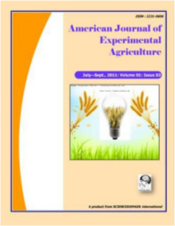

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Fungicide Selection and Application Timing for Management of Peanut Pod Rot

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Authors' contributions

This work was carried out in collaboration between all authors. Author LDT, initiated the experiments, collected the data, performed the statistical analysis, managed the literature review and wrote the first drafts of the manuscript. Author JEW, designed the study, wrote the protocol, assisted with statistical analysis and contributed to the final draft. Author KLO provided technical and editorial support. All authors read and approved the final manuscript.

Original Research Article

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ABSTRACT

Aims: To evaluate the effect of fungicide regimes and application timing on pod rot incidence, peanut yield, grades, and diseased kernels.
Study Design: Randomized complete block design with nine treatments and four replicates.
Place and Duration of Study: Studies were conducted during the 2010 and 2011 growing seasons on producers farms located west of Seminole, Texas in Gaines County.
Methodology: Rows were spaced 101.6 cm apart on raised beds. Plot size was four rows wide by 304.8 m in length. Fungicide regimes comprised of azoxystrobin and/or mefenoxam, or flutolanil were evaluated. Initial applications were made 68 or 82 days after planting (DAP) with subsequent applications occurring 30 days later. All fungicides were applied in a 50.8 cm band.
Results: In 2010, the percentage of pods affected and percent damaged kernels were reduced by early applications of mefenoxam and azoxystrobin. The flutolanil treatment in 2010 showed the greatest improvement in yield compared to the control. The 2011 trial was greatly affected by drought, and no appreciable differences were seen for any of the

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parameters evaluated. Despite pod set in this region not occurring later than 82 DAP, early fungicide applications at 68 DAP provided better control of pod rot in peanuts in this region than later applications beginning at 82 DAP in 2010, and no appreciable differences were seen in 2011.

Conclusion: Trends were not consistent between the two years, thus conclusions or recommendations on fungicide selection and application timing are lacking. Further studies are needed to better identify when applications should be initiated to minimize losses due to pod rot. Identifying the ideal application timing of fungicides for the High Plains production region.

Keywords: Arachis hypogaea L.; pod rot complex; pythium and rhizoctonia; disease control; fungicides.

1. INTRODUCTION

Peanut (*Arachis hypogaea* L.) is an important crop in Texas, contributing more than $1 billion to the state's economy in 2012 [1]. Several market types including runner, spanish, valencia and virginia-types are grown in the state [1,2]. Several foliar and soilborne fungal pathogens are capable affecting production [3,4], quality and value are affected by with thepod rot complex being the most economically important disease. Besler et al. [5] found that losses between 22% and 28% occurred under conducive conditions, likewise, Wheeler et al. [6] reported losses to pod rot in excess of $780/ha. This complex is comprised of several fungal pathogens, including *Rhizoctonia solani* Kühn AG-4 and numerous *Pythium* spp. In a recent survey, Wheeler et al. [7] found *R. solani* present in approximately 35% of fields in this region and *Pythium* spp. were found in approximately 40% of fields. *Pythium myriotylum*, *P. irregulare*, and *P. ultimum*, were found to be the most prevalent species associated with diseased pods. A similar survey conducted in North Carolina found that *Pythium* spp., primarily *P. irregulare*, and *Rhizoctonia* spp. were the most commonly isolated pod rot fungi in all 11 major peanut producing counties [8].

Pod rot not only affects the hulls of peanuts, but may also infect the kernels, which lowers the crop value [9]. Yield losses caused by *R. solani* and *Pythium* spp. are difficult to determine due to the variety of fungal pathogens that cause pod rot. Management of pod rot through resistant peanut cultivars is important. In general, virginia types appear to be more susceptible, whereas spanish peanuts tend to be more resistant [3]. The spanish cultivar, 'Toalson,' may provide resistance to both *Pythium* spp. and *R. solani* [3,4]. Partial resistance to *R. solani* has also been identified in the runner cultivar, 'Georgia Browne' [3]. Although some resistance has been identified, there is limited information regarding cultivar reaction to pod rot pathogens.

Fungicides are the primary management method for pod rot in the Southern High Plains region of Texas. Various fungicide chemistries are used for pod rot management. Typical fungicide regimes require two to three applications at maximum label rates [2] costing as much as $250/ha. Azoxystrobin, a strobilurin fungicide, and mefenoxam, a phenylamide fungicide, are the most widely used in the region [10,11]. Strobilurin fungicides target the Q_{oI} site of Cytochrome b and inhibit electron transport [12]. Azoxystrobin has activity against basidiomycetes such as *R. solani* and has limited activity against *Pythium* spp. [2,13]. Wheeler et al. [6] found that the application of azoxystrobin increased yields and improved yields in each year of a three-year study. Mefenoxam, inhibits RNA synthesis, and only has activity against oomycetes such as *Pythium* spp. [14,15]. While mefenoxam is commonly used as a cottonseed treatment, it is seldom used in peanut production [10,11]. Flutolanil is also used as a foliar spray targeting basidiomycete fungi by affecting infection cushion formation and mycelial growth [16,17]. There is little information available regarding the performance of flutolanil in this region.

