayed trees in close vicinity (<500 yards) to the orchard block tested, or recently abandoned orchard blocks with identical fungicide histories, are an adequate mirror of the sensitivities established throughout other orchard blocks. We will experiment with all three options of the **proactive** SMOR service.

We have found, however, that growers are **also** interested in SMOR in **response** to unexpected development of scab in their orchards. In such cases, the sampling of diseased leaves poses no problem, when they are sampled **prior** to the application of rescue sprays. We realize that in this **responsive** mode of SMOR, the sensitivities to the fungicide used will be lower, because resistant isolates were selected to an elevated frequency during the initial part of the season. However, we also found that the magnitude of this additional sensitivity shifts was small in comparison to the shift already established in the orchards (Köller and Wilcox 1999; Turechek and Köller 2004). We found that potential upgrades from 'strong shift' to 'resistant' were **functionally** of low significance.

Although a **responsive** approach to SMOR will **not** protect growers from crop losses during one season, the results will be crucial in guiding informed management decisions in the following years. We will, therefore, accommodate both **proactive** and **responsive** sensitivity tests in the work anticipated under the 3-year term of this project.

Once diseased leaves are sampled, they are shipped to our test laboratory at Cornell. We have, over the past decade, developed a sampling and shipping protocol: Leaves **must** be placed in **paper** bags (to avoid an explosion of leaf epiphyte growth). The paper bags should not be left in 'hot cars' (germination of scab spores declines rapidly at high temperatures). Shipment to our test laboratory must be through an express service; if shipment is delayed to the next day, the bags should be stored in a refrigerator. During our 2004 testing, several growers managed this task without direct assistance. We realized, however, that we must continue to optimize sampling and shipment instructions. This task will be included by discussing the sampling protocol with

participating growers and by incorporating their responses and suggestions into the written instructions aimed at the direct sampling and shipment of leaves by growers as a crucial component of SMOR.

Communication of results to growers: During our recent testing of commercial orchards (Table 1), we have developed and refined a report form discussed with growers. The information conveyed included detailed information on the orchard tested, the measured fungicide sensitivities and the scab management options deduced from measured sensitivities, as exemplified in Table 2 for the DMIs. In order to optimize the effectiveness of these reports to growers, the results and their utility will be discussed between participating growers and the PDs.

Reliability of recommendations deduced from orchard sensitivities: The reliability of recommended management options constitutes the second pillar of the SMOR service. Thus far, our experience has been positive, with management changes yielding excellent control of scab in the next following season. However, the number of cases we were able to assess was too small to warrant broad certainty. We will examine this question by measuring the incidence of fruit scab prior to harvest (examination of 300 randomly selected apples per orchard) in the season in which leaves were sampled and tested, and in the following season after the test results and management options were discussed with the participating growers. During these personal discussions with growers, we will also recruit precise spray records for both seasons under question. With sensitivity, disease incidence data and spray records in hand, we will be able to assess the effectiveness of our SMOR recommendations and the responsiveness of participating growers in adjusting their scab management practices.

Number of sampling sites to be tested per production unit: We found that fungicide sensitivities of scab populations at particular orchard sites most often reflected the fungicide use histories (Köller et al. 1997; 1999; manuscript in preparation). We also found that all apple growers we have cooperated with 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 (Table 1; orchards 13A-C), suggesting that sensitivity tests conducted in one **typical** orchard per operation will reflect the status quo throughout the entire operation. However, we also realized that many growers have consolidated their businesses through orchard purchases. The fungicide use history at such purchased sites are often different from the core operations, and significant differences in the fungicide sensitivities of scab populations must be expected. We will address this question by comparing sensitivities of 'core' orchards with 'purchased' (or newly planted) orchards. We have identified several suitable growers in New York as potential cooperators, and these efforts will, therefore, be focused on orchards in New York.

Frequency of sensitivity tests: The first orchards in New York were tested in 2003, and the results were discussed with respective growers. We will retest the same sites in 2007 after four years and will correlate the results with the fungicide use at the site. This comparison will allow us to determine the time at which sensitivity tests should be repeated.

