Influence of Crop Rotation on Peanut (*Arachis hypogaea* L.) Response to *Bradyrhizobium* in North Carolina

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ABSTRACT

Peanut (*Arachis hypogaea* L.) response to inoculation with *Bradyrhizobium* can vary depending on edaphic and environmental conditions and cropping history. Determining if response is associated with the number years between peanut plantings may increase understanding of when to expect a positive response to inoculation of peanut. Four experiments were conducted in North Carolina to determine peanut response to in-furrow inoculation with *Bradyrhizobium* when a range of years and typical crops grown in North Carolina often separating peanut plantings. Rotations varied from continuous peanut in some experiments to as many as five years of a non-peanut crop separating peanut plantings. The interaction of crop rotation by inoculation treatment (no inoculation versus in-furrow application of *Bradyrhizobium*) was not significant for visually estimated peanut canopy color or pod yield in any of the experiments. However, the main effect of rotation was significant in three of four experiments while the main effect of inoculation was significant in two of four experiments. Increasing the number of years a non-peanut crop was planted between peanut plantings increased yield in three of four experiments. Results from these experiments suggest that using the number of non-peanut crops included between peanut plantings is not a good indicator of determining when peanut will respond positively to inoculation with *Bradyrhizobium*.

Key Words: Biological nitrogen fixation, crop rotation, *Bradyrhizobium*.

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Introduction

Peanut (*Arachis hypogaea* L.), a leguminous crop, is capable of biological nitrogen fixation (BNF) by *Bradyrhizobium* (Schiffman and Alper, 1968; Shimshi *et al.*, 1967; Walker *et al.*, 1976). Inoculants can be applied with the seed or as granular or liquid products in the seed furrow at planting to ensure adequate amounts of *Bradyrhizobium* are present for root infection (Baughmann *et al.*, 2007; Chapin *et al.*, 2007; Godsey *et al.*, 2007; Jordan, 2008a). Research indicates that in-furrow applications are often more effective than application to the seed when peanut is planted in fields that have never been seeded to peanut (Baughmann *et al.*, 2007; Lanier *et al.*, 2005). Cost of *Bradyrhizobium* inoculant is relatively low compared with other variable costs (Bullen and Jordan, 2008). Approximately 77% of growers in North Carolina apply inoculant to peanut (Rhodes *et al.*, 2008).

Crop rotation is a critical component of pest management in peanut (Lamb *et al.*, 1993; Rodriguez-Kabana *et al.*, 1987; Rodriguez-Kabana and Touchton, 1984). Increasing the number of non-peanut crops between plantings of peanut often decreases incidence of disease and nematodes and can result in higher peanut yield (Bailey and Matyac, 1988; Pataky *et al.*, 1983; Rodriquez-Kabana *et al.*, 1987; Rodriguez-Kabana, 1984). Peanut also offer advantages for non-N fixing crops such as corn (*Zea mays* L.) and cotton (*Gossypium hirsutum* L.) by fixing N_2 into approximately 124 kg/ha soil N when planted the year prior to these crops (Elkan, 1995).

Practitioners often pose the question of whether fumigation for Cylindrocladium black rot (caused by *Cylindrocladium parasiticum*) is needed if a certain number of non-peanut crops separate peanut plantings or if soybean [*Glycine max* (l.) Merr.], a host for Cylindrocladium black rot, is included in the rotation. Similarly, determining if the number of non-peanut crops between peanut plantings that result in a positive response to inoculation can be established would benefit practitioners. Although benefits of BNF to other non-legume crops in rotation with peanut are relatively well defined, interactions of crop rotation and inoculation are not well defined for peanut with respect to the role of rotation and rotation length on survival of *Bradyrhizobium*. Cooperative

Table 1. Crop rotations including corn (CR), cotton (CT), peanut (PN), soybean (SB), and tobacco (TB) in experiments conducted in North Carolina at Lewiston-Woodville, Rocky Mount, and Whiteville.[a]

