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ARTICLE

Evaluation of Three Fungicide Programs Across Five Virginia-type Peanut Cultivars

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ABSTRACT

The predominant diseases affecting peanut production in Virginia are late leaf spot (LLS), caused by *Nothopassalora personata,* and Sclerotinia blight (SB), caused by *Sclerotinia minor*. Field trials were conducted at two locations per year in 2022 and 2023 to evaluate the potential of fungicide programs across commercial peanut varieties for disease management and economic return. Fungicide programs served as main plots which were a HIP (high input program), a standard program that only targets leaf spot (SLSP), and a program that times applications according to both the Virginia Leaf Spot and Sclerotinia advisories (AP). Peanut varieties chosen were Bailey II, Sullivan, N.C. 20, Emery, and Walton. Results showed that in both years, all fungicide programs effectively controlled LLS, while SB was observed only in one location in 2023 and was suppressed by all programs. Yield responses varied across years and locations. In 2022, the AP and HIP programs yielded higher in Location 1, while the HIP program performed best in Location 2. In 2023, the AP and SLSP outperformed the HIP and untreated control in Location 1, while the HIP program had the greatest yield in Location 2. Economic returns varied by year. In Location 2, HIP resulted in a $232.65 loss in 2022 and a $371.45 gain in 2023, while AP had a $27.36 gain in 2022 and a $284.03 loss in 2023. The SLSP program incurred a small loss in Location 1 in 2022 but produced positive returns for the other location and year, indicating more consistent performance under the disease conditions observed in this study.

INTRODUCTION

Late leaf spot (LLS), caused by *Nothopassalora personata* [(Berk. and M.A. Curtis) U. Braun C. Nakash., Videira and Crous (syn. *Cercosporidium personatum* (Berk & M.A. Curtis) Deighton)], and Sclerotinia blight (SB) caused by *Sclerotinia minor* Jagger are the two major peanut diseases in Virginia. The prevalence of these diseases is primarily driven by environmental conditions and crop rotation history. Sclerotinia blight is favored by cooler (15-20 C) (Matheron and Porchas, 2005) and wet conditions, differing from southern stem rot, caused by *Agroathelia rolfsii*, which is more prevalent in the hotter, wetter climates of the southern United States (Aycock, 1966). Optimal conditions for LLS are 20 ^{o}C with prolonged leaf wetness periods (Butler *et al.*, 1994). LLS symptoms vary from small spots to severe leaf defoliation. A threshold of 40% defoliation caused by leaf spot was predicted to potentially cause a 10% yield loss for Virginia-type peanuts (Anco *et al.*, 2020). Moreover, lateral stem damage, caused by SB, is estimated to cause yield loss of 1598 kg/ha (Smith *et al.*, 1992), reinforcing the importance of a preventive management. However, there are no conclusive yield loss studies with SB to confirm whether this figure remains accurate or has changed over time.

Commercially available peanut cultivars grown in Virginia are Bailey II, Sullivan, Emery, Walton, and N.C. 20. All these cultivars are high oleic, Virginia-types (Balota *et al.*, 2023), and exhibit varying levels of resistance to LLS and SB (Balota *et al.*, 2021, Isleib *et al.*, 2011, Mehl, 2017, PVP-Bailey II, 2020). Despite the use of partially resistant varieties and crop rotation (Branch *et al.*, 2021, Jordan *et al.*, 2019), peanut production in Virginia currently rely heavily on preventive fungicide applications to reduce disease levels to maintain sustainable yields.

Leaf spot management uses the rotation of multiple fungicide modes of action using a 14-day spray interval or according to Virginia/North Carolina disease advisory programs (Balota *et al.*, 2023, Phipps *et al.*, 1997), which may include spraying for SB with additional treatments of fluazinam (Omega® 500F, Syngenta Crop Protection, Greensboro, NC) (Wei *et al.*, 2018, Woodward *et al.*, 2015). For many years, Omega® 500F was the primary fungicide used to control SB, though it added up to $99.6/ha in additional application costs to a standard leaf spot program (Langston, personal communication). Recently, a combination of Elatus (Syngenta Crop Protection) (azoxystrobin and benzovindiflupyr) and Miravis (Syngenta Crop Protection) (pydiflumetofen) has emerged as an alternative, offering effective control of both LLS and SB at a lower cost to growers (Batista da Silva and Langston, 2024). Cost of control is also related to number of applications within the season due to disease pressure and cultivar with partially resistance disease traits (Kaur *et al.*, 2024, Woodward *et al.*, 2008). The goal of this study was to determine the most cost-effective spray program for growers to control LLS and SB. The objectives of this study were to: i) evaluate five Virginia-type peanut cultivars and three different spray programs for their efficiency in controlling LLS and SB, and ii) assess the cost-benefit of these spray programs to growers.

