# CHEMICAL CONTROL OF BLACK SHANK (*PHYTOPHTHORA NICOTIANAE*) IN STRIP-TILLAGE DARK FIRE-CURED TOBACCO

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Black shank, a soil-borne disease caused by *Phytophthora nicotianae*, is one of the most devastating oomycetes affecting dark tobacco worldwide. Field trials were conducted in 2018 and 2022 at an established black shank site near Hopkinsville, KY, to evaluate the efficacy of mefenoxam, fluopicolide, and oxathiapiprolin for management of black shank in dark fire-cured tobacco. Black shank field trials at this location have been conducted each year since 2006. KT D6LC, a dark-fired cultivar with moderate resistance to race 0 and race 1 black shank, was used in 2018 and 2022. Black shank infection was much greater in 2022, resulting in greater stand and yield loss in 2022 compared to 2018. Rainfall amount and timing differences between the 2 years likely contributed to these differences in final stand and yield. Final stand and total yield ranged from 80.7 to 99.3% and 2,374 to 2,882 kg ha$^{-1}$, respectively, in 2018, and from 10.3 to 81.8% and 238 to 2,637 kg ha$^{-1}$, respectively, in 2022. In both years, all oomyceticide treatments increased final stand and yield compared to untreated tobacco. In 2018, highest final stand came from tobacco that received mefenoxam or oxathiapiprolin plus mefenoxam at transplanting alone or followed by fluopicolide and mefenoxam after transplanting, or fluopicolide followed by mefenoxam after transplanting. Total yield was similar for tobacco treated with any oomyceticide treatment and higher than the yield of untreated tobacco in 2018. In 2022, tobacco treated with oxathiapiprolin plus mefenoxam in transplant water either alone or followed by fluopicolide and mefenoxam had significantly higher final stand and yield than all other treatments. Across both years, it was evident that oomyceticide applications made in transplant water, particularly oxathiapiprolin plus mefenoxam, had the greatest impact on black shank management in dark fire-cured tobacco.

**Additional key words:** *Phytophthora nicotianae*, black shank, final plant stand counts, yield

## INTRODUCTION

*Phytophthora nicotianae* is a soil-borne oomycete pathogen that is the causal agent of black shank. *Phytophthora nicotianae* is one of the most devastating diseases affecting both burley and dark tobacco production worldwide (8). The disease was first described by Van Breda de Hann from Java (Indonesia) in 1896 and first observed in the United States in 1915 in southern Georgia. By the 1930s, the oomycete was present in Kentucky and Tennessee and is now the most damaging disease in dark tobacco production (10).

Black shank can affect both roots and basal portions of the stalk and can occur during all stages of plant development, although disease symptomology varies (7, 9). During early stages of disease, root symptoms can have dead or blackened lateral roots with no symptoms visible on the lower stalk. In older plants, symptoms will appear on the lower stalk as a black lesion. If the stalk is cut in half, the pith of the stalk may appear dry and separated into plate-like disks with a brown/black coloration (4, 7, 9).

According to Shew and Lucas (10), black shank is a warm-weather disease that requires soil temperatures above 20°C for significant levels of infection to occur. High soil moisture levels also enhance disease infection. Saturation of the soil stimulates the release of motile zoospores from sporangia, the primary infective propagules (5, 9). Infected plants later collapse quickly when conditions become dry due to the compromised nature of the plant's root and vascular systems.

Management recommendations for black shank focus on crop rotation, variety resistance, and use of oomyceticides, in that order of importance. Crop rotation recommendations for black shank management state that tobacco production should not occur in the same field for 2 consecutive years, and rotational crops should be unrelated to tobacco (6).

There are 2 primary physiological races of *Phytophthora nicotianae* that affect tobacco, race 0 and race 1 (8). Of the 19 dark tobacco varieties that are currently available to dark tobacco producers, 5 of those have no resistance to either *Phytophthora nicotianae* race 0 or race 1. Three varieties have no resistance to race 1 but have complete resistance to race 0. There are 14 dark tobacco varieties that have some level of resistance to both races of black shank. It is recommended that dark tobacco growers select varieties that have at least some resistance to both *Phytophthora nicotianae* race 0 and race 1 in fields that have any history of black shank (2).