Time Table Objective 1: In 2005, we will identify 5 cooperating growers in each NY, MA and WV. Diseased leaves will be collected in June and their sensitivities will be tested. Incidences of fruit scab will be determined in August prior to harvest, and the sensitivity data will be discussed with participating growers. In 2006, we will identify another set of 5 cooperating growers in each NY, MA and WV and repeat the 2005 routine. In order to evaluate management changes made by participating growers and their effectiveness, the incidence of fruit scab will be measured again in 2006 in all orchards tested in 2005. In 2007, the incidence of fruit scab will be

measured in all orchards sampled and tested in 2006. We also have received frequent requests for tests from growers who had experienced unexpected control failures. We will accommodate four to six such requests in 2005 and 2006, and will treat these orchards according to the routine followed in all other orchards. Our objective to determine the number of orchards to be tested per grower operation will be met by testing three different sites per 3-4 operations in 2005 and 2006 each. Several growers managing orchards with diverging fungicide histories have been identified in NY. Overall, we will address the pertinent technical questions of SMOR with approximately 40 orchards analyzed. Our implementation efforts during 2005 and 2006 (described below) are expected to disseminate sufficient SMOR information to spur interest of growers in the service. We therefore will dedicate our 2007 test season to such grower requests.

Objective B: Preparing the ground for broad implementation of SMOR

Broad dissemination of information and results: Our SMOR service enabling growers to tailor 'low-risk' fungicide programs for their individual orchards without risking outbreaks of unexpected resistance is a novel concept, and thus requires cautious yet systematic implementation. Over the past decade, the PD has been engaged in disseminating information on fungicide resistance to apple growers. The same channels will be utilized in disseminating the SMOR information and will include oral presentations, written information reaching apple growers in all three states and the design of web-accessible information.

In 2005, we will focus on describing the previous successes of the SMOR pilot projects and the impact of results on scab management. The PD has already agreed to present results in January at the NY Fruit and Vegetable EXPO and at the HortConference in WV. The PD has also agreed to write an article published in the spring issue of the *NY Fruit Quarterly*, a publication distributed to all commercial apple growers in NY. In addition, we will continuously write articles describing the SMOR service and respective results and publish them in local Cooperative Extension newsletters in NY, MA, and WV, such as *Fruit Fax*, the *Northeastern NY Fruit Newsletter*, the *Hudson Valley Fruit Newsletter*, *Scaffolds*, *Fruit Notes*, etc. in order to reach growers, consultants and Extension educators. We are confident that trade magazines (*Fruit Grower News*, *American Fruit Grower*) will disseminate much of the information, as they have done in the past.

Starting in 2006 and continuing in 2007, the design of web pages will be developed. They will detail the technical aspects of SMOR, promote the benefits of SMOR, and provide step-by-step information on how to utilize the SMOR service. The locations of these web pages will be determined during the development of a business plan. A very suitable location would be the NE IPM website with links to all local Fruit Extension websites throughout the entire NE-IPM region.

Results of SMOR will also be 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 NY Winter Fruit Schools in the Hudson Valley and Northeastern NY, the New England Fruit Meeting and Trade Show, and the Mid Atlantic Fruit and Vegetable Convention.

Grower survey: Subsequent to the initial phase of disseminating information about SMOR, we will conduct, at the end of 2006, a grower survey aimed at the response of growers to the availability of the service and their valuations. Because the SMOR service will ultimately have to become a 'fee-for-service' enterprise, the survey will be essential to conduct market research and

to determine the feasibility of offering the service to apple growers and the associated fee structure needed to support this effort. The written survey will reach the majority of commercial apple growers (approximately 600 growers). Address lists are available to us through Cooperative Extension. The Survey Research Institute (SRI), School of Industrial and Labor Relations, Cornell University, will assist us in the design of survey questions and will conduct the survey (see Appendix).