In general, the initial application of fungicides for management of soilborne pathogens of peanut is based on the models developed in the southeastern [18] and Carolina regions of the United States [19,20], where applications are made approximately 60 days after planting (DAP) with subsequent applications made on a 30 day interval if needed. The environmental conditions in west Texas, with cool nights and low humidity, are different than those in the southeast. As a result, peanut plants in the Southern High Plains display a different rate of development (Woodward, unpublished data), which may affect the onset of disease. Growers in the west Texas region spray fungicides twice during the growing season, thus delaying initial applications may be more effective at decreasing losses caused by pod rot. The objective of this study was to evaluate fungicide programs with different initial application timings.

2. MATERIALS AND METHODS

2.1 Fungicide Timing

Large plot fungicide trials were conducted in Gaines County, Texas in fields with a history of pod rot. Trials were conducted in fields that had been planted to cotton (*Gossypium hirsutum* L.) the three previous years. Plots were four rows wide by 304.8 m in length, approximately 0.1 hectares. In 2010, the runner cultivar 'Flavor Runner 458' was planted at a rate of 19.7 seeds/m on 29 April; whereas, the virginia cultivar 'Gregory' was planted at a rate of 18.0 seeds/m on 9 May in 2011. All production practices other than the application of fungicides were in conjunction with local extension recommendations [2] and implemented by producer collaborators.

Three fungicides were evaluated: azoxystrobin (Abound 2.08F, Syngenta Crop Protection, Greensboro, NC), mefenoxam (Ridomil Gold 4F, Syngenta Crop Protection, Greensboro, NC), and flutolanil (Convoy 3.8F, Nichino America, Inc., Wilmington, DE). Fungicide treatments included the following: the industry standard of two applications of azoxystrobin (1.79 L/ha) at 68 and 98 DAP, the maximum input treatment consisting of mefenoxam (0.58 L/ha) at 68 DAP, and azoxystrobin (1.79 L/ha) at 98 and 128 DAP, an early mefenoxam (0.58 L/ha) application at 68 DAP and azoxystrobin (1.79 L/ha) application at 98 DAP, an increased rate of mefenoxam (1.17 L/ha) at 68 DAP and an azoxystrobin (1.79 L/ha) application at 98 DAP, an early azoxystrobin (1.79 L/ha) application at 68 DAP and a late mefenoxam (1.17 L/ha) application at 98 DAP, an azoxystrobin (1.79 L/ha) application at 82 DAP and mefenoxam (1.17 L/ha) application at 112 DAP, a late application of mefenoxam (1.17 L/ha) at 82 DAP and azoxystrobin (1.79 L/ha) application at 112 DAP, and a *R. solani* treatment, consisted of two flutolanil (2.33 L/ha) applications at 68 and 98 DAP. A non-treated control was used for the comparison of fungicide applications. Treatments were arranged in a randomized complete block design with four replications. Fungicides were applied in 187 L/ha of water delivered at 276 kPa by a Spider sprayer (Lee Inc, Idalou, TX) equipped with one flat fan (8003EVS, Tee Jet Technologies, Wheaton, IL) per row. The height of the boom was adjusted to apply fungicides in a 50.8 cm band.

2.2 Data Collection and Analysis

Final pod rot incidence was determined immediately after plants were inverted (1 and 3 October in 2010 and 2011, respectively) by estimating the proportion of pods exhibiting symptoms within 25 arbitrarily chosen areas across the test area that were 0.9 to 1.5 m in length and examining the number of affected plants. Vines were allowed to cure in windrows 8-10 days, and pod yields were determined by weighing harvested plots in drying trailers with load cells. Final yields were adjusted to 10% moisture by air drying. Grade data were obtained using Federal Inspection Service Guidelines [9] by determining the percentage sound mature kernels plus sound splits (SMK+SS) of 250 g sub-samples. The percentage of damaged kernels was also used to compare treatments.

Pod rot, yield, grade, and damaged kernels data were analyzed using Proc GLM (Statistical Analysis System, version 9.2, Cary, NC) and Fisher's protected least significant differences (LSD) were calculated for the separation of means. Subsequent references to significant differences among means are at the $P \le 0.10$ level, unless otherwise specified.