MATERIAL AND METHODS

Experimental design, Location layout and treatment structure

Experiments were conducted in two different locations at the Virginia Tech Tidewater Agricultural Research & Extension Center (TAREC) in Suffolk in 2022 and 2023. In 2022, the soil type for Location 1 was 40% Eunola loamy fine sand and 60% Suffolk loamy sand, while Location 2 was 97% Suffolk loamy sand and 3% Nansemond fine sandy loam. In 2023, Location 1 was 90% Eunola loamy fine sand and 10% Suffolk loamy sand, and Location 2 was 95% Nansemond fine sandy loam and 5% Dragston fine sandy loam. Locations 1 and 2 in 2022 planted with peanut were rotated previously with sorghum and cotton, and barley, cotton, and corn, respectively. In 2023, both locations followed a three-year rotation cycle of cotton, corn, and peanuts. Locations were within a maximum radius of 4 km from each other.

Five commercial Virginia-type peanut cultivars were selected for this test (Bailey II, Sullivan, Walton, Emery, and N.C. 20). The peanut planting window in Virginia is between early and mid-May (Balota *et al.*, 2023). In 2022, peanuts were planted on May 11 in Location 1 and on May 5 in Location 2. In 2023, planting occurred later, with peanuts planted on May 22 in Location 1 and May 23 in Location 2. For both years planting density was 17 seeds per meter. The experiment employed a randomized split-plot design with four replications. Spray programs served as the main plot treatments, with cultivars being subplots. Subplots were two 11 m long at 91.44 cm spacing with a 2 m alley between replicates. Two untreated border rows were placed between fungicide treatment main plots and 2.38-m bare-ground borders were used on plot ends. The high input program (HIP) included a tank mix of pydiflumetofen with the premix of azoxystrobin + benzovindiflupyr at 60 days after planting (DAP), a tank mix of pydiflumetofen, with the premix azoxystrobin + benzovindiflupyr, and the premix of prothioconazole + tebuconazole at 90 DAP, the premix of prothioconazole + tebuconazole at 105 DAP, and chlorothalonil at 120 DAP. The standard leaf spot program (SLSP) included chlorothalonil at 60 DAP and rotated with the premix of prothioconazole + tebuconazole every 14 days, which was designed to treat only leaf spot. There was a total of three chlorothalonil applications and one of the premix of prothioconazole + tebuconazole in 2022, and two chlorothalonil applications and one of the premix of prothioconazole + tebuconazole in 2023. The advisory program (AP) called for application of chlorothalonil at 60 DAP rotated with prothioconazole + tebuconazole according to the Virginia Peanut Leaf Spot Advisory's Last Effective Spray Date, with additional fluazinam applications made according to the Virginia Peanut Sclerotinia Advisory (https://webipm.ento.vt.edu/cgi-bin/infonet1.cgi) (Table S1). All other inputs followed standard Virginia Cooperative Extension recommendations (Balota *et al.*, 2023).

Disease assessment

LLS was evaluated bi-weekly using the Florida scale (1-10), where 1 indicates no disease and 10 indicates complete defoliation and death (Chiteka *et al.*, 1988) and percentage of defoliation was calculated as previously reported (Jordan *et al.*, 2017, Li *et al.*, 2012).

$$\%\text{Defoliation} = \frac{100}{1 + e^{-\frac{Florida\ 1-10\ scale - 6.0672}{0.7975}}}$$

Sclerotinia blight (SB) incidence was recorded as infection foci exhibiting symptoms and/or signs of SB in increments of 30.5 cm of row length for each treatment row per plot. Both LLS and SB were quantified using the area under the disease progress curve (AUDPC), where Yi = percent defoliation at the i^{th} observation, and Xi = time (days) at the i^{th} observation as described by Shaner and Finney (1977).

$$AUDPC = \sum_{i=1}^{n} \left[\frac{Y_{i+n_1+Y_i}}{2}\right] [X_{i+1} - X_i]$$

Yield assessment

In 2022, Location 1 and Location 2 were dug on October 24 and October 21 and harvested on November 11 and November 4, respectively. In 2023, Location 1 and Location 2 were dug on October 6 and harvested on October 25. Peanuts were dug and harvested using a KMC two-row digger and a Hobbs peanut combine (Model 325A). Peanut pod yield by weight was determined using a 7% (w/w) moisture content conversion.

