Evaluation of SDHI and DMI Fungicides in Mix with Surfactants and of New DMI Revysol® for Control of Apple Scab in the Hudson Valley

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Apple scab caused by a plant pathogenic fungus *Venturia inaequalis* is the top concern for New York apple growers at the beginning of every growing season. It is the economically most significant apple disease that if preventive fungicide sprays are not applied can cause 100% fruit losses. The pathogen survives over the winter in apple leaf litter on the orchard floor (Figure 1A). Rarely, fungus can overwinter as mycelium in twig lesions or on bud scales (Sutton et al., 2014). In the dead apple leaf litter, below apple scab lesions from the previous season, fungus forms the initials of pear-like fruiting bodies called pseudothecia (Figure 1B). After winter rest, pseudothecia mature late in winter and early spring ultimately developing ascospores that will cause infections in spring (Figure 1B). Once ascospores become mature, with each rain or dew wetting of leaf litter they get discharged from pseudothecia into the air (Figure 1C). Wind then disseminates ascospores to the green tissues of developing apple buds and initiate germination only if they land in droplets or film of water on them (Figure 1D). Germination process continues only if the relative air humidity is higher than 95%. Whether or not a scab infection will be established by germinating hyphae penetrating into the green tissue depends on temperature and hours of wetness duration and can be determined by using the Mills and Laplante apple scab infection chart (1944, 1951; modified by Jones 1980, Gadoury and McHardy 1989). By incorporating weather forecasts for the next 5 – 10 days, an easy way to predict and track when scab infections will or have occurred is by using online apple scab prediction models like NEWA: http://newa.cornell.edu/index.php?page=apple-diseases (Cornell University, Ithaca, NY, U.S.A.) and RIMpro: https://www.rimpro.eu/ (RIMpro B.V., Zoelmond, Netherlands). These models allow growers to precisely time their fungicide applications just before the periods when infection risks are high warranting a protection with fungicides. They also provide an opportunity to reduce the number of early season fungicide applications, depending on the year weather conditions (Aćimović et al. 2018). In addition, these valuable tools incorporate digital ascospore maturity models that signal when the primary apple scab season will end due to depletion of ascospore reserves in leaf litter and scab infection risks no longer require frequent fungicide applications.

> **"In years with rainy weather conditions like in 2017 and 2018, which allowed severe apple scab infection pressure and many major infection periods, SDHI fungicides should be alternated with DMI-s with/or AP-s, while adding surfactants should further improve the efficacy of the SDHI-s and probably DMI-s too. A new DMI fungicide Revysol provided largely similar apple scab control in comparison to the SDHI fungicides and Inspire Super which contains a DMI and a AP premix. Overall, the non-ionic surfactants seem to allow better systemic penetration of SDHI fungicides into the leaves and fruit, which probably allows longer SDHI residual activity through the rain and a better eradication potential for apple scab infections that are incubating."**

In spring and early summer, apple scab management with fungicides is the pivotal driver of the timing for all the other applications of pesticides and plant growth regulators. Commercial apple producers depend on synthetic fungicides to successfully control apple scab and produce blemish free fruit that reach the top price in fresh fruit market. Besides the multi-site fungicide groups, the key single-site fungicide groups listed here with FRAC codes are anilinopyrimidines or AP fungicides – FRAC 9 (cyprodinil, pyrimethanil), quinone outside inhibitors or QoI fungicides – FRAC 11 (trifloxystrobin, pyraclostrobin), demethylation inhibitors or DMI fungicides – FRAC 3 (difenoconazole, myclobutanil), guanidines – FRAC U12 (dodine), and benzimidazoles (carbendazim) and thiophanates (thiophanate-methyl) – FRAC 1 (FRAC 2018, FRAC stands for Fungicide Resistance Action Committee). The most recent class introduced are the succinate-dehydrogenase inhibitors or SDHI fungicides – FRAC 7, that affect respiration in fungi: penthiopyrad, fluxapyroxad, fluopyram, benzovindiflupyr, pydiflumetofen and pyraziflumid. Besides the need to increase the number of fungicide classes for apple scab control that allows more choices in alternating applications of fungicides with different modes of action to avoid fungicide resistance