Design of a business plan: The development of a business plan and the design of a business structure to insure the success and sustainability of the SMOR service for apple growers will be done in consultation with faculty in the Department of Applied Economics and Management (AEM), Cornell University. The process of developing a business plan with AEM faculty will occur in 2007 and will be based on the survey results. It is anticipated that the SMOR service will be located in NY. Some potential locations for the SMOR service at Cornell University include the Plant Diagnostic Clinic, the Northeast Plant Diagnostic Network or the NY State Agricultural Experiment Station, which would require institutional cooperation. Free-market options for the service will be explored. We realize that the **direct** costs of the service with our current technology are \$500-600 per orchard. Costs could be reduced through automation if the demand for the service is higher than expected. We expect to retrieve information on both, the grower demand and acceptable service fees from the survey. The results will be incorporated into our business plan. We also will explore opportunities for subsidizing the SMOR service, be it through chemical companies or pesticide distributors, or through government funding channels.

Time Table Objective 2: Dissemination of current information about the SMOR service and its results will be pursued through the duration of the project. The grower survey will be planned and conducted in 2006, leading to the development of a business plan in 2007

COOPERATION AND INSTITUTIONAL UNITS INVOLVED

The lead institution on the project is Cornell University, New York, with significant collaboration from West Virginia University, Tree Fruit Research and Education Center, Kearneysville, and from the University of Massachusetts. The units involved at Cornell University are the Department of Plant Pathology and the NY-IPM program. The departmental units involved at the collaborating institutions are the Departments of Plant Pathology and Microbiology. All sensitivity tests will be conducted at the Cornell Plant Pathology unit, with several technical aspects under Objective 1 conducted in all three collaborating states. The implementation efforts under Objective 2 will be spearheaded by the NY-IPM program but will involve both collaborating states.

The information retrieved from participating growers will be transmitted to the PD at Cornell, where all information will be compiled to a SMOR recommendation for the particular orchard site. This information will be conveyed to the cooperators. All four cooperators will meet at the end of each season in order to analyze results, to compile a final report and to plan the details of activities for the next following season.

IMPLEMENTATION AND EVALUATION PLANS

The need for SMOR as a service to growers: With a rapidly declining profitability of the processing apple market in the NE and other regions, the unexpected outbreak of fruit scab has had and will have severe economical impact on the economy of apple production. Unexpected outbreaks of scab are most frequently caused by the establishment of resistance to the 'low-risk' fungicides used in the management of apple scab. In particular the increasing severity of resistance to the class of DMI fungicides will have impact on the arsenal of fungicides apple growers are able to use without risking unforeseeable losses. This class of DMIs had been incorporated into highly successful IPM programs (Wilcox et al. 1992, Agnello et al. 1999), but their effectiveness is eroding on a broad scale. Growers are currently left with two choices. They can revert to exclusive use of the conventional protectants with their poor fit into IPM programs and inconveniences inherent in their lack of post-infection activities, or they can diversify their management programs to all options of 'low-risk' fungicides currently available. This latter option is risky, because growers are unaware of the resistance status of these 'low-risk' options in their individual orchards. We intend to ease this situation by introducing SMOR as a site-specific service to growers. SMOR will allow growers to design 'tailor-made' scab management programs without risking revenue losses caused by resistance. The service will consist of a sensitivity test measuring the status quo of resistance to all currently available 'low-risk' fungicides and a site-specific use recommendation deduced from the measured fungicide sensitivities.

Evaluation and implementation of SMOR. Our pilot project aimed at studying the feasibility of SMOR as a service to growers has reached the 'proof-of-principle' stage. We were able to simplify and unify our sensitivity test, and management recommendations deduced from orchard-specific sensitivities of the scab fungus were effective. In order to implement SMOR as a service accessible and accepted by growers, we will further explore, evaluate and refine the technical merits of the service in a multi-state cooperative project. This will involve major objectives such as adequate and convenient sampling protocols and the reliability of management recommendations conveyed to growers.