Economic assessment

To calculate the net return of each fungicide program, the following formula was used:

$$C/B_{fungicide} = \left(Y_{w\ fungicide} - Y_{no\ fungicide}\right) \times P_{peanut} - Cost_{spray\ program}$$

where:

$C/B_{fungicide}$ = cost/benefit of the fungicide program ($/ha)

$Y_{w\ fungicide}$ = Yield with fungicide (kg/ha)

$Y_{no\ fungicide}$ = Yield without fungicide (kg/ha)

P_{peanut} = Peanut price ($/kg)

$Cost_{spray\ program}$ = Total cost of spray program ($/ha)

Statistical analysis

Analysis of variance (ANOVA) was conducted to evaluate the effects of spray programs (plots) and peanut cultivars (subplots), as well as their interaction, and AUDPC. Data were analyzed using the MIXED procedure (PROC MIXED) in SAS (version 9.4, SAS Institute Inc., Cary, NC, USA). A linear mixed-effects model was fitted with treatment, variety, and their interaction as fixed effects, and block and block x spray program as a random effect. Residuals from the initial model were examined for normality using the *PROC UNIVARIATE* procedure and inspecting the histograms. If the residuals did not meet the assumption of normality, the data were subjected to a square-root transformation. Least square means were back-transformed and used for graphical presentation. Model parameters were estimated using the restricted maximum likelihood (REML) method, and denominator degrees of freedom were computed using the Kenward–Roger approximation. Least square means (LSMEANS) were compared using Tukey's honestly significant difference (HSD) adjustment to control for multiple comparisons. Significance was assessed at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Environmental conditions in 2022 were less favorable for SB development due to lower rainfall compared to 2023 (Table S2). However, SB was observed only in Location 1 in 2023, while disease pressure for LLS was low (Florida 1-3) to moderate (Florida 4-6) in both years.

Late leaf spot and Sclerotinia blight

The development of cultivars with improved disease resistance have the potential to reduce reliance on fungicide applications (Woodward *et al.*, 2008), subsequently lowering application costs. However, complete resistance to LLS and SB in peanuts is not yet available, resulting in variable disease responses each season among cultivars. Disease analysis for 2022 revealed no significant main effect of cultivars in Location 1 (p=0.39), and no interactions of cultivars and application programs were observed (p=0.40). However, there was a notable effect of fungicide programs, with all treatments displaying significant control of LLS compared to untreated plots (Figure 1). In Location 2, an interaction between cultivar and fungicide program was observed (p< 0.0001). When combined with fungicide programs, all cultivars exhibited significantly lower LLS disease pressure compared to untreated Bailey II, Sullivan, and Emery. Among the untreated plots, Bailey II demonstrated the greatest AUDPC of all, which conflicts with data from previous research (Jordan *et al.*, 2025).

