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Field and Forage Crops

Value of Neonicotinoid Insecticide Seed Treatments in Mid-South Soybean (*Glycine max*) Production Systems

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Abstract

Early-season insect management is complex in the Mid-South region of the United States. A complex of multiple pest species generally occurs simultaneously at subthreshold levels in most fields. Neonicotinoids are the only insecticide seed treatment widely used in soybean, *Glycine max* L., production. An analysis was performed on 170 trials conducted in Arkansas, Louisiana, Mississippi, and Tennessee from 2005 to 2014 to determine the impact of neonicotinoid seed treatments in soybean. The analysis compared soybean seed treated with a neonicotinoid insecticide and a fungicide with soybean seed only treated with the same fungicide. When analyzed by state, soybean yields were significantly greater in all states when neonicotinoid seed treatments were used compared with fungicide-only treatments. Soybean treated with neonicotinoid treatments yielded 112.0 kg ha^{-1}, 203.0 kg ha^{-1}, 165.0 kg ha^{-1}, and 70.0 kg ha^{-1}, higher than fungicide-only treatments for Arkansas, Louisiana, Mississippi, and Tennessee, respectively. Across all states, neonicotinoid seed treatments yielded 132.0 kg ha^{-1} more than with fungicide-only treated seed. Net returns from neonicotinoid seed treatment usage were US$1,203 per ha^{-1} compared with US$1,172 per ha^{-1} for fungicide-only treated seed across the Mid-South. However, economic returns for neonicotinoid seed treatments were significantly greater than fungicide-only treated seed in 4 out of the 10 yr. When analyzed by state economic returns the neonicotinoid seed treatments were significantly greater than fungicide-only treated seed in Louisiana and Mississippi. These data show that in some areas and years, neonicotinoid seed treatments provide significant economic benefits in Mid-South soybean.

Key words: neonicotinoid, seed treatment, soybean

Soybean production in the Mid-southern United States has changed considerably in recent years. The Mid-southern region includes Arkansas, Louisiana, Mississippi, western Tennessee, and extreme southeast Missouri. Higher yielding varieties and favorable market prices have led to increased soybean hectares United States Department of Agriculture–National Agricultural Statistics Service (USDA–NASS 2015). Many growers have adopted the early soybean production system where early maturing, indeterminate soybean varieties are planted from March through early May (Heatherly 1999). Historically, soybean producers planted soybean later, often experiencing drought conditions and high temperatures during the pod and seed development stages, reducing yield potential. The early production system was developed to avoid drought conditions and extensive heat, thereby increasing yield potential throughout the Mid-South (Kane and Grabau 1992, Bowers 1995, Sweeney et al. 1995, Heatherly 1999). In soybean, the price of seed in addition to the price of other inputs has increased in recent years. Technology fees associated with herbicide tolerance (Rawlinson and Martin 1998) and increased weed management costs to combat herbicide resistant weeds (Bradley et al. 2000, Johnson et al. 2000) have led to a greater investment at the time of planting. Therefore, many producers have adopted insecticide seed treatments to help manage early-season insect pests and decrease the risk of stand loss and replanting. These assumptions were made by producers without sufficient evidence, and a comprehensive analysis of the benefits of insecticide seed treatments needs to be conducted in the Mid-South.

These changes in soybean production practices and the subsequent increased yield potential have led to increased management for insect, disease, and weed pests. Early-season insect pests observed in Mid-South soybean production include bean leaf beetle, *Cerotoma trifurcata* (Forster); white grubs, *Phyllophaga* spp. and *Cyclocephala* spp.; wireworms, *Melanotus* spp., *Limonius* spp., and *Agiotes mancus* (Say); lesser cornstalk borer, *Elasmopalpus lignosellus* (Zeller); threecornered alfalfa hopper, *Spissistilus festinus* (Say); grape colaspis, *Colaspis brunnea* (F.); pea leaf weevil, *Sitona lineatus* (L.); and multiple species of thrips (Davis et al. 2009, 2010). Thrips species that feed on soybean include *Frankliniella fusca* (Hinds), *Frankliniella occidentalis* (Pergande), *Frankliniella tritici* (Fitch), and *Neohydatothrips (Serico-thrips) variabilis* (Beach) (Irwin et al. 1979; Chamberlin et al. 1992; Davis et al. 2009, 2010). Soybean insect infestations throughout the seedling stage tend to be greater and more detrimental to yield potential in the early-season production system (Baur et al. 2000). These early-season soybean pests can have a significant effect on plant population densities and health which can affect yield. Additionally, a complex of multiple species at subthreshold levels commonly infests soybean seedlings in the Mid-South, making scouting and treatment decisions difficult. Neonicotinoid insecticide seed treatments provide control of early-season pests that infest soybean (Baur et al. 2000) and are widely used throughout the Mid-South in all row crops. Neonicotinoids are active against both aboveground and belowground insects because of their systemic ability to be absorbed into plant tissue (Maienfisch et al. 2001). Longevity in the soil plays a major role in the efficacy of these insecticides on early-season soybean pests. While many experiments have been previously conducted on neonicotinoid seed treatments in soybean, there is a shortage of published data on the value of neonicotinoid insecticide seed treatments in soybean production systems in the Mid-South. Therefore, an analysis of previous unpublished research with neonicotinoid insecticide seed treatments across the Mid-South region was conducted to determine the value of neonicotinoid insecticide seed treatments in soybean production systems.