Along with crop rotation and use of resistant varieties, the use of oomyceticides is an important component of black shank management. Dark tobacco varieties generally have lower levels of black shank resistance than burley or flue-cured tobacco varieties, making appropriate use of available oomyceticides more critical for profitable dark tobacco production. There are currently 4 different oomyceticide active ingredients

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**Table 1. Transplant dates and application timings for 2018 and 2022 trials.**

| Year | Transplant Date | TPW Application Date | First Cultivation Application Date | Layby Application Date | Harvest Date |
|---|---|---|---|---|---|
| 2018 | June 18 | June 18 | July 2 | July 18 | October 4 |
| 2022 | June 3 | June 3 | June 24 | July 7 | October 3 |

available for black shank management in dark tobacco production: fluopicolide (Presidio, Valent, Walnut Creek, CA), mefenoxam (Ridomil Gold, Syngenta, Greensboro, NC), oxathiapiprolin (Orondis Gold, Syngenta, Greensboro, NC), and metalaxyl (Meta-Star, LG Life Sciences, Englewood Cliffs, NJ). These active ingredients have a range of oomyceticide resistance action committee (FRAC) codes and modes of action (MOA). Fluopicolide is a FRAC code 43 with a mode of action targeting the cytoskeleton and motor proteins. Mefenoxam and metalaxyl are FRAC code 4 and a MOA targeting nucleic acids metabolism. Oxathiapiprolin has a FRAC code 49 with a MOA targeting lipid synthesis or transport/membrane integrity or action. Mefenoxam was registered in 1996 and is the more active isomer of the first registered black shank oomyceticide, metalaxyl, that was registered for tobacco in 1977. In 2015 fluopicolide was registered for tobacco production, followed by oxathiapiprolin in 2016 (3).

There has been very limited research published on oomyceticide efficacy against black shank in dark fire-cured tobacco. The objective of this study was to evaluate the efficacy of mefenoxam, fluopicolide, and oxathiapiprolin for management of black shank in dark fire-cured tobacco.

## MATERIALS AND METHODS

Dark fire-cured tobacco field trials were conducted in 2018 and 2022 at a private farm near Hopkinsville, KY. This field location had a history of black shank since the early 1990s and has been in continuous tobacco production as a black shank research site since 2006. Ongoing field trials conducted each year have evaluated oomyceticide performance as well as black shank resistance in dark and burley tobacco varieties. Soil type was Sadler silt loam (fine-silty, mixed, semiactive, mesic Oxyaquic Fraglossudalfs) (11).

Dark tobacco variety utilized in both years of this study was KT D6LC, which has moderate resistance to both race 0 and race 1 black shank (2). For both years, plots were 4.5 m wide by 12.2 m long. Plots were four rows with a row spacing of 112 cm and a plant spacing of 74 cm for both years. Plant population was 12,147 plants ha$^{-1}$. Trials were arranged in a randomized complete block design with 4 replications of treatments. All field management practices in addition to oomyceticide treatments followed University of Kentucky extension recommendations (1).

The field site was prepared for strip-tillage tobacco production each year. A wheat cover crop sown the previous fall was killed in early April with glyphosate. Approximately 1 week prior to transplanting, rows were prepared by forming strips into the desiccated wheat cover crop using a ripper-stripper implement (Ripper-Stripper Strip-Till Subsoiler, Unverferth Manufacturing Co., Kalida, OH). Approximately 1 day before transplanting, strips were tilled using an in-line PTO-driven tiller (Multivator, Ford Distributing, Columbus, OH) set to match the previously prepared strips. Pretransplant herbicide was sulfentrazone applied broadcast at 0.35 kg ai/ha. Tobacco was transplanted into prepared strips on June 18 and June 3 in 2018 and 2022, respectively (Table 1). Treatment application timings included transplant water (TPW) simulations applied at transplanting, banded spray applications at first cultivation (approximately 3 weeks after transplanting), and banded spray applications at layby (approximately 5 weeks after transplanting; Table 2). TPW simulations were made immediately following transplanting by applying 157 mL of spray solution to the base of each transplant. This volume per plant was based on a standard TPW application volume of 1,907 L ha$^{-1}$ for the plant population used (Table 2). TPW simulations were applied using a pressurized backpack sprayer (Solo Incorporated, Newport News, VA) calibrated to deliver 157 mL per plant. First cultivation and layby applications were made at 187 L ha$^{-1}$ using a $CO_2$-pressurized sprayer equipped with a single 8002EVS even flat fan tip that was configured to apply a 36-cm wide band to each side of each plot row approximately 10 cm from each plot row. As no cultivation was used in this strip-tillage system, band applications were timed when rainfall was predicted within 24 hr after each application to help activate these products.