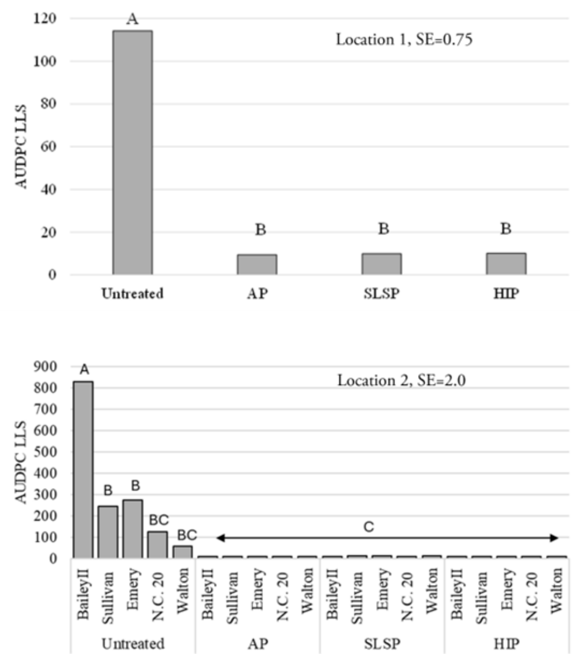

Figure 1. Late leaf spot severity over three evaluation periods in Location 1 and Location 2 at the Tidewater Agricultural Research & Extension Center in 2022. AUDPC LLS (area under the disease progress curve for late leaf spot) was calculated from data pooled between August 16 and October 10. AP (advisory program), SLSP (standard leaf spot program), HIP (high input program), and Standard Error (SE). Treatment means for fungicide programs followed by different letters are significantly different according to Tukey-Kramer-adjusted pairwise comparison at 5% significance.

In 2023, significant interactions between fungicide programs and cultivars were observed at both Location 1 (p = 0.0087) and Location 2 (p = 0.003) (Figure 2). All fungicide programs demonstrated significant control of LLS across all cultivars at both locations. Among the untreated plots, Emery, Walton, and N.C. 20 exhibited lower AUDPC than Bailey II, while Sullivan did not differ statistically from any of the cultivars in Location 1. In Location 2, N.C. 20 and Walton exhibited lower AUDPC values than Emery, whereas Sullivan did not differ from other cultivars. Bailey II was only different from Walton. This variable disease response observed across both years and

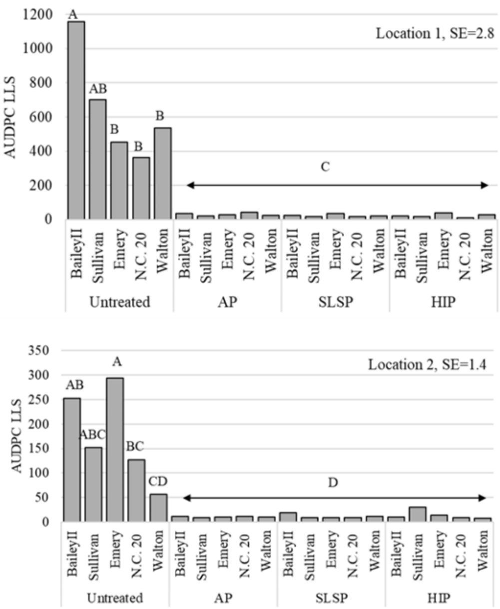

Figure 2. Late leaf spot severity over three evaluation periods in Location 1 and Location 2 at the Tidewater Agricultural Research & Extension Center in 2023. AUDPC LLS (area under the disease progress curve for late leaf spot) was calculated from data pooled between September 2 and October 10. AP (Advisory program), SLSP (standard leaf spot program), HIP (high input program), and Standard Error (SE). Treatment means for fungicide programs followed by different letters are significantly different according to Tukey-Kramer-adjusted pairwise comparison at 5% significance.

Although weather conditions in both 2022 and 2023 did not appear to be ideal for SB development, SB was present in Location 1 in 2023 (Figure 3). No significant interaction between spray programs and cultivars was observed for SB (p=0.23), and there was no main effect of cultivars (p=0.22). However, there was a main effect of spray program (p <0.0001). All spray programs effectively reduced SB compared to untreated plots. Although both AP and HIP showed numerically and significantly lower levels of SB compared to SLSP, respectively, the SLSP treatment still provided measurable SB suppression, despite not including a fungicide specifically targeting SB. The premix of prothioconazole and tebuconazole, rotated with chlorothalonil, has been a long-established and highly effective treatment for controlling LLS in peanut crops (Culbreath *et al.*, 2008); however, there is some evidence that the premix of prothioconazole and tebuconazole

locations may be attributed to the resistance to LLS being linked to quantitative trait loci located on two distinct chromosomes and their associated gene networks (Chu *et al.*, 2019, Dang *et al.*, 2021). A similar cultivar response pattern was also reported in Runner-type peanuts (Kaur *et al.*, 2024), suggesting that peanut cultivar performance is influenced by environmental factors affecting disease pressure.

(Batista da Silva and Langston, 2024) and timing (Woodward *et al.*, 2015) of application may contribute to SB control.