Materials and Methods

Numerous efficacy trials were conducted at the University of Arkansas, Louisiana State University, Mississippi State University, and the University of Tennessee from 2005 to 2014 to estimate the impact of neonicotinoid insecticide seed treatments on insect pest populations and soybean yield.

These experiments included a neonicotinoid seed treatment with a base fungicide. The neonicotinoids were imidacloprid (Gaucho 600, Bayer CropScience, Research Triangle Park, NC) or thiamethoxam (Cruiser 5FS, Syngenta Crop Protection, Greensboro, NC). Gaucho 600 is applied at 0.0747 to 0.2336 mg ai per seed (Anonymous 2015a). Cruiser 5FS is typically applied at 0.0756 to 0.1512 mg ai per seed (Anonymous 2015b). In all tests, a base fungicide treatment without an insecticide was included. The base fungicide was the same for both the insecticide seed treatments and the fungicide-only treatment within a test. All available unpublished data from University research and extension specialists within each state that met the above criteria were included in the analysis. Tests were implemented as a randomized complete block design with replications that varied across states from four to nine repeated blocks with one test consisting of only one replication. Plot sizes ranged from 4 to 16 rows by 12.2 to 30.5 m long and planted on 76.2- to 101.6-cm centers. Various measurements were taken to evaluate insect control. These included but were not limited to actual insect counts, damage ratings, stand counts, plant height, plant vigor, and etc. Evaluations of insect control were not standardized across experiments and varied based on soybean growth stage, location, and year. Timings and methods of evaluation were not consistently recorded across tests and are not included in this analysis. Overall, the most common insect group evaluated included thrips, but other insects observed included various soil insects, threecornered alfalfa hopper, bean leaf beetle, grape colaspis, and pea leaf weevil. In most experiments, insect populations consisted of a complex of multiple species occurring simultaneously or in sequence throughout seedling growth.

Tests were harvested at physiological maturity, and this was the only dependent variable that was recorded in a consistent manner. Experiments were conducted at multiple locations within each state across the Mid-South. Twenty-four tests were conducted at three locations in Arkansas. They included the Lon Mann Cotton Research Station (Marianna, AR), the University of Arkansas at Pine Bluff (Pine Bluff, AR), and Phillips County, Arkansas (Helena, AR). Twenty-four tests were conducted in Louisiana at the LSU AgCenter Macon Ridge Research Station (Winnsboro, LA). Seventy-three tests were conducted in Mississippi at multiple locations including the R.R. Foil Plant Science Research Center (Starkville, MS), the Delta Research and Extension Center (Stoneville, MS), the Brown Loam Experiment Station (Raymond, MS), North Mississippi Research and Extension Center (Verona, MS), as well as several producer fields throughout the state. Forty-nine tests were conducted in Tennessee at the West Tennessee Research and Education Center (Jackson, TN) and at the Milan Research and Education Center (Milan, TN).

Yield and economic data were analyzed with a mixed-model analysis of variance (ANOVA; PROC MIXED SAS ver. 9.3, SAS Institute, Cary, NC). Year, location, and replication nested within year and location were considered random effects, and treatments were considered fixed effects. Residual plots and normal distribution plots were generated to verify that data met ANOVA assumptions. Means were separated using Fisher's protected LSD procedure at the 0.05 level of significance. Economic data were determined using yield for each treatment and the price of soybean seed (harvested grain) in that particular year and state based on data from the National Agricultural Statistics Service (Table 1; NASS 2015). Insecticide seed treatment prices were obtained through personal correspondence from Bayer CropScience. The costs of the insecticide seed treatments were accounted for during economic analyses. To calculate gross economic returns, the yield of each treatment was multiplied by the average price received (Table 1) for the state and year of that trial. The cost of the seed treatment was then subtracted from the gross economic return to give the net economic return for each treatment.