Lewiston-Woodville			
Experiment 1 (2001–2006)	Experiment 2 (1999–2006)	Rocky Mount (2001–2006)	Whiteville (2001–2006)
CR-PN (three cycles)	CT-PN (four cycles)	CT-CT-CT-CT-CT-PN	CR-CR-CR-CR-CR-PN
CT-PN (three cycles)	CR-PN (four cycles)	CT-CT-SB-CT-CT-PN	CR-CR-PN (two cycles)
CT-CR-PN (two cycles)	CT-CT-CT-PN (two cycles)	CT-CT-PN (two cycles)	TB-CR-PN (two cycles)
CT-CT-PN (two cycles)	CT-CT-CR-PN (two cycles)	CT-PN (three cycles)	CR-TB-PN (two cycles)
SB-CR-PN (two cycles)	-	Continuous peanut	CR-CR-TB-CR-CR-PN
SB-CT-PN (two cycles)	-	-	-
CR-CR-PN (two cycles)	-	-	-
CR-CR-CR-CR-CR-PN	-	-	-
Continuous peanut	-	-	-

[a]Peanut was planted in all plots the year prior to establishing these experiments.

Extension Services in several states in the United States recommend inoculation of peanut regardless of rotation (Baughmann *et al.*, 2007; Chapin *et al.*, 2007; Godsey *et al.*, 2007; Jordan, 2008a). A definite length of rotation when peanut will respond to inoculation has not been established for Virginia market type peanut. However, there is some debate among peanut growers and their advisors as to whether this approach is viable given the diversity factors that can influence nodulation of peanut by *Bradyrhizobium*. Therefore, research was conducted in North Carolina to determine the effect of crop rotation on peanut response to *Bradyrhizobium*.

Material and Methods

Experiments were conducted in North Carolina from 1999 through 2006 at the Border Belt Research Station near Whiteville, the Peanut Belt Research Station located near Lewiston-Woodville, and the Upper Coastal Plain Research Station near Rocky Mount on Norfolk sandy loam soil (fine-loamy, siliceous, thermic Aquic Paleudalts). Soil pH ranged from 5.7 to 6.1 and soil organic matter content ranged from 1.7 to 2.2%. The cultivars NC-V 11 (Wynne *et al.*, 1991) (Lewiston-Woodville and Rocky Mount) and Perry (Isleib *et al.*, 2003) (Whiteville) were planted in conventionally prepared seedbeds in early May to achieve a final in-row plant population of 13 plants/m. Plot size was 12 rows (Lewiston-Woodville and Whiteville) or 8 rows (Rocky Mount) by 15 m. Row spacing at all locations was 91 cm.

Cropping systems for the duration of the experiment varied considerably depending upon location (Table 1). At Lewiston-Woodville in one experiment, crop rotations from 2001–2006 included continuous peanut, peanut separated by five years of corn, three cycles of corn-peanut or cotton-peanut, and two cycles of corn-corn-peanut, cotton-cotton-peanut, cotton-corn-peanut, soybean-corn-peanut, or soybean-cotton-peanut. Peanut was planted in the entire test area during 2000. In a second experiment from 1999–2006 at this location, rotations included two cycles of cotton-cotton-cotton-peanut or cotton-cotton-corn-peanut and four cycles of corn-peanut or cotton-peanut. Peanut was planted in the entire test area during 1998. At Rocky Mount, rotations from 2001–2006 included five years of cotton followed by peanut, three cycles of cotton-peanut, two cycles of cotton-cotton-peanut, cotton-cotton-soybean-cotton-cotton-peanut, and continuous peanut. Rotations from 2001–2006 at Whiteville included five years of corn followed by peanut; two cycles of corn-corn-peanut, tobacco (*Nicotiana tobacum* L.)-corn-peanut, or corn-tobacco-peanut; and the rotation of corn-corn-tobacco-corn-corn-peanut.

In 2006 at all locations, peanut was not inoculated or was inoculated with *Bradyrhizobium* (Optimize Lift®, EMD Crop Bioscience, Brookfield, WI) in the seed furrow at planting. Optimize Lift® delivers 2.2×10^{12} viable cells of bacteria/ha when applied at 1.2 L/ha in 47 L/ha aqueous solution immediately after seed drop but prior to furrow closure. Spray solution directly contacted seed. Peanut was not inoculated during any year of the experiment except in 2006. Peanut was planted in all fields the year prior to initiating the experiments. No attempt was made to quantify N concentration in soil.