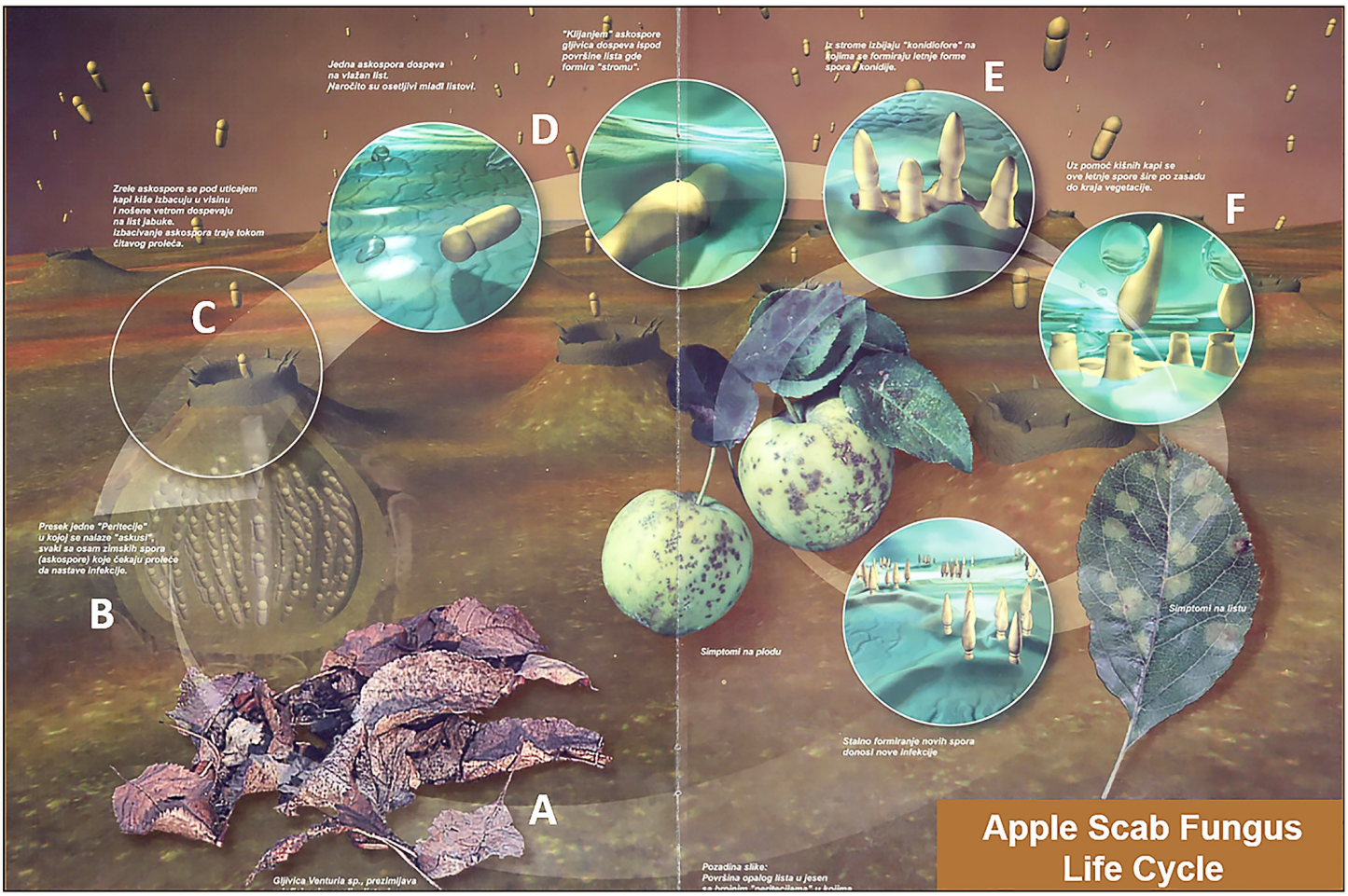

Figure 1. Life cycle of apple scab fungus *Venturia inaequalis*: (A) Overwintering in leaf litter on the orchard floor, (B) Formation of bullet-like sexual spores or ascospores in pear-like fruiting bodies embedded in dead leaf tissue, (C) Spore discharge in air after wetting events in spring, (D) Ascospore landing on green tissues, germination and initiation of primary scab infections by hyphae penetration below the cuticle on green tissue, (E) Emergence of asexual spores aka conidia on infected tissues visible as pale olive apple scab lesions that later turn black or brown, (F) Dissemination of conidia to leaves and fruit by rain and wind facilitating secondary scab infections during summer and fall (Source: reprint from an apple scab marketing sheet by an unknown company).

development in *V. inaequalis*, in recent years significant attention has focused on the potential of non-ionic surfactants to increase the efficacy of new SDHI and DMI fungicides in apple scab control.

The goal of our research was to determine the efficacy of newer SDHI and DMI fungicides for apple scab control ,used alone or in mix with non-ionic surfactants such as LI 700 and Widespread Max, and compare the efficacy of new DMI fungicide Revysol in apple scab control to the leading SDHI and DMI fungicides. Our goal was to provide NY apple growers with new efficacy data that can increase the number of fungicide and surfactant choices in management of apple scab.

Which Spray Programs of SDHI and DMI Fungicides with Surfactants Were Evaluated?

Two apple scab management trials were conducted in the experimental orchards at Cornell's Hudson Valley Research Laboratory in Highland, NY. In 2017 trial, we evaluated the efficacy of several leading SDHI fungicides alone or in mixtures with the surfactants LI 700 (80% phosphatidylcholine, methylacetic acid and alkyl polyoxyethylene ether) and Widespread Max (100% polyether-polymethylsiloxane-copolymer, polyether). In 2018 trial, we evaluated the efficacy of new DMI triazole fungicide Revysol (mefentrifluconazole, proposed FRAC 3) and compared it to different leading SDHI fungicides alone or in mixture with LI 700. We used 22-yr-old (2017) and 23-yr-old apple trees (2018) on M.9 rootstock with Jersey Mac, Redcort and Golden Delicious cultivars. Each spray treatment program was replicated four times. One replicate plot consisted of all three cultivars listed above. To secure good coverage, all the treatments were spray-applied dilute to drip (300 gal/A) using a tractor-carried handgun sprayer (Rear's Pak-Tank 100-gal sprayer, 250 PSI). In 2017, we applied programs listed in Table 1 at 7-14-day intervals and in 2018 treatments listed in Table 2 at 2-20-day intervals, depending on weather conditions, apple bud development and RIMpro apple scab model predictions. Fungicide cover sprays in 2107 were applied in per acre basis on 23 May (Captan 2.5 lb + Pristine 18 oz); 8 June (Captan 2.5 lb + Pristine 18 oz); 21 June (Captan 2.5 lb + Flint 3 oz); 5 July (Merivon 5.5 fl oz + Captan 2.5 lb); 16 July (Topsin M 1.5 lb + Captan 3.5 lb); 6 August (Captan 3.5 lb); and 28 August (Captan 2.5 lb + Flint 3 oz).