Results and Discussion

In total, 170 experiments were conducted over the 10-yr period in Arkansas, Louisiana, Mississippi, and Tennessee. There was a significant difference in mean soybean yield among treatments where there was a neonicotinoid seed treatment applied ($F = 25.71$; df = 2, 169; $P < 0.01$). Thiamethoxam and imidacloprid resulted in significantly greater yields compared with fungicide seed treatment alone. There were no differences in yield between the thiamethoxam and imidacloprid treatments. Yields of soybean treated with thiamethoxam or imidacloprid averaged $3{,}172 \pm 1.1$ kg ha^{-1} and $3{,}158 \pm 1.1$ kg ha^{-1}, respectively. Because no differences were observed between thiamethoxam and imidacloprid, a separate

Table 1. Values used to calculate net economic returns in each state for each year (USDA–NASS 2015)

Arkansas	Year	US$/Kg	Kg/ha^{-1}	Insecticide seed treatment price/ha^{-1}
	2005	US$0.22	2,285	US$17.29
	2006	US$0.24	2,352	US$17.29
	2007	US$0.33	2,419	US$17.29
	2008	US$0.35	2,554	US$17.29
	2009	US$0.35	2,520	US$19.76
	2010	US$0.40	2,352	US$16.67
	2011	US$0.45	2,587	US$16.67
	2012	US$0.52	2,923	US$16.67
	2013	US$0.48	2,923	US$16.67
	2014	US$0.48	3,360	US$16.67
Louisiana				
	2005	US$0.22	2,285	US$17.29
	2006	US$0.22	2,419	US$17.29
	2007	US$0.31	2,890	US$17.29
	2008	US$0.35	2,218	US$17.29
	2009	US$0.35	2,621	US$19.76
	2010	US$0.39	2,755	US$16.67
	2011	US$0.44	2,419	US$16.67
	2012	US$0.53	3,125	US$16.67
	2013	US$0.49	3,259	US$16.67
	2014	US$0.49	3,830	US$16.20
Mississippi				
	2005	US$0.22	2,453	US$16.80
	2006	US$0.23	1,747	US$16.80
	2007	US$0.31	2,722	US$16.80
	2008	US$0.34	2,688	US$16.80
	2009	US$0.34	2,554	US$19.20
	2010	US$0.38	2,587	US$16.20
	2011	US$0.44	2,621	US$16.20
	2012	US$0.53	3,024	US$16.20
	2013	US$0.48	3,091	US$16.20
	2014	US$0.48	3,494	US$16.20
Tennessee				
	2005	US$0.21	2,554	US$16.80
	2006	US$0.23	2,621	US$16.80
	2007	US$0.38	1,277	US$16.80
	2008	US$0.35	2,285	US$16.80
	2009	US$0.36	3,024	US$19.20
	2010	US$0.41	2,083	US$16.20
	2011	US$0.45	2,150	US$16.20
	2012	US$0.54	2,554	US$16.20
	2013	US$0.48	3,125	US$16.20
	2014	US$0.49	3,091	US$16.20

analysis was done where data for thiamethoxam and imidacloprid seed treatments were pooled and comparisons were made between soybean with a neonicotinoid seed treatment and soybean without an insecticide seed treatment. Averaged across all trials, soybean yield following a neonicotinoid seed treatment was significantly ($F = 51.07$; df = 1, 1269; $P < 0.01$) greater than yields of soybean where a neonicotinoid seed treatment was not used (Table 2). The average difference in yield was 135 kg ha^{-1} across all trials. There also was a significant difference in mean returns in dollars per hectare between treatments ($F = 17.86$; df = 1, 1269; $P < 0.01$; Table 2). Across years and locations, returns for soybean that received a neonicotinoid seed treatment were greater than where no insecticide seed treatment was used. The neonicotinoid seed treatment resulted in a US$33 per hectare return over soybean where no insecticide seed treatment was used.