Aldicarb [2-methyl-2-(methylthio)propionaldehyde *O*-methylcarbamoloxime] at 1.1 kg ai/ha was applied in the seed furrow. All other production and pest management practices were held constant over the entire test area and were based on Cooperative Extension Service recommendations

Table 2. Analyses of variance for peanut canopy color and peanut pod yield during 2006 as influenced by rotation and inoculation with *Bradyrhizobium*.[a]

	Lewiston-Woodville							
	Experiment 1		Experiment 2		Rocky Mount		Whiteville	
Treatment factor	Canopy color	Yield	Canopy color	Yield	Canopy color	Yield	Canopy color	Yield
	F statistic							
Rotation	0.6	12.0**	0.3	5.9*	1.4	3.0*	0.1	1.2
Inoculation	4.8*	3.0	1.2	8.4*	1.2	0.4	0.1	4.4*
Rotation*Inoculation	1.0	0.8	1.0	3.5	0.8	1.1	0.1	1.1

[a]* significance at $p = 0.01$ to 0.05. ** significance at $p \leq 0.01$.

appropriate for the region (Brandenburg, 2007; Jordan, 2008a 2008b; Shew, 2007).

During the second week of August in 2006, color of the entire peanut canopy was estimated visually on a scale of 0 to 5 where 0 = the entire peanut canopy expressing a pale yellow color and 5 = the entire peanut canopy expressing a dark green color. Determining canopy color at this stage of peanut development minimized possible confounding of canopy color due to development of Cylindrocladium black rot and other diseases resulting from crop rotation. While determining N concentration in peanut leaves or recording chlorophyll content would have been more informative than assessing the canopy visually, practitioners most likely will use a visual assessment for this comparison. Peanut was dug and vines inverted in late September or early October based on pod mesocarp color determination (Williams and Drexler, 1981). Digging was initiated when approximately 65% of pods were in the brown and black color pod mesocarp color category (Jordan *et al.*, 2005). Pods were harvested 4 to 7 d after digging and vine inversion.

The experimental design in all experiments was a split plot with sub-plots replicated four times. Cropping system served as the whole plot unit and inoculation treatment served as the split plot unit. Data for canopy color and pod yield were subjected to analysis of variance appropriate for the treatment structure (SAS, 2006). Means of significant main effects and interactions were separated using Fisher's Protected LSD test at $p \leq 0.05$.

Results and Discussion

The interaction of rotation by inoculation was not significant for peanut canopy color or peanut pod yield in any of the experiments or locations (Table 2). Crop rotation did not affect peanut canopy color but did affect pod yield in three of the four experiments (Table 2). Inoculation affected canopy color in one experiment at Lewiston-Woodville and affected pod yield in two of four experiments (Table 2). Data for peanut canopy color and pod yield are presented for all experiments regardless of significance of the main affect at a location or within an experiment at a particular location.

Crop rotation. Increasing the number of years between peanut plantings did not affect canopy color but did affect pod yield at Lewiston-Woodville in both experiments (Tables 3 and 4). The lowest pod yield in the first experiment was noted for continuous peanut while the highest pod yields were noted for two cycles of corn-corn-peanut, cotton-cotton-peanut, or cotton-corn-peanut and the rotation with five years of corn and one year of peanut (Table 3). Rotation with only one year of corn or cotton between peanut or including

Table 3. Peanut canopy color and pod yield during 2006 as influenced by crop rotation at Lewiston-Woodville, Experiment 1. Peanut was planted in all plots during 2000.

Rotation (2001–2006)	Canopy color[b]	Pod yield
	Scale-5	kg/ha
Corn-Peanut (three cycles)	4.8 a	4880 b
Cotton-Peanut (three cycles)	4.7 a	4410 c
Cotton-Corn-Peanut (two cycles)	4.6 a	5060 ab
Cotton-Cotton-Peanut (two cycles)	4.5 a	5460 a
Soybean-Corn-Peanut (two cycles)	4.6 a	4910 b
Soybean-Cotton-Peanut (two cycles)	4.7 a	4650 bc
Corn-Corn-Peanuts (two cycles)	4.7 a	5440 a
Corn-Corn-Corn-Corn-Corn-Peanut	4.7 a	5370 a
Continuous peanut	4.5 a	3310 d

[a]Means within a treatment factor for canopy color and pod yield followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$. Data are pooled over inoculation treatments.

