Interactive Effects of Fungicide, Application Timing, and Spray Volume on Peanut Diseases and Yield

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Abstract
Fungicide penetration of the peanut (Arachis hypogaea) canopy to target soilborne pathogens is difficult due to the dense foliage present when mid- to late-season applications are made. To assess the effect of application timing and volume on leaf spot and stem rot control as well as peanut yield, pyraclostrobin (0.21 kg a.i./ha) or chlorothalonil (1.26 kg a.i./ha), a systemic and a contact fungicide, respectively, were applied four times on cv. Georgia Green during the day (on unfolded leaves) or at night (on folded leaves) at 187, 243, or 355 liters/ha. Night application of pyraclostrobin, across spray volumes, gave the best stem rot control and pod yield increase. Pyraclostrobin applied during the day at higher spray volumes also slightly increased control of stem rot, apparently by improving canopy penetration. Neither application timing nor spray volume affected leaf spot control with pyraclostrobin. Higher spray volumes for the chlorothalonil applications tended to improve control of early and late leaf spot, possibly by increasing coverage of foliage and stems.

Introduction
The cultivated peanut (Arachis hypogaea) is a uniquely geotropic legume that flowers aboveground and produces pods belowground in the top 8-cm of the soil (9). During the time necessary for pod formation and maturity, pods and other plant tissues at or below the soil surface are exposed to several soilborne plant pathogens.

In Georgia, stem rot (caused by Sclerotium rolfsii) has been the most important peanut disease since the 2005 growing season in both percent reduction in crop value and damage (12,13,14,15,16). Initial infection by S. rolfsii occurs within the first two months after planting when plant stems spread across the soil and pod formation initiates (2). The fungus continues to colonize more tissue throughout the season and can rot pods, pegs, roots, and stems. Aboveground symptoms and signs of S. rolfsii infection are typically spreading white mycelia and/or sclerotia on diseased tissues at the soil surface, as well as rotting stems and wilted, dying plants (Fig. 1A). The fungus can grow very well in the soil near the surface and colonize belowground tissues as well (Fig. 1B).
The most desirable control option for stem rot is planting peanut cultivars with resistance against *S. rolfsii*, but only cultivars with moderate resistance are available (10). Growers often choose to plant high yielding cultivars with little resistance and rely on multiple fungicide applications for stem rot control (22). Unfortunately, by the time fungicide applications are initiated, the canopy of most commercial cultivars is already dense. During the day, when fungicides are usually applied, peanut leaves unfold to maximize interception of sunlight (Fig. 2A) but fungicide penetration to *S. rolfsii* infection sites at the soil surface is limited due to the overlapping layers of leaves (2). At sunset, as a result of nyctinastic leaf movement (23), each peanut leaf folds up resulting in a more open canopy (Fig. 2B).

In previous studies, night applications of systemic peanut fungicides consistently decreased stem rot incidence, provided similar control of early leaf spot, and increased pod yield compared with standard day applications (1,2,3). This effect has been shown with various fungicides to different degrees, but it...
has been most consistent with pyraclostrobin (1,3). Pyraclostrobin is very
effective against leaf spot diseases (18), but high rates (0.21 to 0.27 kg a.i./ha)
are also recommended for control of stem rot (17,18). In the previous night
fungicide application studies (1,3), pyraclostrobin and other fungicides were
applied in 187 liters of water per hectare (LPH) delivered at 254 pKa by a
sprayer boom equipped with three hollow cone (TX-SS6) nozzles per row. Since
night fungicide applications improved control of stem rot primarily by
increasing spray penetration of the peanut canopy (3), we hypothesized that
higher spray volumes and pressures to deliver fungicides could have a similar
effect. Spray nozzles are available to produce a wide variety of droplet sizes and
spray patterns that could influence fungicide deposition. Hollow cone nozzles
provide balance between canopy penetration and complete coverage of leaf
surfaces, but have potential for spray-drift due to small droplets produced.
Hollow cone nozzles have sometimes been considered to be superior to flat fan
nozzles for leaf spot control in peanut due to the more uniform coverage, but a
previous study has shown them to give similar levels of control (19). Flat fan
nozzles produce droplet sizes ranging from small to large depending on spray
pressure and special features. For example, flat fan nozzles with air induction
produce larger droplets that are less prone to drift, and may provide increased
canopy penetration. This study focused on the partial and interactive effects of
fungicide, application timing, and spray volume on the control of leaf spot and
stem rot and the resulting benefits on pod yield.