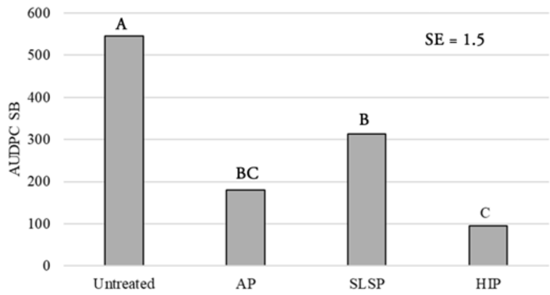

Figure 3. Sclerotinia blight severity over three evaluation periods in Location 1 at the Tidewater Agricultural Research & Extension Center in 2023. AUDPC SB (area under the disease progress curve for Sclerotinia blight)) was calculated from data pooled between September 2 and October 10. AP (Advisory program), SLSP (standard leaf spot program), HIP (high input program), and Standard Error (SE). Treatment means for fungicide programs followed by different letters are significantly different according to Tukey-Kramer-adjusted pairwise comparison at 5% significance.

Recently, combinations including pydiflumetofen and the premix of azoxystrobin and benzovindiflupyr have emerged as a viable alternative to fluazinam offering control for both LLS and SB simultaneously (Batista da Silva and Langston, 2024). This newer spray program can reduce overall fungicide application costs because it does not require additional sprays of fluazinam to manage SB. However, the onset of SB is driven by weather conditions, and applying fungicides on a fixed schedule as was used in the HIP may lead to unnecessary fungicide inputs in years where unfavorable weather conditions lead to low disease pressure.

Yield

There was no main effect of cultivar on yield in either 2022 (Location 1: p = 0.24; Location 2: p = 0.66) or 2023 (Location 1: p = 0.08; Location 2: p = 0.12). Additionally, the interaction between fungicide program and cultivar did not affect yield in 2022 (Location 1: p = 0.58; Location 2: p = 0.38) or 2023 (Location 1: p = 0.48; Location 2: p = 0.60). Fungicide programs did have a significant effect on yield in both years (Table 1). In 2022, Location 1 showed a greater yield response with HIP, yielding ca. 500 kg/ha greater than the untreated. However, the SLSP performed better at

Location 2, producing yields 927 and 761 kg/ha higher than the untreated and HIP, respectively. The AP did not differ significantly from any of the spray programs at either location.

Table 1. Effect of fungicide programs on peanut pod yield in 2022 and 2023 in two different locations.

	Pod yield (kg/ha)			
	2022		2023	
Fungicide programs[x]	Location 1	Location 2	Location 1	Location 2
Untreated	5456 b[y]	6774 b	6229 b	5579 b
AP	5842 ab	7163 ab	7642 a	5474 b
SLSP	5701 ab	7701 a	7170 ab	6001 ab
HIP	5942 a	6940 b	6202 b	6799 a
P(f)	0.022	0.0024	0.03	0.0024

[x] HIP= High input program; AP=Advisory program; and SLSP=Standard leaf spot program.
[y] Means in a column followed by different letters are significantly different according to Tukey–Kramer–adjusted pairwise comparisons at 5% significance.

In 2023, the AP treatment improved yield compared to the untreated control and the HIP program in Location 1. Specifically, the AP yielded 7642 kg/ha, whereas the untreated and HIP plots produced 1413 and 1440 kg/ha less, respectively, despite the HIP providing significant suppression of both diseases relative to the untreated control. Conversely, in Location 2, the HIP program outperformed by ca. 1200 and 1300 kg/ha the untreated and AP treatment, respectively. The SLSP treatment yielded 6001 kg/ha, which did not differ statistically from any other spray program or the untreated check. The premix of azoxystrobin and benzovindiflupyr, tank-mixed with pydiflumetofen applied at 60 DAP and 90 DAP has proven to be an effective fungicide treatment for the simultaneous control of LLS and SB, resulting in yield improvement (Batista da Silva and Langston, 2024). However, because the application schedule differed slightly among locations, the yield response was not consistent across all sites, highlighting the importance of maintaining a well-timed fungicide program to achieve consistent disease suppression and maximize yield benefits.

Economic assessment

Although untreated cultivars differed in disease control, none of the cultivars showed statistically significant differences in yield. Therefore, only fungicide cost was included in the calculations.

