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Peanut Yield and Injury from Thrips with Combinations of Acephate, *Bradyrhizobium* Inoculant, and Prothioconazole Applied in the Seed Furrow at Planting

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Crop Management

Core Ideas

- Acephate and prothioconazole did not adversely impact peanut response to *Bradyrhizobium* inoculant.
- Peanut was more responsive to *Bradyrhizobium* inoculant when planted in fields with no history of peanut production than in fields with recent peanut plantings.
- Acephate, *Bradyrhizobium* inoculant, and prothioconazole can be applied simultaneously in the seed furrow without losing effectiveness of individual components.

Abstract

Peanut (*Arachis hypogaea* L.) growers often apply commercial inoculant in the form of *Bradyrhizobium* to the seed furrow at planting to promote biological nitrogen fixation. Additionally, disease and injury from thrips (*Frankliniella* spp.) feeding can be reduced when prothioconazole and acephate, respectively, are applied in the seed furrow. Interactions of these products have not been determined for Virginia market-type peanut. Six experiments were conducted during 2009 and 2010 to define interactions of acephate, *Bradyrhizobium* inoculant, and prothioconazole when co-applied in the seed furrow at planting. Acephate and prothioconazole did not affect peanut yield response to *Bradyrhizobium* inoculant. Peanut yield increased in two of six experiments when *Bradyrhizobium* inoculant was applied. The increase in yield was observed in fields that did not have a known history of peanut production. Visible thrips damage was lower when prothioconazole was applied in absence of acephate, although acephate was more effective in minimizing injury from thrips than prothioconazole. Although acephate did not affect peanut yield, prothioconazole increased yield in all experiments regardless of acephate or *Bradyrhizobium* treatment. Results from these experiments indicate that acephate, inoculant containing *Bradyrhizobium*, and prothioconazole are compatible in peanut production systems.

Fungicides, inoculants containing *Bradyrhizobium*, and insecticides can be applied in the seed furrow to peanut at planting to control seedling and other diseases, promote biological nitrogen fixation, and control thrips, respectively (Lanier et al., 2005; Carley et al., 2009; Drake et al., 2009; Carroll et al., 2015). Determining whether these agrochemicals can be applied simultaneously would be beneficial in assisting farmers to formulate peanut-production and pest-management strategies. This issue is especially

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Abbreviations: CBR, Cylindrocladium black rot.

Conversions: For unit conversions relevant to this article, see Table A

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Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
2.54	inch	centimeter, cm (10^{-2} m)
0.304	foot, ft	meter, m
2.96×10^{-2}	ounce (liquid), oz	liter, L (10^{-3} m^3)
1.12	pound per acre, lb/acre	kilogram per hectare, kg/ha
9.35	gallon per acre, gal/acre	liter per hectare, L/ha

important because of the limited availability of aldicarb and an increased reliance on acephate for thrips management (Brandenburg, 2015; Brandenburg et al., 2015). Although imidacloprid is often applied in the seed furrow at planting to suppress thrips in peanut (Thagard et al., 2013; Morgan et al., 2014; Rhodes et al., 2015;), concern over the resistance of western flower thrips (*Frankliniella occidentalis*; Gao et al., 2012) and tobacco thrips (*Frankliniella fusca*; Huseth et al., 2016) to neonicotinoid insecticides also makes determining the utility of acephate important.

Prothioconazole suppresses Cylindrocladium black rot (CBR; caused by *Cylindrocladium parasiticum*) and stem rot disease (caused by *Sclerotium rolfsii*) in peanut when applied in the seed furrow at planting (Musson et al., 2006; Brenneman and Young, 2007; Tyson and Kemerait, 2013; Shew et al., 2015). Surveys in North Carolina and Virginia indicated that 30–37% of farmers applied prothioconazole in the seed furrow to suppress CBR (Thagard et al., 2013; Morgan et al., 2014; Rhodes et al., 2015).