Implementation of SMOR will not only require refinement of the technical aspects involved but also the broad dissemination of information about the service. The SMOR concept is novel, and the site-specific management of resistance has never been attempted on a broad scale. It will therefore be necessary to make growers aware of the existence and benefits of SMOR, and to develop the infrastructure needed to offer the service.

Both aspects technical refinement of SMOR and the implementation of SMOR will be strictly coordinated and continuously evaluated during the three-year duration of the project. Technical aspects will be covered during the first two years of the project. Dissemination of information to growers will be pursued during the entire duration of the project and will involve contributions at conferences and schooling sessions attended by growers and consultants, print material accessible to growers, and web-based information. Feedback from growers will be obtained through a survey conducted in 2006. The third year of the project will be dedicated to test grower interest in SMOR and to finalize the development of an adequate infrastructure for the testing part of the service. Criteria of our continuous evaluations will be guided by questions relating to the broad implementation of SMOR, and they will involve close cooperation among all PDs. In order to foster this cooperation, we will meet at the end of each season for a working and planning session.

REFERENCES

- Agnello, A., Kovach, J., Nyrop, J., Reissig, H., Rosenberger, D., and Wilcox, W. 1999. Apple IPM. A Guide for sampling and managing major apple pests in New York State. Cornell University, NYS Program Bulletin No. 207.
- Avila-Adame, C., and Köller, W. 2002a. Disruption of the alternative oxidase gene in *Magnaporthe grisea* and its impact on host infection. *Molec. Plant-Micr. Interact.* 15: 493-500.
- Avila-Adame, C., and Köller, W. 2002b. Impact of alternative respiration and target site mutations on responses of germinating conidia of *Magnaporthe grisea* to Qo-inhibiting fungicides. *Pest Managem. Sci* 59:303-309.
- Avila-Adame, C., and Köller, W. 2003. Characterization of spontaneous mutants of *Magnaporthe grisea* expressing stable resistance to the Qo inhibiting fungicide azoxystrobin. *Curr. Genet.* 42: 332-338.
- CAST. 2004. Management of Resistance: Strategies Using Crop Management, Biotechnology, and Pesticides. Special Publication No. 24.
- Gilpatrick, J. D. 1982. Case study 2: *Venturia* on pome fruit and *Monilinia* on stone fruits. Pages 195-206 in: *Fungicide resistance in Crop Protection*. J. Dekker and S. G. Georgopoulos, eds. Pudoc, Wageningen.
- Köller, W. 1990. Fungicide resistance in plant pathogens. Pages 679-720 in: *CRC Handbook of Pest Management in Agriculture*, 2nd Ed., Vol. 2. D. Pimentel, ed. CRC Press, Boca Raton.
- Köller, W. 1992a. Antifungal agents with target sites in sterol function and biosynthesis. Pages 119-206 in: *Target Sites of Fungicide Action*. W. Köller, ed. CRC Press, Boca Raton.
- Köller, W. 1994. Chemical control of apple scab - Status quo and future. *Norw. J. Agric. Sci.* 17: (Suppl.):149-170.
- Köller, W. 1995. Managing resistance to sterol demethylation inhibitors. Pages 340-349 in: *Options 2000*. N.N. Ragsdale, P.C. Kearny, and J.R. Pimmer, eds. American Chemical Society, Washington, CD.
- Köller, W. 1996. Recent developments in DMI resistance. Pages 301-311 in: *Modern Fungicides and Antifungal Compounds*. H. Lyr, P.E. Russell, and H.D. Sisler, eds. Intercept, Andover.
- Köller, W. 1999. Chemical approaches to managing plant pathogens. Pages 337-376 in: *Handbook of Pest Management*. J. R. Ruberson, ed. Marcel Dekker, Inc., New York.
- Köller, W. 2001. Fungicide Resistance. Pages 483-488: *Encyclopedia of Plant Pathology*. O. C. Maloy and T. D. Murray, eds., John Wiley & Sons, Inc., New York.
- Köller, W. 2004. Pathogens. Pages 17-19 in: *Management of Pest Resistance: Strategies Using Crop Management, Biotechnology, and Pesticides*. CAST Special Publication No. 24, Ames, Iowa.
- Köller, W., and Wilcox, W. F. 1999. Evaluation of tactics for managing resistance of *Venturia inaequalis* to sterol demethylation inhibitors. *Plant Dis.* 83: 857-863.
- Köller, W., and Wilcox, W. F. 2000. Interactive effects of dodine and the DMI fungicide fenarimol in the control of apple scab. *Plant Dis.* 84: 863-870.
- Köller, W., and Wilcox, W.F. 2001. Evidence for the predisposition of fungicide-resistant isolates of *Venturia inaequalis* to a preferential selection for resistance to other fungicides. *Phytopathology* 91:776-781.