Field Evaluation of Fungicide, Application Timing, and Spray Volume

The experiment was conducted at the University of Georgia Tifton Campus,
Blackshank Farm (31°30.066'N, 83°32.801'W), in a Tifton Loamy sand soil with
2 to 5% slope (7) in 2009 and 2010. The field, which had been under continuous
peanut cultivation for at least 6 years and had a history of leaf spot and stem rot
epidemics, was bottom plowed to a depth of 20 to 25 cm and then disk
harrowed and marked off in beds 1.83 m wide. Ethalfluralin (0.72 kg a.i./ha)
and S-metolachlor (1.5 kg a.i./ha) were incorporated with a rototiller 5 cm deep
a week before planting for weed control. The cv. Georgia Green (5) was planted
with a two-row Monosem planter at 23 seeds/m on 11 and 15 May in 2009 and
2010, respectively. Aldicarb was applied in furrow (0.67 kg a.i./ha) and on a
0.3-m band (1.68 kg a.i./ha) at planting for thrips and nematode control. The
postemergence herbicide imazapic (0.07 kg a.i./ha) was applied 40 days after
planting (DAP). Gypsum (1120 kg/ha) was applied at early pegging (4).

The experimental design was a split-split plot with treatments arranged in
four replications. Each plot was a two-row bed 7.62 m long and row spacing was
0.91 m. Replications were separated by 2.44-m fallow alleys. Fungicides were
applied in the main plots and were chlorothalonil (1.26 kg a.i./ha),
pyraclostrobin (0.21 kg a.i./ha), and a nontreated control. Each fungicide
treatment was applied as a midseason four-spray block from application 3 to 6
in a seven-spray program. All plots, except for the nontreated control, also
received cover sprays of chlorothalonil (1.26 kg a.i./ha) for applications 1, 2, and
7. Fungicide applications were initiated 30 to 40 DAP, and subsequent
applications followed a 14-day schedule. The sub-plot treatment was application
timing where midseason fungicide applications were scheduled at night (3 a.m.
to 5 a.m.) when leaves were folded, or later the same day (10 a.m. to 12 p.m.)
when leaves were unfolded. The sub-sub-plot treatment was spray water volume
where fungicides were applied either at 187 LPH delivered at 276 kPa by three
hollow-cone TX-SS6 nozzles per row (Fig. 3), 243 LPH delivered at 207 kPa by
two flat-fan nozzles per row (Fig. 4), or 355 LPH delivered at 345 kPa by two
flat-fan air-induction nozzles per row (Fig. 5). All applications were made with a
CO₂-pressurized, belt-pack broadcast sprayer boom.
Fig. 3. Broadcast CO₂-pressurized sprayer boom equipped with three hollow cone TX-SS6 nozzles per row of peanut used to apply fungicide in a spray water volume of 187 liters/ha at 276 kPa. Note the fine droplets.

Fig. 4. Broadcast CO₂-pressurized sprayer boom equipped with two flat fan 11003VS nozzles per row of peanut used to apply fungicide in a spray water volume of 243 liters/ha at 207 kPa. Note the relatively medium droplets compared with Fig. 5.
Compounded early and late leaf spot intensity was visually assessed using the Florida 1-to-10 severity scale, where 1 = no disease (0% defoliation) and 10 = plants defoliated or dead (8). Plot leaf spot estimate was an arithmetic mean of the individual assessment values of all plants within the plot. Therefore, the rated leaf spot severity scale is a discrete variable at the level of the individual plant, but it is a (pseudo-) continuous variable at the plot level as a result of the arithmetic averaging (21). In both years, leaf spot assessments were taken two days before the crop was dug. Stem rot was assessed by counting the number of disease foci two days before peanut was dug for aboveground incidence, and within a day after peanut was dug and inverted for belowground incidence. Stem rot focus consisted of one or more consecutive affected plants in a 30-cm section of row. The number of 30-cm sections affected was divided by total number of 30-cm sections and multiplied by 100 to determine stem rot incidence in a plot. The field plots were mechanically dug and inverted between 130 to 140 DAP based on the hull-scrape method of estimating pod maturity (24). Windrows were mechanically harvested with a two-row combine approximately five days later. The final pod moisture content after air-drying was about 9% (wt/wt).

Leaf spot severity, aboveground and belowground stem rot incidence, and pod yield were subject to analysis of variance using the mixed procedure of SAS (version 9.2, SAS Institute Inc., Cary, NC) to determine significant differences ($P \leq 0.05$) among treatments. Analysis of variance was performed with data arranged in a split-split plot design nested within years. The mixed procedure provided the correct error terms for the partial and interactive effects of fungicide, application timing, and spray volume of the split-split-plot design. The ddfm=satterth option in the "model statement" was used to perform Satterthwaite approximation of the degree of freedom. The interaction of year $\times$ treatment for the variables was assessed to determine if data could be pooled across years. Means were separated by Fisher’s protected least significant difference (LSD) at the 5% level.
The interaction of year × fungicide × application timing × spray volume was significant for leaf spot severity ($P \leq 0.001$), stem rot incidence aboveground ($P = 0.001$) and belowground ($P = 0.007$), and pod yield ($P = 0.092$). Therefore, the results are presented separately for each year.