The majority of growers in North Carolina (75–77%) apply inoculant containing *Bradyrhizobium* to peanut, and very often the inoculant is applied as a liquid in the seed furrow at planting (Thagard et al., 2013; Morgan et al., 2014; Rhodes et al., 2015). Failure of the inoculant to perform can be expensive to correct, especially in fields without native *Bradyrhizobium* present (Lanier et al., 2005; Carroll et al., 2015). Determining if fungicides or insecticides adversely affect inoculant performance is important to prevent the need for additional production costs to correct nitrogen-deficient peanut.

Reports that acephate and prothioconazole interact with *Bradyrhizobium* inoculant are limited in the peer-reviewed literature, especially in fields where native *Bradyrhizobium* is not present. In previous research in fields without a history of peanut production, often referred to as new ground fields, the fungicide tebuconazole did not adversely affect efficacy of *Bradyrhizobium* inoculant when co-applied in the seed furrow (Jordan et al., 2006). Surprisingly, visible injury from thrips feeding following tebuconazole applied in the seed furrow at planting decreased compared with injury in the absence of tebuconazole. Peanut emergence was delayed when tebuconazole was applied, and it was postulated that peanut emerging later had less injury from thrips. Peanut emerging in late May or early June in North Carolina often experiences lower populations of thrips and less injury caused by thrips feeding compared with emergence in early May (Drake et al., 2009; Brandenburg, 2015). However, the cause of reduced thrips damage was not elucidated in those experiments. Prothioconazole has the same mechanism of action as tebuconazole (Shew et al., 2015). In contrast to tebuconazole, pyroclostrobin applied in the seed furrow reduced the efficacy of the inoculant and, subsequently, yield (Jordan et al., 2010). Tubbs et al. (2015) reported that phorate applied in the seed furrow did not adversely affect nodulation or peanut response to *Bradyrhizobium* inoculant. In addition to concerns over inoculant performance, seed is the single most expensive input in peanut crops (Bullen and Jordan, 2015), and determining if agrochemicals adversely affect peanut stand establishment is important.

Information relative to interactions of acephate, inoculant containing *Bradyrhizobium*, and prothioconazole is limited. Therefore, research was conducted to determine compatibility of the insecticide acephate, the fungicide prothioconazole, and the liquid inoculant *Bradyrhizobium* when applied in the seed furrow at planting in both new ground fields and fields with a history of peanut production.

Locations, Soil Series, and Establishment Practices

The research was conducted in North Carolina during 2009 and 2010 at three locations each year: the Peanut Belt Research Station near Lewiston-Woodville (36.1 N, −77.1 W) on a Norfolk loamy sand soil (fine-loamy, kaolinitic, Typic Kandiudults); the Upper Coastal Plain Research Station located near Rocky Mount (35.9 N, −77.7 W) on a Goldsboro loamy sand soil (fine-loamy, siliceous, Aquic Paleudults); and commercial fields near Faison (35.6N, −78.8W) on an Autryville fine sandy loam soil (fine-loamy, siliceous, Typic Paleudults). During each year, two locations were in fields with a recent history of peanut production (Lewiston-Woodville and Rocky Mount), whereas one field during each year had not been planted to peanut in recent memory (Faison). The peanut cultivar Perry (Isleib et al., 2003) was planted in conventionally prepared, raised seedbeds at a seeding rate designed to obtain five plants/liner foot of row. Plot size was two rows (36-inch spacing) by 30 ft long. Peanut at Lewiston-Woodville during both years, Rocky Mount during 2009, and Faison during 2010 was planted between 2 May and 10 May. At Faison during 2009 and Rocky Mount during 2010 peanut was planted 20 May and 27 May, respectively.

Treatment Combinations and Plot Maintenance

A factorial arrangement of treatments consisting of two rates of *Bradyrhizobium* (0 and 16 fluid oz/acre as Optimize Lift, formerly Nitragen Co. and now Monsanto BioAg, St. Louis, MO), two rates of prothioconazole (0 and 0.23 lb a.i./acre as the formulated product Proline, Bayer CropScience, Research Triangle Park, NC), and two rates of acephate (0 and 0.9 lb a.i./acre as the formulated product Orthene 97, Valent Corp., Richmond, CA) was used in the experiment. The experimental design was a randomized complete block with treatments replicated four times. Optimize Lift delivers approximately 0.9×10^{12} viable cells of bacteria/acre when applied at 16 fluid oz/acre. Agrochemicals were applied in a 5 gal/acre water solution immediately after seed drop and before furrow closure. The cultivar Perry was selected to minimize CBR to focus on peanut response to thrips damage and inoculant performance with these combinations.