Insecticide applications and spray applications after the first cover in 2017 were applied with an air-blast sprayer

(Turboteuton Mistblower, Uni–green Crop Protection, S.p.A., Reggio Emilia, Italy) to all plots including untreated control trees. In 2017, the untreated trees randomized among the other scab fungicide treatment plots throughout the experiment block were labeled as Untreated control 1 (treatment #1) (Figures 2 – 4). Trees in the untreated two rows on the east side of experiment plot, which never received fungicide sprays in the past, were labeled as Untreated control 2 (treatment #2) in 2017 trial (Figures 2 – 4) and in 2018 trial as Untreated control (treatment #1) (Figure 6). In 2018, control trees not treated with fungicides until the first cover and then treated with Captan from the first to sixth cover were labeled as treatment #2. Captan covers (Figure 6).

In 2017, the first apple leaf scab symptoms expressed on 10 May on untreated Redcort trees. According to weather data collected with an onsite NEWA-RainWise station in Highland NY, connected to RIMpro apple scab model, major apple scab infection events occurred on 19 and 25 April and on 5 and 13 May 2017. Additional weaker infection events were reported on 23, 25 and 29 May. We rated apple scab incidence on spur leaves and immature fruit on 23 June and on mature fruit on 29 August 2017. In 2018, the first scab symptoms expressed on 11 May on untreated Redcort leaves. A total of 8 major scab infection events were recorded with RIMpro in 2018: 25 and 27 April and 6, 11, 12, 15, 17, and 19 May 2018. The first 2018 scab infection at HIG (25 April) led us to apply mancozeb at 1.5 lb/A which was not anticipated by the treatment protocol (all programs were to start at tight cluster). The last weak scab infection event was on 22 May. Apple scab incidence on spur leaves was rated on 12 July and on fruit on 10 August 2018. We calculated the percent scab incidence on spur leaves from the number of leaves with scab lesions in relation to the leaves without any lesions on 20 randomly selected leaf clusters per each cultivar tree. We calculated the percent scab incidence on fruit from the number of fruit with scab lesions in relation to the fruit without any lesions on 25 randomly selected fruit clusters per each cultivar tree, for a total of up to 100 fruits per tree replicate. In 2017 only, we rated and calculated the percent incidence fruit russet from the number of fruit with russet, without counting fruit with stem bowl russet, in relation to the russet-free fruit on 25 randomly selected fruit clusters per tree, for a total of up to 50 fruits per each cultivar tree replicate. Apple leaf, fruit scab and fruit russet incidences from both trials were analyzed in SAS Studio (SAS Institute Inc., Cary, NC).

Table 1. Apple scab efficacy trial in 2017 with SDHI and DMI fungicides in mix with surfactants. Treatments were applied on 11 April – HIG, half-inch green; 17 April – TC , tight cluster; 27 April – PK, pink bud; 29 April – BL, bloom; 6 May – PF, petal fall; 12 May – FC , first cover . All references to Manzate in this table are for Manzate Pro-Stick 75 DF.

#	Treatment programs with amount per 100 gal	Spray Timing
1	Untreated control 1	/
2	Untreated control 2	/
3	Manzate Pro-Stick 75 DF 1 lb	TC, PK, BL, PF, FC
4	Merivon 4.17 SC 1.33 fl oz + Manzate 1 lb + Widespread Max 6 fl oz	TC, PK, BL, PF, FC
5	Sercadis 300 SC 1.17 fl oz + Manzate 1 lb + Widespread Max 6 fl oz	TC, PK, BL, PF, FC
6	Luna Sensation 500SC 1.33 fl oz + Manzate 1 lb Manzate 1 lb	TC, PK, PF, FC BL
7	Luna Tranquility 500SC 3.73 fl oz + Manzate 1 lb Manzate 1 lb	TC, PK, PF, FC BL
8	Manzate 1 lb + Captan 80 WD G 0.83 lb Fontelis 1.67 SC 5.33 fl oz + Manzate 1 lb + LI 700 32 fl oz Inspire Super 2.82EW 12 fl oz + Manzate 1 lb	HIG, TC, FC PK, PF BL
9	Manzate 1 lb + Captan 80 WDG 0.83 lb Fontelis 5.33 fl oz + Manzate 1 lb + LI 700 32 fl oz Inspire Super 12 fl oz + Manzate 1 lb	HIG, TC, FC PK, BL PF
10	Manzate 1 lb + Captan 80 WDG 0.83 lb Aprovia 10.27 EC 5.5 fl oz + Manzate 1 lb + LI 700 32 fl oz Inspire Super 12 fl oz + Manzate 1 lb	HIG, TC, FC PK, PF BL
11	Manzate 1 lb + Captan 80 WDG 0.83 lb Aprovia 5.5 fl oz + Manzate 1 lb + LI 700 32 fl oz Inspire Super 12 fl oz + Manzate 1 lb	HIG, TC, FC PK, BL PF
12	Inspire Super 12 fl oz + Manzate 1 lb Manzate 1 lb	TC, PK, PF, FC BL