- Köller, W., Parker, D. M., and Reynolds, K. L. 1991. Baseline sensitivities of *Venturia inaequalis* to sterol demethylation inhibitors. *Plant Dis.* 75: 726-728.
- Köller, W., Wilcox, W. F., Barnard, J., Jones, A. L., and Braun, P. G. 1997. Detection and quantification of resistance of *Venturia inaequalis* populations to sterol demethylation inhibitors. *Phytopathology* 87: 184-190.
- Köller, W., Wilcox, W. F., and Jones, A. L. 1999. Quantification, persistence and status of dodine resistance in New York and Michigan orchard populations of *Venturia inaequalis*. *Plant Dis.* 83: 66-70.
- 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.
- Olaya, G., and Köller, W. 1999a. Diversity of kresoxim-methyl sensitivities in baseline populations of *Venturia inaequalis*. *Pestic. Sci.* 55: 1083-1088.
- Olaya, G., and Köller, W. 1999b. Baseline sensitivities of *Venturia inaequalis* populations to the strobilurin fungicide kresoxim-methyl. *Plant Dis.* 83:274-278.
- Smith, F.D., Parker, D.M., and Köller, W. 1991. Sensitivity distribution of *Venturia inaequalis* to flusilazole: Baseline sensitivity and implications for resistance monitoring. *Phytopathology* 81:392-396.
- Szkolnik, M. 1981. Physical modes of action of sterol-inhibiting fungicides against apple diseases. *Plant Dis.* 65:981-985.
- USDA-NASS. 2004. *Noncitrus Fruits and Nuts – 2003 Summary*.
- Turechek, W. W., and Köller, W. Managing resistance of *Venturia inaequalis* to the strobilurin fungicides. *Plant Health Progr.* doi: 10.1094/PHP-2004-0908-01-RS.
- Wilcox, W. F., Wasson, D. I., and Kovach, J. 1992. Development and evaluation of an integrated, reduced spray program using sterol demethylation inhibitor fungicides for the control of primary apple scab. *Plant Dis.* 76:669-677.
- Zheng, D., Olaya, G., and Köller, W. 2000. Characterization of laboratory mutants of *Venturia inaequalis* resistant to the strobilurin-related fungicide kresoxim-methyl. *Curr. Genet.* 35: 148-155.

KEY PERSONNEL

ROLES AND RESPONSIBILITIES:

- PD Wolfram Koeller**, Cornell University, Department of Plant Pathology, NYSAES, Geneva, NY. Responsible for all technical aspects of SMOR and for coordinating all aspects of the project.
- Co-PD Juliet Carroll**, Cornell University, NY-IPM Program, NYSAES, Geneva, NY. Major responsibilities are to serve as the liaison to IPM programs and to Cooperative Extension Educators in New York. Dr. Carroll will assume a leading role in the dissemination of SMOR information to growers.
- Co-PD Daniel Cooley**, University of Massachusetts, Department of Microbiology, Amherst, MA. Dr. Cooley will assume the same responsibilities for Massachusetts and will serve as liaison to other NE states.
- Co-PD Alan Biggs**, West Virginia University, Tree Fruit Research and Education Center, Kearneysville, WV. Dr. Biggs will conduct research and extension work to address the goals of the project in West Virginia. To complete the objectives of the proposed research, Dr. Biggs will conduct field experiments, collect data on disease incidence and severity, collect post-harvest data, interact with growers in West Virginia, conduct extension meetings with growers and interested citizens, participate with other researchers in planning meetings, prepare newsletter and trade journal articles, and assist in the preparation of manuscripts for publication.