Plots were maintained weed-free using soil-applied and postemergence herbicides. Chlorpyrifos (Lorsban, Dow AgroScience, Indianapolis, IN) was applied 45 to 50 days after planting to control southern corn rootworm (*Diabrotica undecimpunctata*). Biweekly fungicide sprays were initiated 50 days after planting and included chlorothalonil (Bravo Weather Stik Agricultural Fungicide, Syngenta Crop Protection, Greensboro, NC), two sequential applications of tebuconazole (Folicur 3.6 F Foliar Fungicide, Bayer CropScience, Research Triangle Park, NC) plus chlorothalonil, a single application of pyraclostrobin (Headline Fungicide, Research Triangle Park, NC), and a final application of chlorothalonil to control leaf spot disease (caused by the fungi *Cercospora arachidicola* and *Cercosporidium personatum*) and stem rot disease. Pesticides were applied at the manufacturer's suggested use rate.

Measurements and Data Analysis

Visible injury from thrips feeding was recorded 3 weeks after planting using a scale of 0 to 5 where 0 = no damage, 1 = noticeable feeding but no stunting, 2 = noticeable feeding and 25% stunting, 3 = feeding with blackened terminals and 50% stunting, 4 = severe feeding and 75% stunting, and 5 = severe feeding and 90% stunting (Carley et al., 2009; Drake et al., 2009). No attempt was made to determine seedling disease, plant growth, or vigor independent of thrips damage or peanut stand. Peanut was dug and vines inverted in late September or early October based on pod mesocarp color (Williams and Drexler, 1981). Peanut pods were harvested 4 to 7 days after digging and vine inversion and final yield was adjusted to 8% moisture.

Data for thrips damage and pod yield were subjected to ANOVA using the GLM procedure in SAS (SAS Institute, 2006) considering the 6 (year-location combination) $\times$ 2 (acephate treatment) $\times$ 2 (*Bradyrhizobium* inoculant treatment) $\times$ 2 (prothioconazole treatment) factorial treatment arrangement. Means of significant main effects and interactions were separated using Fisher's Protected LSD test at $p \leq 0.05$.

Table 1. Analysis of variance for thrips damage and pod yield as influenced by the interaction of experiment, acephate, prothioconazole, and *Bradyrhizobium*.

Treatment factor	Thrips injury	Pod yield
	Scale of 0–5	lb/acre
Experiment (Exp)	<0.0001	0.0002
Acephate	<0.0001	0.9282
Prothioconazole	<0.0001	0.0322
Bradyrhizobium	0.5361	0.0515
Acephate × prothioconazole	<0.0001	0.8361
Acephate × *Bradyrhizobium*	0.2783	0.1034
Prothioconazole × *Bradyrhizobium*	0.2124	0.9709
Acephate × prothioconazole × *Bradyrhizobium*	0.3012	0.4874
Exp × acephate	0.0007	0.4020
Exp × prothioconazole	0.0018	0.7580
Exp × *Bradyrhizobium*	0.9160	<0.0001
Exp × acephate × prothioconazole	<0.0001	0.7254
Exp × acephate × *Bradyrhizobium*	0.0592	0.4075
Exp × prothioconazole × *Bradyrhizobium*	0.6247	0.9059
Exp × acephate × prothioconazole × *Bradyrhizobium*	<0.0001	0.8252
Coefficient of variation (%)	79.6	14.6