[b]Peanut canopy color was visually rated on a scale of 0 to 5 where 0 = the entire peanut canopy expressing a yellow color and 5 = the entire peanut canopy expressing a dark green color.

Table 4. Peanut canopy color and pod yield during 2006 as influenced by crop rotation at Lewiston-Woodville, Experiment 2.

Rotation (1999–2006)	Peanut canopy[b]	Pod yield
	Scale-5	kg/ha
Cotton-Peanut (four cycles)	4.6 a	3760 b
Corn-Peanut-(four cycles)	4.6 a	3890 b
Cotton-Cotton-Cotton-Peanut (two cycles)	4.7 a	5690 a
Cotton-Cotton-Corn-Peanut (two cycles)	4.6 a	5180 a

[a]Means within a treatment factor for canopy color and pod yield followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$. Data are pooled over inoculation treatments.

[b]Peanut canopy color was visually rated on a scale of 0 to 5 where 0 = the entire peanut canopy expressing a yellow color and 5 = the entire peanut canopy expressing a dark green color.

soybean in the rotation (two cycles of soybean-corn-peanut or soybean-cotton-peanut) yielded more than continuous peanut but lower than peanut in several of the highest yielding rotations (Table 3). In the second experiment at Lewiston-Woodville, peanut canopy color was not affected by rotation but yield was higher with two cycles of cotton-cotton-cotton-peanut or cotton-cotton-corn-peanut compared with three cycles of corn-peanut or cotton-peanut (Table 4).

At Rocky Mount, pod yield but not canopy color was affected by rotation (Table 5). The highest yield was noted when five years of cotton separated peanut plantings (Table 5). Yield was similar for rotations including two cycles of cotton-cotton-peanut, cotton-cotton-soybean-cotton-cotton-peanut, and three cycles of cotton-peanut, and yield of peanut from these rotations was lower than yield of peanut following five years of cotton. Yield following a 3-yr cycle of cotton-peanut and continuous peanut was similar. In contrast, canopy color and pod yield at Whiteville was not affected by rotation (Table 6). However, at this location alternating peanut with other crops and continuous peanut was not included. Cylindrocladium black rot was present at all locations, and lack of a response to rotation at Whiteville may have been associated with planting the Cylindrocladium black rot resistant cultivar Perry (Shew, 2007) as well as rotations at this location being at least three years in all cases. Increasing the length of rotation increased yield compared with shorter rotations when the Cylindrocladium black rot susceptible cultivar NC-V 11 was planted at the other locations (Shew, 2007).

Table 5. Peanut canopy color and pod yield as influenced by crop rotation at Rocky Mount.

Rotation (2001–2006)	Canopy color[b]	Pod yield
	Scale-5	kg/ha
Cotton-Cotton-Cotton-Cotton-Cotton-Peanut	4.7 a	3770 a
Cotton-Cotton-Soybean-Cotton-Cotton-Peanut	4.7 a	3090 b
Cotton-Cotton-Peanut (two cycles)	4.6 a	3050 b
Cotton-Peanut (three cycles)	4.5 a	2880 bc
Continuous peanut	4.5 a	2420 c

[a]Means within a treatment factor for canopy color and pod yield followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$. Data are pooled over inoculation treatments.

[b]Peanut canopy color was visually rated on a scale of 0 to 5 where 0 = the entire peanut canopy expressing a yellow color and 5 = the entire peanut canopy expressing a dark green color.

Peanut response to crop rotation observed in these experiments is similar to previous findings demonstrating that increasing the number of non-peanut crops in the rotation generally increases peanut yield (Bailey and Matyac, 1988; Lamb *et al.*, 1993; Pataky *et al.*, 1983). These data also demonstrate that planting at least two years of corn or cotton or a sequence of these crops often optimizes yield. Results from these experiments also support previous findings demonstrating that corn and cotton are more effective than soybean in maintaining peanut yield (Jordan *et al.*, 2002). Variation in canopy color when comparing experiments could have been a result of the time of evaluation relative to planting, infection by *Bradyrhizobium*, and soil N

Table 6. Peanut canopy color and pod yield as influenced by crop rotation at Whiteville.