RELEVANCE STATEMENT

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Title:

Site-specific Management of Resistance (SMOR) in the Control of Apple Scab: Final Phase of Development and Implementation.

Project Summary:

Apples are the most important fruit crop grown in the NE-IPM region, with a farm-gate value of \$260 Million in 2003. The profitability of apple production for the processing market has sharply declined, and sustained viability of the industry will rely on producing fresh apples. Scab lesions caused by *Venturia inaequalis* are one of the most common causes of blemishes on apples not tolerated by the fresh market, resulting in a 90% lower value of the crop. The disease occurs regularly and must be controlled with 4-10 applications of fungicides per season.

The arsenal of scab fungicides includes conventional protectants such as mancozeb or captan. These nonspecific fungicides have been under continuous scrutiny regarding their toxicology and their poor fit into IPM programs. Several classes of 'low-risk' fungicides with post-infection activities are available as alternatives and are also in wide use. Unfortunately, all 'low-risk' fungicides have developed or will develop resistance, rendering them ineffective in scab control. Outbreaks of scab caused by resistance are always unexpected by the growers affected and have become increasingly costly in a changing market place. Our research over the past 15 years has shown that levels of resistance can vary considerably from orchard to orchard. Many growers continue to apply 'low-risk' fungicides in spite of resistance, thereby risking unexpected and severe economical losses. Other growers, who still could effectively use some classes of 'low-risk' and post-infection fungicides have converted back to the conventional protectants to avoid potential losses caused by resistance.

The goal of the proposed work is to establish and implement a novel service: The Site-specific Management Of Resistance (SMOR) offered to apple growers on demand. The SMOR concept consists of orchard-specific sensitivity tests combined with management recommendations deduced from respective sensitivities to all 'low-risk' options available. Implementation of SMOR will require to validate the diagnostic precision of the orchard-

specific sensitivity test we have developed, and to establish an infrastructure allowing us to provide the SMOR service to growers.

Project Objectives:

Implementation of SMOR as the major objective of our project will allow apple growers to assess the sensitivity status of *V. inaequalis* in their individual orchards and then to design 'tailor-made' scab control programs without risking unexpected economical hardship. We have developed a simplified and unified sensitivity test.

However, successful implementation of SMOR requires:

- (1) A final technical development phase to refine the important questions of sampling and shipment of diseased apple leaves and, perhaps most importantly, to insure the validity and success of site-specific management recommendations.
- (2) Promoting the awareness of current problems with resistance (= unexpected yet severe economical losses) and conveying the benefits offered by SMOR. This task will be crucial to the implementation of SMOR, because the cost for the service will have to be covered by the growers requesting the service and will necessitate the establishment of a fee structure to make this crucial service available to growers.

Problem:

Traditionally, apple production in the NE has served both the fresh and the processing market. During the past years, however, profitability of the processing apple market has declined sharply. A single fully developed scab lesion on a fruit will downgrade an apple from "wholesale" to "cider" quality, resulting in a 90% revenue loss. Unexpected outbreaks of fruit scab in well-managed orchards are increasingly caused by the development of resistance to 'low-risk' and IPM-compatible fungicides. The current situation has become even more risky to growers, because we have documented a steadily increasing and by now alarming number of orchards affected by resistance to the DMI class of fungicides. For over a decade, the DMIs have been the mainstay of scab management with 'low-risk', post-infection and IPM-compatible fungicides. Unfortunately, their effectiveness has eroded in approximately half of the orchards under production in NY, because resistance developed. We also found that the level of resistance to previous 'low-risk' fungicides such as dodine and the benzimidazoles remains too high in many orchards to recommend reintroduction without knowledge of their at-site sensitivities. Our surveys have also shown that resistance to two classes of fungicides introduced in 1999, the strobilurins and the anilinopyrimidines, is progressing.