Reductions in Thrips Damage by In-Furrow Treatments

The interaction of experiment $\times$ acephate $\times$ prothioconazole $\times$ *Bradyrhizobium* inoculant was significant for early season injury from thrips feeding (Table 1). This interaction most probably was caused by differences in thrips damage in the absence of acephate (Table 2). In two experiments in fields where peanut was planted in late May (Faison in 2009 and Rocky Mount in 2010), injury ranged from 0.2 to 1.1 on a scale of 0 to 5 for untreated peanut while injury ranged from 3.2 to 3.9 for untreated peanut on this scale in the other fields that were planted between 2 and 10 May. Thrips damage is often more prevalent when peanut is planted in early May compared with late May (Drake et al., 2009). Less thrips damage was observed in the absence of acephate when either *Bradyrhizobium* inoculant or prothioconazole was applied at Faison in 2010 compared with untreated peanut. Injury from thrips feeding was lower when these products were co-applied compared with untreated peanut at Lewiston-Woodville or Rocky Mount during both years. In previous research (Jordan et al., 2006), less thrips damage was noted when tebuconazole was applied in the absence of acephate. In Jordan et al.'s research, *Bradyrhizobium* inoculant did not contribute to protection or recovery from thrips damage. Few differences in thrips damage were noted among co-applied products when acephate was applied, with injury ranging from 0.1 to 2.1 on a scale of 0 to 5 (Table 2). Although results with acephate were not surprising, the apparent decrease in thrips damage in the presence of prothioconazole alone or with *Bradyrhizobium* inoculant was not expected. While it is possible that prothioconazole directly affected thrips feeding, the more probable possibility is improved

Table 2. Peanut injury from thrips feeding as influenced by the interaction of experiment, acephate, prothioconazole, and *Bradyrhizobium*.†

In-furrow product‡			Lewiston-Woodville		Rocky Mount		Faison	
Acephate	Prothioconazole	*Bradyrhizobium*	2009	2010	2009	2010	2009	2010
			0–5§					
No	No	No	3.2 a	3.3 a	3.9 a	1.1 a	0.2 a	3.4 a
No	No	Yes	3.3 a	3.5 a	3.9 a	0.5 ab	0.1 a	0.5 b
No	Yes	No	0.9 b	0.8 c	1.8 b	0.5 ab	0 a	1.9 b
No	Yes	Yes	0.9 b	1.8 b	0 c	0.1 b	0 a	3.2 a
Yes	No	No	0.8 b	1.6 b	0.5 bc	0.3 b	0 a	0.3 b
Yes	No	Yes	0.1 b	0.7 c	0.3 c	0.5 ab	0 a	2.1 ab
Yes	Yes	No	1.5 b	0.7 c	0.1 c	0.1 b	0.1 a	1.4 b
Yes	Yes	Yes	0.8 b	1.1 b	1.1 bc	0.1 b	0.2 a	1.2 b

†Means within a location and year followed by the same letter are not significantly different at $p < 0.05$ according to Fisher's Protected LSD test.

‡Acephate applied at 0.9 lb/acre. Prothioconazole applied at 0.23 lb/acre. *Bradyrhizobium* inoculant applied as Optimize Lift at 16 fluid oz/acre delivers approximately 0.9×10^{12} viable cells of bacteria/acre.

§Visible injury from thrips feeding was recorded 3 wk after planting using a scale of 0 to 5 in which 0 = no damage, 1 = noticeable feeding but no stunting, 2 = noticeable feeding and 25% stunting, 3 = feeding with blackened terminals and 50% stunting, 4 = severe feeding and 75% stunting, and 5 = severe feeding and 90% stunting.

Table 3. Influence of acephate, *Bradyrhizobium*, and prothiocanzole on peanut yield.†

In-furrow treatment‡	Acephate	*Bradyrhizobium* inoculant						Prothioconazole
		Lewiston-Woodville		Rocky Mount		Faison		
		2009	2010	2009	2010	2009	2010	
	lb/acre							
No	3450 a	3650 a	3520 a	2420 a	4330 a	2940 b	2930 b	3370 b
Yes	3750 a	3750 a	3330 a	2180 a	4170 a	4040 a	3360 a	3520 a

†Means within a main effect (acephate or prothioconazole) or site-year combination for *Bradyrhizobium* inoculant followed by the same letter are not significantly different at $p \leq 0.05$ according to Fisher's Protected LSD test. Data for acephate and prothioconazole are pooled across experiments and levels of other treatment factors. Data for *Bradyrhizobium* are pooled across levels of acephate and prothioconazole.