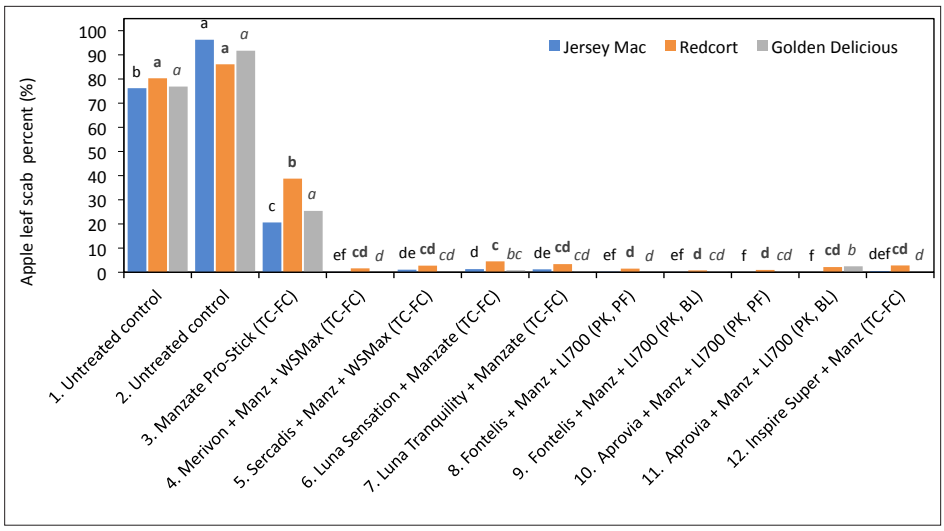

Figure 2. Apple leaf scab incidence on 23 June 2017 on spurs. Means within each cultivar i.e. bar color followed by different letters are significantly different (LSD test, $P < 0.05$). Each mean consists of four replicate trees.

Can Surfactants Mixed with SDHI Fungicides Increase Their Efficacy in Scab Control?

On 23 June 2017, Redcort had slightly more scab developing on leaves in comparison to the other two cultivars (Figure 2). Even though scab control was good across all the treatments, Manzate used alone allowed more scab than the other fungicide programs. On apple fruit, a similar trend was

detected (Figure 3A), although Manzate alone allowed less disease on fruit than on the leaves of Redcort and Golden Delicious. On these two cultivars, fruit scab incidence in the Manzate alone treatment was not statistically different from the Untreated control 1 (treatment #1) (Figure 3A). Until 29 Aug, the fruit scab incidence in majority of the fungicide treatments increased on Jersey Mac and Redcort in comparison to the Golden Delicious, indicating that established primary infections on leaves allowed onset of secondary infections on fruit (Figure 3B). Under these conditions, the two treatments of Aprovia and Fontelis each mixed with LI 700, performed the best, with Merivon and Sercadis both in mixtures with Widespread Max, just behind them (Figure 3B). Luna Sensation and Luna Tranquility allowed quite more scab to develop, except on Golden Delicious (Figure 3B). The higher efficacy of Aprovia and Fontelis programs in scab control on Jersey Mac and Redcort in comparison to the Luna treatments could have been due to the additional Inspire Super spray applied in bloom or at petal fall, and the added surfactants that further increased their activity. Added surfactants most likely facilitated a better systemic penetration of SDHI-s into the leaves and fruit, which may have secured longer residual activity through the rain and, along with 48 h kick-back activity, better eradication of any incubating scab infections (Figure 3). This appears to be the case with treatments of Merivon and Sercadis in mixtures with Widespread Max where Inspire Super sprays at bloom or at petal fall were not included in the spray program (Figure 3). On Jersey Mac there was no difference among fungicide treatments in causing/promoting fruit russet, while on Redcort and Golden Delicious there were very few significant differences (Figure 4). Cool weather, frequent rains and high relative humidity in 2017, especially from 30 April to 15 May and 19 May to 7 Jun, were probably the sole cause of russet formation in this trial (Figure 5).

Table 2. Apple scab efficacy trial in 2018 with SDHI fungicides and DMI Revysol. Treatments were applied on 24 April – HIG, half-inch green; 1 May – TC, tight cluster; 5 May – PK, pink; 7 May – EB, early bloom; 9 May – BL, bloom; 14 May – PF, petal fall; 25 May – 1C, first cover; 6 June – 2C, second cover; 26 June – 3C, third cover; 16 July – 4C, fourth cover; 23 July – 5C, fifth cover; 4 August – 6C, sixth cover. All references to Manzate in the table are for Manzate Pro-Stick 75 DF.

#	Treatment programs with amount per 100 gal	Spray Timing
1	Untreated control	/
2	Captan 80 WDG 1 lb	1C – 6C
3	Manzate Pro-Stick 75 DF 0.5 lb Revysol 1.33 fl oz + LI 700 16 fl oz Captan 80 WDG 1 lb	HIG TC, EB, BL, PF 1C – 6C
4	Manzate 0.5 lb Revysol 1.67 fl oz + LI 700 16 fl oz Captan 80 WDG 1 lb	HIG TC, EB, BL, PF 1C – 6C
5	Manzate 0.5 lb Rhyme 2.17 fl oz + LI 700 16 fl oz Captan 80 WDG 1 lb	HIG TC, EB, BL, PF 1C – 6C
6	Manzate 0.5 lb Rally 1.67 fl oz + LI 700 16 fl oz Captan 80 WDG 1 lb	HIG TC, EB, BL, PF 1C – 6C
7	Manzate 0.5 lb Inspire Super 4 fl oz + LI 700 16 fl oz Captan 80 WDG 1 lb	HIG TC, EB, BL, PF 1C – 6C
8	Manzate 0.5 lb Sercadis 1.5 fl oz + Manzate 1 lb + LI 700 16 fl oz Captan 80 WDG 1 lb	HIG TC, EB, BL, PF 1C – 6C
9	Manzate 0.5 lb Revysol 1.67 fl oz + Manzate 1 lb + LI 700 16 fl oz Captan 80 WDG 1 lb	HIG TC, EB, BL, PF 1C – 6C
10	Manzate 0.5 lb Inspire Super 4 fl oz + Manzate 1 lb + LI 700 16 fl oz Captan 80 WDG 1 lb	HIG TC, EB, BL, PF 1C – 6C
11	Manzate 0.5 lb Aprovia 10.27 EC 1.83 fl oz + Manzate 1 lb + LI 700 16 fl oz Captan 80 WDG 1 lb	HIG TC, EB, BL, PF 1C – 6C
12	Manzate 0.5 lb Indar 2 fl oz + Manzate 1 lb Rally 1.67 fl oz + Manzate 1 lb Luna Sensation 1.67 oz/a + Manzate 1 lb Captan 80 WDG 0.83 lb + Flint Xtra 0.67 fl oz Captan 80 WDG 0.83 lb + Topsin M 0.33 lb Captan 80 WDG 0.83 lb	HIG TC PK BL, PF 1C – 2C 3C – 4C 5C – 6C
13	Manzate 0.5 lb Indar 2 fl oz + Manzate 1 lb Rally 1.67 fl oz + Manzate 1 lb Luna Tranquility 3.73 oz/a + Manzate 1 lb Captan 80 WDG 0.83 lb + Flint Xtra 0.67 fl oz Captan 80 WDG 0.83 lb + Topsin M 0.33 lb Captan 80 WDG 0.83 lb	HIG TC PK BL, PF 1C – 2C 3C – 4C 5C – 6C