Stand counts were taken throughout the growing season to account for plant loss due to black shank infection. Plants that appeared to be green and lush were counted as “alive,” whereas plants that were chlorotic and wilted were considered “dead” and no longer taken into consideration for yield data. Initial stand counts were taken the day trials were transplanted and every 2 to 3 weeks thereafter. Stand counts were taken 6 times in 2018 and 7 times in 2022. Final stand counts were taken the day before plots were harvested in both years and were used to calculate final yield.

Tobacco plants were stalk harvested at maturity (approximately 6 weeks after topping) and allowed to field wilt. Following wilting, 5 or 6 stalks of tobacco were placed on sticks and hung in a typical fire-curing barn. Tobacco was fired with hardwood slabs and sawdust for approximately 28 days with 2 firing events. Following curing, tobacco was allowed to come into order with natural moisture, removed from curing barns, and stripped into lug (lower stalk) and leaf (upper stalk)

Table 2. Treatments, application timings, and application rates for 2018 and 2022 trials.

| Treatment | Treatment Name | Application Timing | Application Rate |
|---|---|---|---|
| 1 | Mefenoxam | TPW | 280 g/ha |
| 2 | Oxathiapiprolin +[a] mefenoxam | TPW | 70 g/ha + 280 g/ha |
| 3 | Fluopicolide | First cultivation | 140 g/ha |
| 4 | Fluopicolide fb[b] mefenoxam | First cultivation fb layby | 140 g/ha fb 280 g/ha |
| 5 | Oxathiapiprolin + mefenoxam fb Fluopicolide fb mefenoxam | TPW fb first cultivation fb layby | 70 g/ha + 280 g/ha fb 140 g/ha fb 280 g/ha |
| 6 | Untreated | — | — |

[a] + = tank mix.
[b] fb = followed by.

stalk positions. Leaves from each stalk position were weighed to calculate final yield (kg ha$^{-1}$) considering the final percent stand.

Data were analyzed using Statistical Analysis Software (SAS) version 9.4 (9). In both years, a randomized complete block design analysis was used to determine the effect of treatments on control of black shank. Plant survival was the response variable, and treatment was the explanatory variable. Analysis conducted was final percent stand and yield, using treatment as a fixed effect and replication as a random effect. Data for each year were analyzed separately with analysis of variance (ANOVA) using PROC GLIMMIX, and means were separated using least square means at $\alpha = 0.10$.

## RESULTS AND DISCUSSION

Data analysis indicated final stand and yield differences between oomyceticide treatments and the untreated check in 2018 (Table 3). Final stand and yield ranged from 93.0 to 99.3% and 2,616 to 2,882 kg ha$^{-1}$, respectively, in tobacco that received oomyceticide treatments compared to 80.7% final stand and 2,374 kg ha$^{-1}$ in untreated tobacco.

Data analysis indicated that there was a significant effect of treatment in 2022 for final stand count and yield (Table 4). Final stand counts ranged from 10.3% in untreated tobacco to 81.8% in tobacco treated with oxathiapiprolin plus mefenoxam in the TPW. Tobacco treated with oxathiapiprolin plus mefenoxam in the TPW alone or followed by fluopicolide and mefenoxam had significantly higher final stand count and yield than all other treatments. Treatments that included oxathiapiprolin plus mefenoxam in TPW had the highest final stand at 71.6 to 81.8%. Yield in 2022 ranged from 238 to 2,637 kg ha$^{-1}$. Tobacco that received oxathiapiprolin and mefenoxam in the TPW also had highest yield (2,239 to 2,637 kg ha$^{-1}$).