‡Acephate applied at 0.9 lb/acre. Prothioconazole applied at 0.23 lb/acre. *Bradyrhizobium* inoculant applied as Optimize Lift at 16 fluid oz/acre delivers approximately 0.9×10^{12} viable cells of bacteria/acre.

seedling health that enabled the seedlings to withstand thrips feeding more effectively or to recover from thrips feeding more quickly. The mechanism of decreased injury from thrips was beyond the scope of this research. The occurrence of less injury from thrips feeding at Faison during 2010 when *Bradyrhizobium* inoculant was applied could not be explained.

Peanut Yield Response to In-Furrow Treatments

Peanut yield was not affected by the main effect of acephate or interactions of acephate with other treatment factors (Table 1). The lack of yield response to acephate was surprising (Table 3). In contrast, other research in North Carolina (Carley et al., 2009; Drake et al., 2009; Brandenburg et al., 2015) reported increased yields when thrips damage was minimized by in-furrow insecticides. In contrast, peanut yield was affected by the interaction of experiment × *Bradyrhizobium* inoculant and the main effect of prothioconazole (Table 1). When pooled across acephate and prothioconazole treatments, pod yield increased at Faison during 2009 and 2010 when *Bradyrhizobium* inoculant was applied compared with uninoculated peanut by 1100 and 430 lb/acre, respectively (Table 3). At this location the yield increase following *Bradyrhizobium* inoculant was anticipated because peanut had not been planted in previous years in these fields. Yield increases of this magnitude are common in fields where native *Bradyrhizobium* is not present and inoculant is applied in the seed furrow at planting (Lanier et al., 2005; Carroll et al., 2015). Yield increased from 3370 lb/acre without prothioconazole to 3520 lb/acre when prothioconazole was applied in the seed furrow, irrespective of acephate or *Bradyrhizobium* inoculant treatment (Table 3). There were no apparent differences in aboveground response of peanut due to disease that may have been affected by prothioconazole treatment that would explain the increase in yield. Other research (Brenneman and Young, 2007; Shew et al., 2015) has shown increased peanut yields when prothioconazole was applied in the seed furrow at planting compared with untreated peanut.

Collectively, the results from these experiments indicate that acephate, *Bradyrhizobium* inoculant, and prothioconazole are compatible for reducing thrips damage and *Bradyrhizobium* inoculant effectiveness when co-applied in the seed furrow.

Therefore, growers can apply these products simultaneously with no negative impact on peanut yield compared with these products applied alone.

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References

Brandenburg, R.L. 2015. Peanut insect and mite management. In: 2015 Peanut Information. North Carolina Coop. Ext. Serv. Publ. AG-331. North Carolina State Univ., Raleigh. p. 81–102

Brandenburg, R., D. Jordan, B. Royals, and D. Johnson. 2015. Developing strategies to manage thrips in absence of aldicarb. Poster presented at: Solutions for a changing world. 8th International IPM Symposium, Salt Lake City, Utah. 23–26 March. Poster P034.

Brenneman, T.B., and H. Young. 2007. Management of CBR with partially resistant cultivars and prothioconazole. Proc. Am. Peanut Res. Educ. Soc. 39:13.

Bullen, S.G., and D.L. Jordan. 2015. Peanut production budgets. 2015 Peanut Information. North Carolina Coop. Ext. Serv. Publ. AG-331. North Carolina State Univ., Raleigh. p. 5–11.

Carley, D.S., D.L. Jordan, R.L. Brandenburg, and L.C. Dharmasri. 2009. Factors influencing response of Virginia market type peanut (*Arachis hypogaea*) to paraquat under weed-free conditions. Peanut Sci. 36:180–189. doi:10.3146/PS07-102.1

Carroll, M., T. Britton, C. Fountain, M. Parrish, D.L. Jordan, and P.D. Johnson. 2015. Peanut response to inoculation and ammonium sulfate rate in North Carolina. Proc. Am. Peanut Res. Educ. Soc. 47:55.