How Effective is Revysol in Comparison to the Leading DMI and SDHI Scab Fungicides?

In 2018, control of apple leaf scab on Jersey Mac was excellent in all the DMI and SDHI fungicide programs, except for Rhyme and Rally (Figure 6A). Similar trend in efficacy of scab control was observed on Jersey Mac fruit, with numerically slightly more scab developing in Revysol applied at 4 and 5 oz and both the Luna Sensation and Luna Tranquility programs (Figure 6B). On 12 July 2018, more leaf scab developed on Redcort trees in comparison to the other two cultivars (Figure 6A). Even though apple leaf scab incidence was significantly lower in all the programs when compared to the untreated control and Captan covers i.e. treatment #2 only, the Revysol 4 oz and Rhyme programs allowed more leaf scab to develop in comparison to the other fungicide programs (Figure 6A). In contrast, fruit scab control on Redcort was excellent in all spray programs on 10 August, except for Rhyme and Rally that allowed more scab to develop (Figure 6B). More leaf scab developed on Redcort probably because the application of mancozeb at 1.5 lb/A at HIG was too low of a rate, not powerful enough to protect the leaf

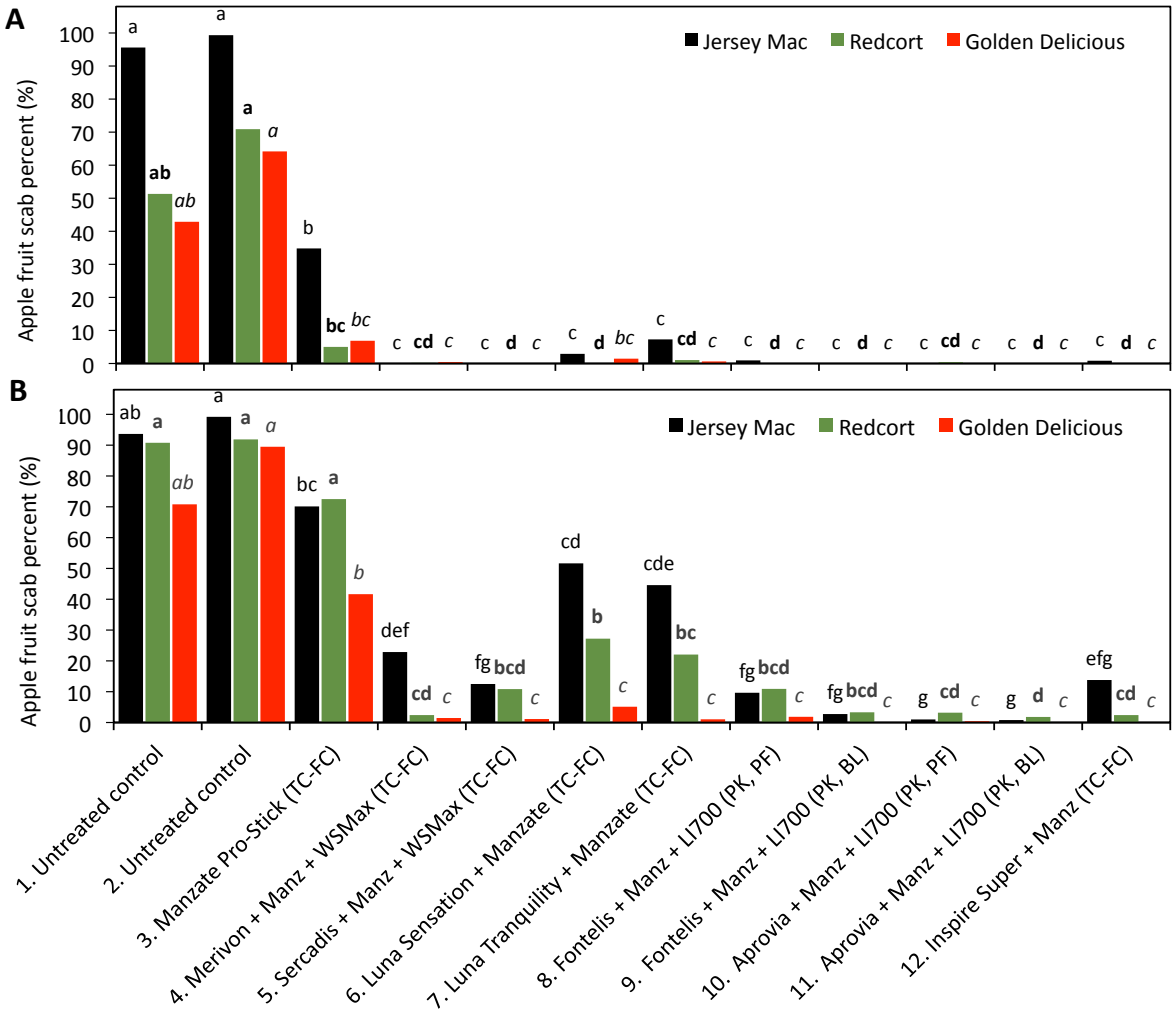

Figure 3. Apple fruit scab incidence on (A) 23 June and (B) 29 August 2017. Means within each cultivar i.e. bar color followed by different letters are significantly different within each date i.e. graph (Tukey's test, $P < 0.05$). Each mean consists of four replicate trees. Treatment names on x-axis apply for both graphs.

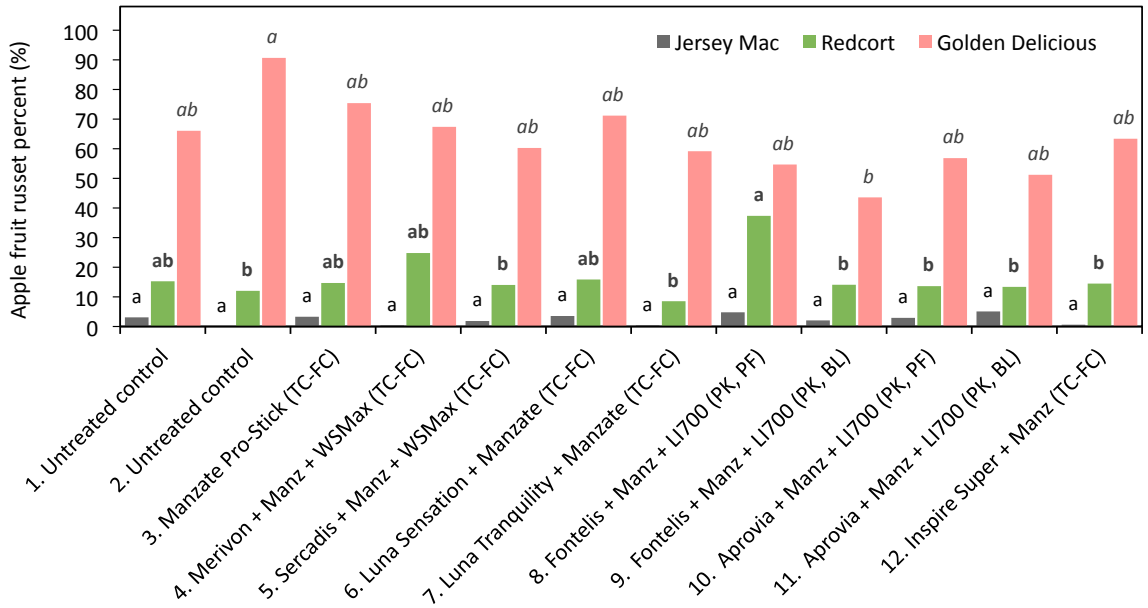

Figure 4. Apple fruit russet incidence on 29 August 2017 after the evaluated fungicide treatment programs. Means within each cultivar i.e. bar color followed by different letters are significantly different (Tukey's test, $P < 0.05$). Each mean consists of four replicate trees.