Trials in both 2018 and 2022 were carried out in a field that has been in tobacco production since the 1990s and in tobacco yearly for the past 17 years. Crop rotation and the use of back shank–resistant varieties are important management tools for the control of *P. nicotiana*. As seen in this study with no crop rotation and a moderately-resistant dark tobacco variety, oomyceticides were effective at controlling *P. nicotiana* compared to untreated tobacco.

According to Kentucky Mesonet (7), total rainfall varied by 11.32 cm between the 2018 and 2022 growing seasons, with 2022 having higher total rainfall between transplanting and harvest. Though there were a higher number of rainfall events in 2018, there were more events in 2022 that were 2.54 cm or greater. One of those events occurring on July 8, the day following the layby application, with 12.14 cm of rainfall. Timing post-transplant applications before a rainfall event can increase activity of these products (6). Though soil moisture is important for product to be taken up by the roots, excessive water can lead to product loss (6). The large rainfall event that occurred following the 2022 layby application could have contributed to the lower final plant stands (Table 4) compared to plant stands in 2018 (Table 3). In addition, a prolonged 14-day dry period just prior to harvest in 2022 may

Table 3. Treatments, application timings, final stand count, and yield for 2018 trial.

| Treatment | Application Timing | Final Stand (%)[a] | Yield (kg ha$^{-1}$) |
|---|---|---|---|
| Mefenoxam | TPW | 99.3 a | 2,737 a |
| Oxathiapiprolin +[b] mefenoxam | TPW | 97.7 ab | 2,736 a |
| Fluopicolide | First cultivation | 93.0 b | 2,616 a |
| Fluopicolide fb[c] mefenoxam | First cultivation fb layby | 99.3 a | 2,738 a |
| Oxathiapiprolin + mefenoxam fb Fluopicolide fb mefenoxam | TPW fb first cultivation fb layby | 98.4 ab | 2,882 a |
| Untreated | — | 80.7 c | 2,374 b |
| P value | — | **0.0009**[d] | **0.0137** |

[a] Means comparing treatment followed by the same letter are not significantly different.
[b] + = tank mix.
[c] fb = followed by.
[d] Boldface indicates a significant response to applied treatment.

Table 4. Treatments, application timings, final stand count, and yield for 2022 trial.

| Treatment | Application Timing | Final Stand (%)[a] | Yield (kg ha$^{-1}$) |
|---|---|---|---|
| Mefenoxam | TPW | 25.7 b | 701 b |
| Oxathiapiprolin +[b] mefenoxam | TPW | 81.8 a | 2,637 a |
| Fluopicolide | First cultivation | 30.9 b | 922 b |
| Fluopicolide fb[c] mefenoxam | First cultivation fb layby | 34.6 b | 1,002 b |
| Oxathiapiprolin + mefenoxam fb Fluopicolide fb mefenoxam | TPW fb first cultivation fb layby | 71.6 a | 2,239 a |
| Untreated | — | 10.3 b | 238 b |
| P value | — | **0.0058**[d] | **0.0065** |

[a] Means comparing treatment followed by the same letter are not significantly different.
[b] + = tank mix
[c] fb = followed by
[d] Boldface indicates a significant response to applied treatment.

have exacerbated stand loss and reduced yield potential compared to 2018.

## CONCLUSION

There was a dramatic increase in disease pressure from 2018 to 2022. Continuous tobacco and more favorable environmental conditions for black shank infection in 2022 likely contributed to this increase in disease. As previously mentioned, higher soil moisture levels can enhance infection as this can stimulate the release of zoospores, and in 2022 the amount of total rainfall was higher than in 2018, 49.53 cm and 38.20 cm, respectively. Subsequent dry conditions just prior to harvest in 2022 may have increased black shank losses compared to 2018. The continuous cropping of tobacco in a known black shank field shows how rapidly disease pressure can increase over a period of time. In 2018, all oomyceticide treatments had higher final stand counts and yields compared to the untreated control (Table 3). In 2022 treatments that included oxathiapiprolin plus mefenoxam in TPW had significantly higher final stand compared to all other oomyceticide treatments and the untreated control (Table 4). Tobacco treated with oxathiapiprolin plus mefenoxam in TPW, whether followed by additional treatments after transplanting or not, had significantly higher yield than all other treatments. These results emphasize the importance of oomyceticides and particularly transplant water oomyceticides applications as part of an integrated black shank management program for dark tobacco.

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