Drake, W.L., D.L. Jordan, R.L. Brandenburg, B.R. Lassiter, P.D. Johnson, and B.M. Royals. 2009. Peanut cultivar response to damage from tobacco thrips and paraquat. Agron. J. 101:1388–1393. doi:10.2134/agronj2009.0185

Gao, Y., L. Zhongren, and S.R. Reitzb. 2012. Western flower thrips resistance to insecticides: Detection, mechanisms and management strategies. Pest Manage. Sci. doi:10.1002/ps.3305

Huseth A. S., T. M. Chappell, K. Langdon, S. C. Morsello, S. Martin, J. K. Greene, et al. 2016. *Frankliniella fusca* resistance to neonicotinoid insecticides: An emerging challenge for cotton pest management in the eastern United States. Pest Manage. Sci. 72:1934–1945. doi:10.1002/ps.4232

Isleib, T.G., P.W. Rice, R.W. Mozingo, II, J.E. Bailey, R.W. Mozingo, and H.E. Pattee. 2003. Registration of 'Perry' peanut. Crop Sci. 43:739–740. doi:10.2135/cropsci2003.0739

Jordan, D.L., R.L. Brandenburg, J.E. Bailey, P.D. Johnson, B.M. Royals, and V.L. Curtis. 2006. Compatibility of in-furrow application of acephate, inoculant, and tebuconazole in peanut (*Arachis hypogaea* L.). Peanut Sci. 33:112–117. doi:10.3146/0095-3679(2006)33[112:COIAOA]2.0.CO;2

Jordan, D.L., P.D. Johnson, R.L. Brandenburg, and J. Faircloth. 2010. Peanut (*Arachis hypogaea* L.) response to *Bradyrhizobia* applied in-furrow with agrichemicals. Peanut Sci. 37:32–38. doi:10.3146/PS09-005.1

Lanier, J.E., D.L. Jordan, J.F. Spears, R. Wells, and P.D. Johnson. 2005. Peanut response to inoculation and nitrogen fertilizer. Agron. J. 97:79–84.

Morgan, J., M. Carroll, P. Smith, R. Rhodes, A. Cochran, A. Bradley, et al. 2014. Survey of key production and pest management practices in peanut in North Carolina and Virginia during 2013. Proc. Am. Peanut Res. Educ. Soc. 46:22–23.

Musson, G., J.R. Bloomberg, R.A. Myers, and R. Rudolph. 2006. Provost 433 SC for control of foliar and soil-borne diseases in peanuts. Proc. Am. Peanut Res. Educ. Soc. 38:53.

Rhodes, R., P. Smith, W. Burgess, C. Ellison, A. Whitehead, A. Cochran, et al.. 2015. Summary of production and pest management practices by top growers in North Carolina from 2010–2013. Proc. Am. Peanut Res. Educ. Soc. 47:58.

SAS Institute. 2006. GLM Procedure. Cary, NC 27513-2414.

Shew, B.B., T.G. Isleib, and D.L. Jordan. 2015. Integrated management of leaf spot and stem rot with partial resistance and applications of foliar and in-furrow fungicides. Proc. Am. Peanut Res. Educ. Soc. 47:64.

Thagard, T., D.L. Jordan, R.L. Brandenburg, B.B. Shew, D. Sande, and D. Seth Carley. 2013. Survey of growers in North Carolina with respect to integrated pest management strategies in peanut. Proc. Am. Peanut Res. Educ. Soc. 45:36.

Tubbs, R.S., R.C. Kemerait, B. Williams, and J.M. Sarver. 2015. Effect of *Bradyrhizobia* inoculant formulation with phorate in new peanut fields. Peanut Sci. 42:138–144. doi:10.3146/0095-3679-42.2.138

Tyson, W.G., and R.C. Kemerait. 2013. Impact of in-furrow and topical prothioconazole treatments on severity of *Cylindrocladium* black rot and white old disease in peanut. Proc. Am. Peanut Res. Educ. Soc. 45:37.

Williams, E.J., and J.S. Drexler. 1981. A non-destructive method for determining peanut pod maturity, pericarp, mesocarp, color, morphology, and classification. Peanut Sci. 8:134–141. doi:10.3146/i0095-3679-8-2-15