The 2009 season was relatively wet and leaf spot severity was higher than in 2010 in non-fungicide treated plots (Fig. 6, A and B). Pyraclostrobin was more effective in controlling leaf spot in both years than chlorothalonil, regardless of application timing and spray volume. In 2009, with high leaf spot intensity, application of chlorothalonil at night resulted in consistently higher disease ratings compared with day application across spray volumes, but differences were not significant. In 2010, chlorothalonil decreased leaf spot compared with the nontreated plots, but in 2009 only day application of chlorothalonil in higher volumes had less disease than nontreated plots. Reduced efficacy of night applications with chlorothalonil could have been due to decreased retention of fungicide on leaves wet from dew, or possibly less deposition on the upper surface of the leaves. Increased fungicide coverage on the foliage and stems at higher spray volumes may account for the better leaf spot control observed with those sprayer configurations.
Stem rot epidemics were severe in both years of the study. Chlorothalonil, which previously was shown to have no significant activity against *S. rolfsii* (6,11), failed to reduced above or belowground stem rot incidence compared to the nontreated control (Figs. 7 and 8, A and B). Day applications of pyraclostrobin were also not highly effective, although reduced aboveground disease incidence was obtained at the higher two spray volumes in 2009.
Spray volume of 243 LPH also showed some reduction in belowground stem rot incidence in 2009 (Fig. 8A). Night application of pyraclostrobin in both years consistently decreased aboveground stem rot incidence across spray volumes compared with the nontreated control, and the similar chlorothalonil treatment (Fig. 7, A and B).

Fig. 7. Effect of fungicide, application timing, and spray volume on aboveground stem rot incidence of peanut at Blackshank Farm, Tifton, GA, in 2009 (A) and 2010 (B). Bar heights are means for application timing and spray volume for each fungicide, and bars with the same letter(s) in each year are not significantly ($P \leq 0.05$) different according to Fisher’s protected LSD.
Night sprays of pyraclostrobin had less stem rot than the corresponding day sprays in every case except with 243 LPH in 2009 (Fig. 8, A). Belowground stem rot incidence for pyraclostrobin treatments was also similar across spray volumes within an application timing (i.e. night or day), with the exception in 2010 when the 243 LPH resulted in less disease than the 187 LPH with night applications (Fig. 8, B). In general, application timing with pyraclostrobin had more impact on stem rot control than did spray volume and superior control was obtained with night than day applications, which confirms results of previous studies (1,3). Night applications of pyraclostrobin, regardless of spray volume, generally had the highest pod yields, particularly in 2009 (Fig. 9, A). Day applications of pyraclostrobin at all spray volumes in 2009 also increased pod yield compared with nontreated control, but only the 243 LPH gave a higher yield than the corresponding chlorothalonil treatments. In 2010, day application of pyraclostrobin regardless of spray volume did not improve pod yield compared with all chlorothalonil treatments and nontreated plots. All chlorothalonil treatments, except for night application at 243 LPH, had similar pod yield compared with nontreated plots in both years (Fig. 9, A and B), presumably due to the severe stem rot epidemics.
Fig. 8. Effect of fungicide, application timing, and spray volume on belowground stem rot incidence of peanut at Blackshank Farm, Tifton, Georgia in 2009 (A) and 2010 (B). Bar heights are means for application timing and spray volume for each fungicide, and bars with different letter(s) in each year are significantly ($P \leq 0.05$) different according to Fisher’s protected LSD.
Conclusions
Contact fungicides for foliar disease control are best applied to dry foliage during the day to obtain the most consistent control. These data support previous findings (19) that chlorothalonil can be applied effectively with a wide range of nozzles and spray volumes, and that hollow cone "fungicide" nozzles are not any more effective than a flat fan or air induction nozzle. Applying...
systemic fungicides at night when peanut leaves are folded facilitates penetration of the peanut canopy to better target soilborne pathogens. Results from this and previous studies (1,3) have shown that applying systemic pyraclostrobin at night increases control of stem rot, improves pod yield, and provides similar protection from leaf spot compared with day application. Multiple applications of standard rates of pyraclostrobin (0.16 to < 0.21 kg a.i./ha) at daylight, when the peanut canopy is dense, have given erratic control of stem rot (18). Pyraclostrobin is known to provide excellent control of leaf spot, which relates to its translaminar movement and quick binding to the leaf surface waxes (20). However, these same traits can result in reduced effectiveness for stem rot since the active ingredient may not reach the infection court of the pathogen. Higher spray volumes and larger droplet sizes were used in this study to try to compensate for this effect. They did not affect control of foliar diseases, and had only marginal benefits on stem rot control and yield increase with pyraclostrobin. Growers using pyraclostrobin only for foliar disease control can spray with a wide range of nozzles and pressures, and do so at any time. Although some trials have shown control of peanut stem rot with daytime applications of pyraclostrobin, to obtain consistent control with this fungicide requires it be applied at night. However, it should also be noted that this study evaluated a 250 g/liter EC formulation of pyraclostrobin. The manufacturer (BASF) is now also producing a SC formulation that may have different properties of retention and redistribution on the foliage.

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Literature Cited