Rotation (2000–2006)	Peanut canopy[b]	Pod yield
	Scale-5	kg/ha
Corn-Corn-Corn-Corn-Corn-Peanut	4.0 a	3770 a
Corn-Corn-Peanut (two cycles)	4.0 a	3450 a
Tobacco-Corn-Peanut (two cycles)	4.0 a	3420 a
Corn-Tobacco-Peanut (two cycles)	4.2 a	3270 a
Corn-Corn-Tobacco-Corn-Corn-Peanut	4.0 a	4280 a

[a]Means within a treatment factor for canopy color and pod yield followed by the same letter are not significantly different according to Fisher's Protected LSD test at $p \leq 0.05$. Data are pooled over inoculation treatments.

[b]Peanut canopy color was visually rated on a scale of 0 to 5 where 0 = the entire peanut canopy expressing a yellow color and 5 = the entire peanut canopy expressing a dark green color.

Table 7. Influence of inoculation with *Bradyrhizobium* on canopy color and peanut yield in 2006.[a]

	Lewiston-Woodville							
	Experiment 1		Experiment 2		Rocky Mount		Whiteville	
Inoculation	Canopy Color[b]	Yield	Canopy color[b]	Yield	Canopy color[b]	Yield	Canopy color[b]	Yield
	Scale-5	kg/ha	Scale-5	kg/ha	Scale-5	kg/ha	Scale-5	kg/ha
No	3.8	4750	4.6	4370	4.5	2880	4.0	3550
Yes[b]	4.4*	4920	4.7	4900*	4.6	2970	4.0	3730*

[a]* significance at p = 0.01 to 0.05. Data are pooled over rotations.

[b]Peanut canopy color was visually rated on a scale of 0 to 5 where 0 = the entire peanut canopy expressing a yellow color and 5 = the entire peanut canopy expressing a dark green color.

[c]Inoculation with *Bradyrhizobium* as Optimize Lift® at 1.2 L/ha delivers 2.2×10^{12} viable cells of bacteria/ha applied in 47 L/ha aqueous solution immediately after seed drop but prior to furrow closure.

remaining from the previous crop. Recording canopy color multiple times during the growing season would have been more informative.

Inoculation with Bradyrhizobium. Inoculation affected peanut canopy color in one experiment at Lewiston-Woodville but not in the second experiment at this location or in experiments at Rocky Mount or Whiteville (Table 7). Pod yield was not affected by inoculation in Experiment 1 at Lewiston-Woodville but did increase by 530 kg/ha in the second experiment (Table 7). Inoculation did not affect pod yield at Rocky Mount (Table 7). However, inoculation with *Bradyrhizobium* increased yield at Whiteville by 180 kg/ha (Table 7).

Differences in peanut response to rotation and inoculation varied in these experiments, but the interaction of rotation by inoculation was not significant in any of the experiments. The objective of this research was to determine the relationship between the number of non-peanut crops between peanut plantings and peanut response to in-furrow application of *Bradyrhizobium*. In these experiments, rotations consisted of as many as five years of corn or cotton between peanut plantings as well as continuous peanut. Results from these experiments indicate that using the number of crops between peanut plantings or visually comparing canopy color does not define whether or not a positive yield response to in-furrow inoculation with *Bradyrhizobium* will occur. Peoples *et al.* (1992) also reported no interaction between crop rotations and inoculant treatment.

Limitations in extrapolating results from this experiment to other regions of the US peanut belt and to other years and differing environments exist. For example, response to inoculation can vary due to environmental conditions and possibly other factors specific to the year when inoculation treatments were compared. It is possible that conditions during 2006 may have had a major impact on peanut response to inoculation, possibly as much as previous cropping system. Additional research is needed to evaluate possible interactions of crop rotation and inoculation on a wider range of environmental and edaphic conditions in additional geographical regions of peanut production. However, expense of inoculation is $12/ha or less depending upon product selection, and this constitutes approximately 1% or less of production cost of $1971/ha to produce Virginia market type peanut (Bullen and Jordan, 2008). Therefore, inoculation of peanut regardless of length of rotation between peanut plantings will often pay dividends and will not be costly in years that yield increases do not occur.

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