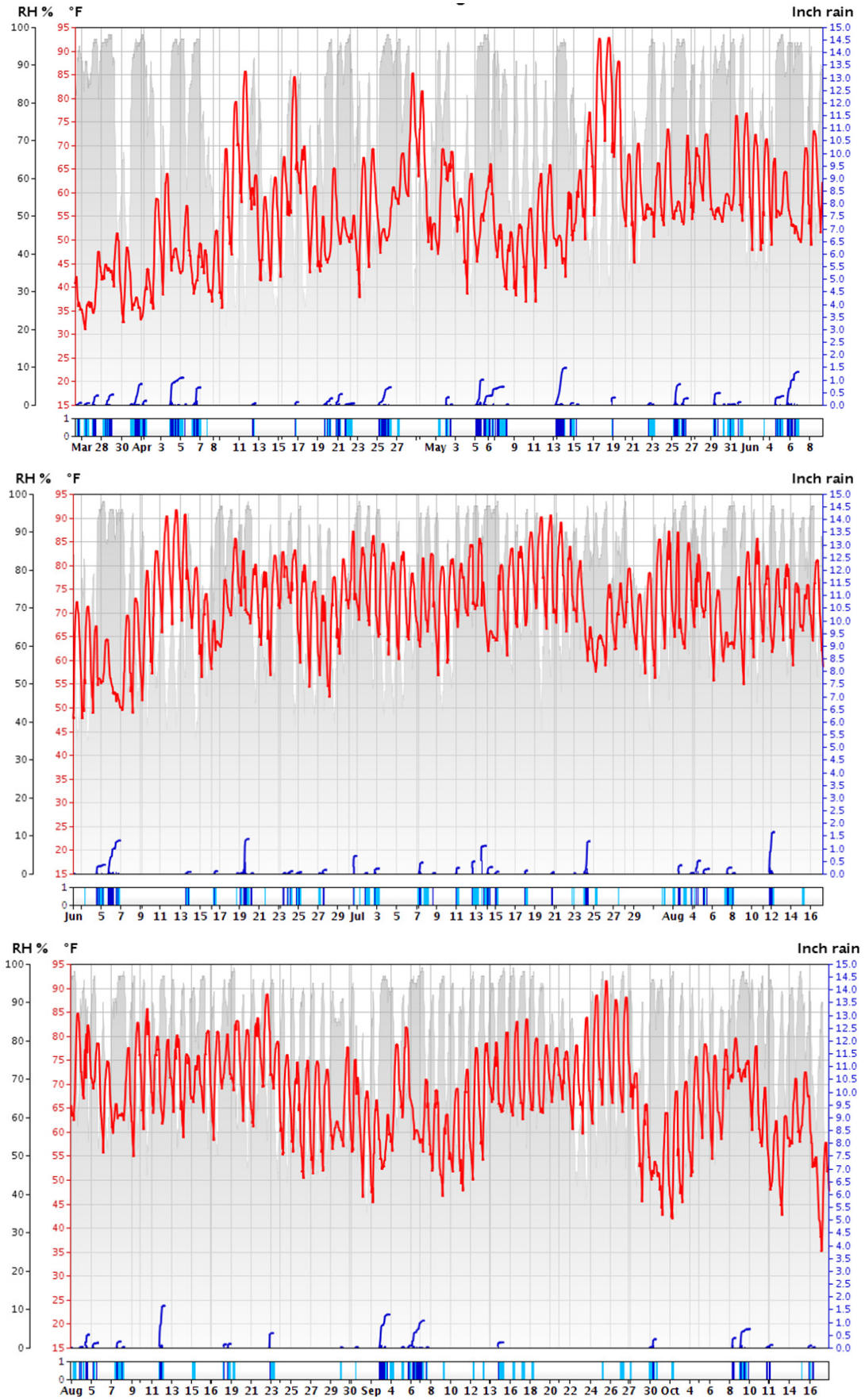

Figure 5. Weather conditions from 28 March – 16 October 2017 recorded from an on-site NEWA weather station in Highland NY, which favored apple fruit russetting during the apple scab efficacy trial in 2017. Red curved lines show temperatures (left y-axis in red), blue curved line/s show rain amounts in inches (right y-axis in blue), grey background represents relative air humidity (RH) in % (far left y-axis in black). Small bottom graph sections with dates show the length of rain (dark blue) and of wetting periods after the rain stopped (light blue). Source: RIMpro B.V., Zoelmond, Netherlands.