3. RESULTS AND DISCUSSION

Test year was significant ($P \le 0.10$) for all parameters observed. Due to differences among trials conducted the two growing seasons data from the two years are presented separately. Differences in environmental conditions may have contributed to the trends observed between the two years. The yearly precipitation in 2010 was 399 mm and was 77 mm for 2011 Table 1, with no precipitation between April and September [21]. The average daily temperature 2010 was 23.6℃ [22] and the average daily temperature in 2011 was 26.2℃ [23].

Table 1. Monthly temperatures and rainfall during the 2010 and 2011 growing seasons compared to the 30-yr average for the High Plains of Texas*

Month	Average temperature (°C)			Rainfall (mm)		
	2010	**2011**	**30-yr avg**	**2010**	**2011**	**30-yr avg**
May	20.8	21.5	21.0	29	1	58
June	27.2	29.9	25.2	65	0	77
July	25.2	30.0	26.8	181	1	49
August	26.8	29.9	26.1	34	9	49
September	23.8	22.1	22.1	24	32	64
October	17.6	23.6	16.4	66	34	49
Average	23.6	26.2	22.9	399	77	346

**data are from the National Weather Service 2010 and 2011 Lubbock summaries [22 and 23].*

3.1 Pod Rot

In 2010, treatments with early initiated applications of fungicides reduced pod rot incidence compared to the non-treated control Table 2. A trend in pod rot (LSD=2.5; P=0.0109) development was observed where early applications (68 DAP) of fungicides, either mefenoxam or azoxystrobin, reduced pod rot, and later applications of fungicides led to pod rot similar to that of the control Table 2. Treatments with early applications of azoxystrobin and mefenoxam showed the greatest reduction of pod rot (<3.7%) compared to the control (7.5%) Table 2. Flutolanil treatments did not follow the same trend as azoxystrobin and mefenoxam treatments in 2010, as *Pythium* spp. were the predominant pathogens isolated from symptomatic pods. No differences in pod rot incidence were observed in 2011 (LSD=1.4; *P*=0.1237) Table 3. Differences not shared between years may be attributed to the harsh environmental conditions of 2011, which reduced disease pressure. While early applications of fungicides reduced pod rot incidence compared to the control, delayed applications of fungicides in 2010 may have led to higher percentages of pod rot due to the interception of fungicides with the increased canopy density later in the season. Delayed mefenoxam applications may have been less effective than earlier applications due to the high affinity of mefenoxam to the foliage [14,15,24].

3.2 Yield

In 2010, the flutolanil treatment improved yields (770 kg/ha) significantly from the control Table 2. Treatments with early applications of mefenoxam and azoxystrobin provided a slight increase in yield (336–400 kg/ha), but was not significantly different from the control Table 2. Differences in yield between treatments in 2010, specifically the high input treatment with three applications (4790 kg/ha), the early higher rate mefenoxam application treatment (4854 kg/ha) and the early azoxystrobin treatment (4803 kg/ha), may be the result of fungicide treatments reducing disease. While flutolanil may not have reduced damaged kernels significantly, it has activity on other diseases, such as southern blight (*Sclerotium rolfsii* Sacc.) [17], which was observed at low levels throughout the test area (data not shown). Rhizoctonia peg rot was also observed in areas adjacent to test plots earlier in the growing season (data not shown). No appreciable differences in yield were observed for any treatment in 2011 Table 3. The similarities in yield between treatments in 2011 may be attributed to the limited precipitation and decreased disease pressure.

Table 2. Effect of initial fungicide application timing on peanut pod rot, yield, grade and damaged kernels in the Southern High Plains of Texas in 2010

Treatment	Description	Rate (L ha^{-1})	Timing (DAP)[w]	Pod rot (%)	Yield (kg ha^{-1})	Grade (%smk+ss)[x]	Damaged Kernels (%)
1	Control	-----	-----	7.5 a[y]	4454 b	70.2	2.5 a
2	Azoxystrobin	1.79	82 & 112	5.7 abc	4548 b	75.8	1.1 bc
3	Mefenoxam	0.58	68	3.4 c	4790 ab	75.7	0.7 bc
	Azoxystrobin	1.79	98 & 128				
4	Mefenoxam	0.58	68	3.6 c	4489 b	75.7	0.6 c
	Azoxystrobin	1.79	98				
5	Mefenoxam	1.17	68	3.7 c	4854 ab	72.1	0.8 bc
	Azoxystrobin	1.79	98				
6	Azoxystrobin	1.79	68	4.5 bc	4803 ab	74.9	0.8 b
	Mefenoxam	1.17	98				
7	Azoxystrobin	1.79	82	6.5 ab	4675 b	74.6	2.0 abc
	Mefenoxam	1.17	112				
8	Mefenoxam	1.17	82	7.3 a	4684 b	75.6	2.1 ab
	Azoxystrobin	1.79	112				
9	Flutolanil	2.33	68 & 98	6.2 ab	5224 a	74.2	1.4 abc
		LSD		2.5	435	NS[z]	1.4
		p-value		0.0109	0.0485		0.0896

[w] Application timing in number of days after planting (DAP). [x]Grade percentage was obtained using Federal Inspection Service Guidelines [9]. [y]Means followed by the same letter are not significantly different according to Fishers protected LSD. [z]Not significant.