Apple growers are currently left with two choices. They can revert to exclusive use of the conventional protectants (EBDCs and captan) with their poor fit into IPM programs and inconveniences inherent in their lack of post-infection activities, or they can diversify their management programs to all options of 'low-risk' fungicides currently available. The former option is often too conservative, because the majority of orchards remain sensitive to some of the 'low-risk' fungicides. The latter option is risky, because outbreaks of resistance are sudden and unexpected by the grower affected. We intend to ease this situation by introducing SMOR as a service to growers. The service consists of a sensitivity test measuring the status quo of resistance to all currently available 'low-risk' fungicides and a site-specific use recommendation deduced from respective sensitivity patterns. Implementation of this novel SMOR concept will allow apple growers to design

‘tailor-made’ scab management programs without risking revenue losses caused by sudden outbreaks of resistance. Rational utilization of all effective management options will also prolong the useful lifetime of our ‘low-risk’ fungicide options.

Justification

Our long-term work on the detection and management of fungicide resistance, which involved all modern ‘low-risk’ fungicides, culminated in the opportunity to implement a first SMOR service. We have developed a simplified and unified sensitivity test, and we have found that our predictions of fungicide performances, as deduced from measured sensitivities, were accurate and reliable. We concluded that our work on SMOR has reached the proof-of-principle stage and justifies moving to the implementation phase.

The need for SMOR in the management of apple scab with ‘low-risk’ fungicides has been emphasized as a research priority in the NE-IPM region:

(1) The current ‘New England Apple Pest Management Strategic Plan’ lists, under ‘Apple Scab’: “Cost effective resistance monitoring tools”.

(2) The Northeastern IPM Center lists, under “Fruit IPM Working Group Priorities”: “Resistance monitoring for fungicides in apples.”

(3) Under the 2003-2004 list of New York-IPM Stakeholder Research Priorities, “Fungicide resistance management and monitoring for apple scab and powdery mildew” was entered as a top research priority. Stakeholder interest is also evident by the continuous funding of our pilot projects by the NY Apple Research and Development Program, a funding source governed by growers.

Multi-State involvement is warranted by the collaborative effort between New York (Cornell University), a New England state (University of Massachusetts) and the southern tier of the NE-IPM region (West Virginia University). The results, however, will undoubtedly be applicable throughout other apple-growing regions such as Michigan, Wisconsin, Virginia and North Carolina, and thus are expected to have impact on multiple regions. Furthermore, SMOR constitutes a novel concept and might, quite possibly, have national and international impact on the management of pesticide resistance in general, with potentially broad importance to multiple stakeholders.

All base priorities of the NE Grants Program are addressed: Environmental stewardship and risk management: If successful, SMOR will significantly enhance environmental quality by promoting the continued use of modern low-risk fungicides and, at the same time, will eliminate wasteful use of fungicides to which apple scab is no longer sensitive. Importance and value of the crop or cropping system to the region: Apples are the most important fruit crop in the Northeast IPM region, with 93,000 acres under production in 2003, generating a crop value of \$260 Million. New York leads in the relative importance of the apple industry (45,000 acres, \$150 Million value). Importance of the pest or pest complex to the crop or cropping system: Apple scab is the most important and consistently threatening apple disease throughout the entire NE-IPM region. Effective management of the disease relies on fungicides, but unexpected outbreaks of scab caused by fungicide resistance can diminish the crop’s value by 90%. Likelihood of implementation: The merits of SMOR have been validated in our pilot studies. Preparing the ground for the broad implementation of SMOR as a service to apple growers constitutes the major thrust of the proposed project.