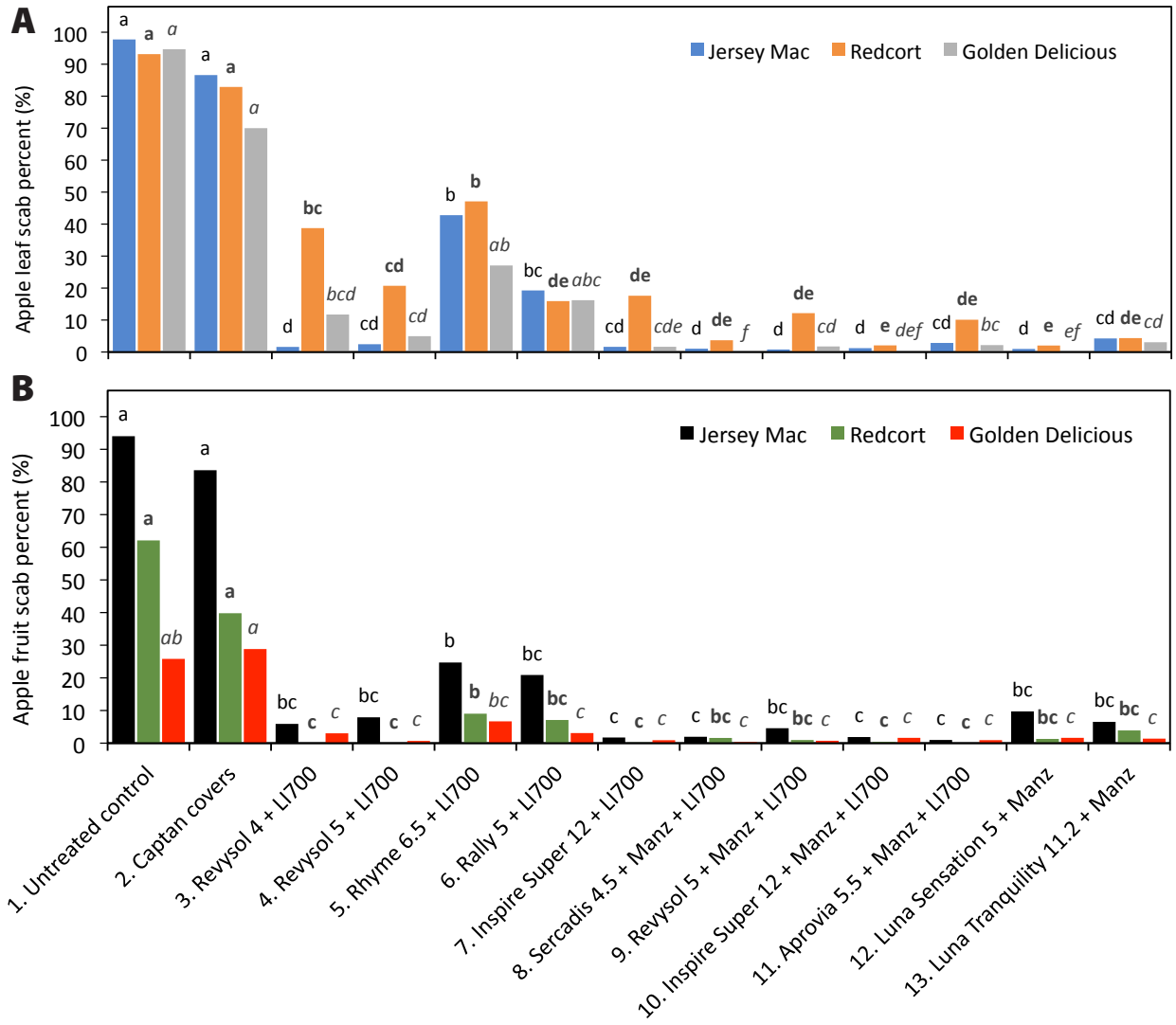

Figure 6. Apple scab incidence (A) on spur leaves on 12 July and (B) on fruit on 10 August 2018. Leaf scab means within each cultivar i.e. bar color followed by different letters are significantly different in graph A (LSD test, *P* < 0.05). Fruit scab means within each cultivar i.e. bar color followed by different letters are significantly different in graph B (Tukey's test, *P* < 0.05). Each mean consists of four replicate trees. Treatment names on x-axis apply for both graphs.

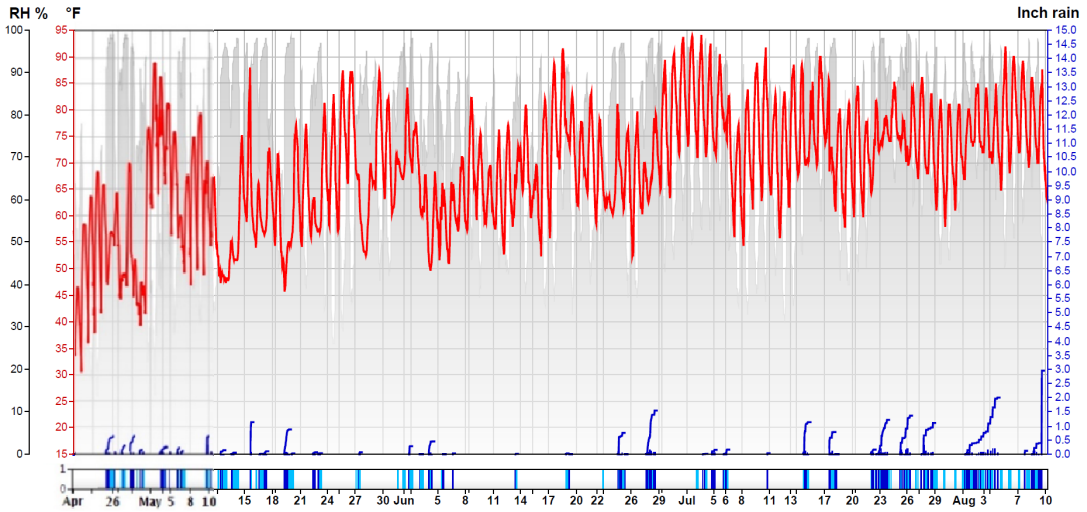

Figure 7. Weather conditions from 24 April – 10 August 2018 recorded from an on-site NEWA weather station in Highland NY. Red curved lines show temperatures (left y-axis in red), blue curved line/s show rain amounts in inches (right y-axis in blue), grey background represents relative air humidity (RH) in % (far left y-axis in black). Small bottom graph sections with dates show the length of rain (dark blue) and of wetting periods after the rain stopped (light blue). Source: RIMpro B.V., Zoelmond, Netherlands.

growth from the first two major infections on 25 and 27 April at HIG (Figure 6A). In conjunction, Redcort also preceded both Jersey Mac and Golden Delicious in flower bud development, thus allowing larger green leaf area to dilute fungicide residue and be targeted by released ascospores during these first two infections in the season. Based on the flower bud stage counts we conducted, on 18 April Redcort was at 67% GT stage while Jersey Mac was at 36% GT and Golden Delicious at 28% GT. On 27 April the same cultivar was at 73% HIG and Jersey Mac at 53% HIG. Leaf scab control was excellent on Golden Delicious, except in Rhyme and Rally treatments and with slightly more scab developing in Revysol 4 and 5 oz treatments when used