3.3 Grade and Damaged Kernels

In 2010, there were no significant differences in grade from the non-treated control Table 2. Despite no differences, fungicide treatments tended to have higher grades than the non-treated control. The threshold for economic deductions due to damaged kernels was reached in 2010 by the control at 2.5% damaged kernels Table 2 [9,25]. All treatments in 2010 reduced damaged kernels (LSD=1.4; *P*=0.0896). Early applications of azoxystrobin and mefenoxam reduced damaged kernels compared to the control in 2010, with damaged kernels ranging from 0.6 to 0.8% for those treatments Table 2.

In 2011, differences were observed in grade percentages (LSD=1.7; *P*=0.0005) Table 3. Results were highly variable (64.7-68.1%) due to a high proportion of immature kernels (data not shown). The flutolanil treatment had a decreased grade by 3.5%, and other treatments had lower grades by as much as 2.6%. Delayed maturity results in smaller kernels and a reduced grade; furthermore, the severity of the drought in 2011 negatively affected growth and development, leading to lower grades. No appreciable differences in damaged kernels were observed Table 3.

Table 3. Effect of initial fungicide application timing on peanut pod rot, yield, grade and damaged kernels in the Southern High Plains of Texas in 2011

Treatment	Description	Rate (L ha^{-1})	Timing (DAP)[w]	Pod rot (%)	Yield (kg h a^{-1})	Grade (%smk+ss)[x]	Damaged kernels (%)
1	Control	-----	-----	3.9	5094	68.2 a[y]	2.1
2	Azoxystrobin	1.79	82 & 112	3.8	5156	68.1 ab	1.1
3	Mefenoxam	0.58	68	2.1	5275	66.6 cd	0.6
	Azoxystrobin	1.79	98 & 128				
4	Mefenoxam	0.58	68	3.2	5294	67.6 abc	1.7
	Azoxystrobin	1.79	98				
5	Mefenoxam	1.17	68	3.1	5314	65.6 de	2.3
	Azoxystrobin	1.79	98				
6	Azoxystrobin	1.79	68	3.8	5187	68.2 a	0.6
	Mefenoxam	1.17	98				
7	Azoxystrobin	1.79	82	2.7	5107	67.9 ab	1.0
	Mefenoxam	1.17	112				
8	Mefenoxam	1.17	82	2.8	5367	66.9 bc	1.0
	Azoxystrobin	1.79	112				
9	Flutolanil	2.33	68 & 98	2.6	5324	64.7e	2.0
		LSD		NSz	NS	1.7	NS
		p-value				0.0005	

[w] Application timing in number of days after planting (DAP). [x] Grade percentage was obtained using Federal Inspection Service Guidelines [9]. [y] Means followed by the same letter are not significantly different according to Fishers protected LSD. [z] Not significant.

Pod rot pathogens are ubiquitous organisms with a broad host range; furthermore, they are necrotrophs and are capable of surviving saprophytically on organic matter. Most peanut tissues are susceptible to infection throughout any point in the growing season [3,4]. Information on peanut resistance to pod rot is limited [5,26,27], and in this region peanut is rotated with cotton, which is also a susceptible host to *R. solani* and *Pythium* spp. In this trial, fungicide treatments reduced damage to pods and kernels caused by pod rot pathogens. Early applications of azoxystrobin and mefenoxam showed the greatest reduction in pod rot percentage and damaged kernels. Despite pod set in this region not occurring after 82 DAP, early applications at 68 DAP provided better control of pod rot in peanuts than later applications beginning at 82 DAP. This may be due to the interception of fungicides with the plant canopy, specifically mefenoxam. In other regions, spraying fungicides at night when leaves are folded has been shown to increase the deposition of the fungicides on the lower portion of the canopy [28]; however, data on the effect of nighttime applications on pod rot in west Texas are lacking (Woodward, unpublished).

4. CONCLUSION

Attention to the history of a field and the pathogen(s) responsible for losses should be considered when developing disease management strategies. Because environmental conditions were drastically different from 2010 to 2011, trends were not consistent between the two years, thus conclusions or recommendations on fungicide selection and application timing are lacking. Further studies are needed to better identify when applications should be initiated to minimize losses due to pod rot. Identifying the ideal application timing of fungicides for the High Plains production region may better protect plants from pod rot without increasing the number of fungicide applications needed and increasing the profitability of the crop.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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