The average peanut prices from local buyers for Virginia-type peanuts in 2022 and 2023 were $0.55/kg and $0.57/kg ($0.25 and $0.26/lb), respectively. The estimated costs for each fungicide program quoted by three local retailers were $186.60/ha (2022) and $224.2/ha (2023) for the AP, $124.60/ha for the SLSP, and $324/ha for the HIP (Table 2). The AP is used to time fungicide sprays as needed based on weather-based diseases advisories provided on the Peanut-Cotton Infonet website. In 2023, environmental conditions were consistently favorable for disease which triggered more sprays using the AP resulting in increased fungicide costs.

In 2022, the AP provided a net return of 0.86% in Location 1 and 0.73% in Location 2. The SLSP provided a 0.07% net loss in Location 1 and a net return of 10.00% in Location 2. The HIP resulted in 1.90% negative net returns in Location 1 and 6.24% in Location 2. In 2023, the AP resulted in a positive return of 16.37% in Location 1 and a loss of 8.93% in Location 2. The SLSP yielded profits of 11.60% in Location 1 and 3.65% in Location 2. The HIP showed a negative net return of 9.60% in Location 1 compared to a positive net gain of 11.70% in Location 2.

In 2023, SB was observed only in Location 1, which limited the ability to fully and accurately assess net returns with fungicide with both diseases combined. Notably, the AP resulted in numerically lower yield compared to the untreated plots in Location 2, leading to negative returns for growers at that location. Nevertheless, the AP offers the potential to reduce the number of sprays during the season, thereby lowering production costs and potentially increasing profitability.

Although yield responses varied among years and locations, it remains unclear under which conditions the HIP would provide a greater economic benefit. Under moderate disease pressure, the HIP did not result in a positive net return for either disease. Moreover, the cost of the HIP ($323.95) was substantially greater than the other fungicide programs, regardless of the number of applications per season, making it an economically unfavorable option. Similar findings were reported by Kaur *et al.* (2024), who observed no significant differences in yield between high- and low-input programs, indicating that higher fungicide expenditures may not be justified. Among the spray programs evaluated, the SLSP generally provided a higher positive economic return than the other programs, except in Location 1 in 2022, indicating its potential as the most effective strategy. However, this program is solely designed for leaf spot management and may not be cost-effective in fields with high SB pressure. Further studies are needed to better understand the role of SLSP in the control of SB.

In conclusion, net returns vary annually based on disease pressure and weather conditions. Additional factors, including labor cost and pod grade, also influence overall net return and may fluctuate from year to year. Further research is needed to evaluate the full impact of fungicide applications on yield under high disease pressure and its impact on growers' net returns.

Table 2. Net return on application of different fungicide programs in 2022 and 2023 in Location 1 and 2.

Fungicide program[x]	Active ingredient	Brand	Rate a.i. (kg/ha)	Single App. Cost/ha	Return ($/ha)[y]			
					2022		2023	
					Location 1[z]	Location 2	Location 1	Location2
AP	Chlorothalonil	Echo	1.68	$12.35	25.71	27.36	581.23	-284.03
	Prothioconazole and Tebuconazole	Provost Silver	0.91	$49.94				
	Fluazinam	Omega 500F	1.12	$99.6				
SLSP	Chlorothalonil	Echo	1.68	$12.35	-2.18	372.92	411.79	115.96
	Prothioconazole and Tebuconazole	Provost Silver	0.91	$49.94				
HIP	Pydiflumetofen	Miravis	0.24	$42.85	-56.65	-232.65	-339.34	371.45
	azoxystrobin and benzovindiflupyr	Elatus	0.67	$63.01				
	Prothioconazole and Tebuconazole	Provost Silver	0.91	$49.94				
	Chlorothalonil	Echo	1.68	$12.35				

[x] HIP= High input program; AP=Advisory program; and SLSP=Standard leaf spot program.

[y] Return was based on biological yield and the contract price per ton of peanuts each year.

[z] Location 1 and 2 in 2022: AP – three applications of Echo and one of Provost Silver and Omega 500 F; SLSP: three applications of Echo and two Provost silver; HIP: two applications of Miravis, Elatus and Provost Silver, and one of Echo. Location 1 and 2 in 2023: AP: two applications of Echo and Provost Silver, and one Omega 500 F; SLSP: two applications of Echo and Provost silver; HIP: two applications of Miravis, Elatus and Provost Silver and one of Echo.

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