alone (Figure 6A). Fruit scab control on Golden Delicious was excellent with all the DMI and SDHI fungicides, even though Rhyme allowed numerically more scab in comparison to the other programs (Figure 6B). Inspire Super used alone or in mix with Manzate performed very well across all the cultivars, except on Redcort leaves where Inspire Super used alone allowed more scab to establish (Figure 6A).

Conclusion

In years with rainy weather conditions like in 2017, which allowed severe apple scab infection pressure and many major infection periods, SDHI fungicides should be alternated with DMI-s with/or AP-s, while adding surfactants should further improve the efficacy of the SDHI-s and probably DMI-s too. Year 2018 had even more favorable weather conditions for apple scab infections depicted in the fact that 90% of NY state had more than 10 inches of yearly precipitation above average, with some Hudson Valley regions having more than 20 inches of yearly precipitation above average (NRCC 2019) and several south NY counties having 8.5 – 60.3% above average precipitation in inches per year (NWS). According to RIMpro model, frequent rains triggered a record 8 major infection periods starting with infections at HIG in Highland NY. Under these severe 2018 scab conditions, a new DMI fungicide Revysol provided largely similar apple scab control in comparison to the SDHI fungicides and Inspire Super which contains a DMI and an AP. Overall, the non-ionic surfactants seem to allow better systemic penetration of SDHI fungicides into the leaves and fruit, which probably allows longer SDHI residual activity through the rain and in conjunction with their 48-h kick-back activity, a better eradication potential for apple scab infections that are incubating.

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