Table 2. Mean yields (SEM) and net economic returns (SEM) of soybean treated with a neonicotinoid seed treatment (Neonicotinoid IST) compared with those not treated with insecticide (Untreated) across the Mid-South Region from 2005–2014

Treatment	Kg ha^{-1}	US$/ha^{-1}
Untreated[a]	3,032 b (75.0) b	1,172 b (39.5) b
Neonicotinoid IST[b]	3,167 a (75.6) a	1,205 a (39.3) a
P value $P > F$	$P < 0.01$	$P < 0.01$

Means within a column and treatment followed by the same letter are not significantly different, $P < 0.05$.

[a]Treated with a fungicide seed treatment but not an insecticide.

[b]Treated with the same fungicide as the untreated, but also included either thiamethoxam or imidacloprid.

When analyzed by state for the years 2005 to 2014, there were significant differences in mean soybean yield among treatments for each state (Arkansas: $F = 5.42$; df = 1, 155; $P = 0.02$; Louisiana: $F = 17.66$; df = 1, 179; $P < 0.01$; Mississippi: $F = 26.67$; df = 1, 554; $P < 0.01$; and Tennessee: $F = 5.18$; df = 1, 376; $P = 0.02$). Plots planted with a neonicotinoid seed treatment produced significantly greater yields than plots planted with no insecticide seed treatment (Table 3). Soybean seed treated with a neonicotinoid seed treatment resulted in 112.0, 203.0, 165.0, and 70.0 kg ha^{-1} more yield than fungicide-only seed treatment in Arkansas, Louisiana, Mississippi, and Tennessee, respectively. Significant differences in net economic returns were observed between soybean that received a neonicotinoid seed treatment and soybean with no insecticide seed treatment in Louisiana ($F = 5.32$; df = 1, 177; $P = 0.02$) and Mississippi ($F = 13.37$; df = 1, 558; $P < 0.01$; Table 3). No differences in mean economic returns between treatments were observed in Arkansas ($F = 2.15$; df = 1, 154; $P = 0.14$) or Tennessee ($F = 0.21$; df = 1, 375; $P = 0.65$).

When analyzed by year, there was a significant difference in yields between seed treated with a neonicotinoid and those only treated with fungicide in 6 out of the 10 yr (Table 4). Soybean yield in 2005, 2006, 2007, 2008, 2011, and 2012 were significantly greater where a neonicotinoid seed treatment was used compared with where no insecticide seed treatment was used (Table 5). However, significant economic returns between the treatments were only observed in 4 yr out of 10 (2006, 2007, 2008, and 2012).

Numerous experiments have investigated the impact of neonicotinoid seed treatments on soybean yield in the United States (Cox et al. 2008, Magalhaes et al. 2009, Cox and Cherney 2011, Reisig et al. 2012, Seagraves and Lundgren 2012). In general, those studies showed little to no benefit to using a neonicotinoid seed treatment in soybean. For instance, Reisig et al. (2012) showed that neonicotinoid seed treatments reduced adult thrips numbers 3 wk after planting; however, there were no significant differences in yield. Similarly, Cox et al. (2008) and Cox and Cherney (2011) found that insecticide seed treatments did not increase soybean yield. These data indicate that an insecticide or fungicide seed treatment is not required for soybean production in the northeastern United States. However, other studies have shown that neonicotinoid seed treatments prevented losses of soybean yields in the United States (McCornack and Ragsdale 2006, Johnson et al. 2008 and 2009, McCarville et al. 2014). In general, those studies showed yield

Table 3. Mean (SEM) yields and net economic returns (SEM) of soybean treated with a neonicotinoid seed treatment compared with those not treated with insecticide within each state in the Mid-South from 2005–2014

Year	Treatment	Kg ha^{-1}	US$/ha^{-1}
Arkansas	Untreated	3,003 b (248.1)b	1,270 a (125.6)a
	Neonicotinoid IST	3,115 a (247.1)a	1,299 a (125.9)a
	$P > F$	0.02	0.14
Louisiana	Untreated	2,842 b (226.0)b	1,022 b (98.3)b
	Neonicotinoid IST	3,045 a (224.7)a	1,065 a (97.9)a
	$P > F$	<0.01	0.02
Mississippi	Untreated	2,936 b (109.0)b	1,070 b (54.9)b
	Neonicotinoid IST	3,101 a (107.8)a	1,120 a (54.5)a
	$P > F$	<0.01	<0.01
Tennessee	Untreated	3,281 b (124.6)b	1,349 a (72.4)a
	Neonicotinoid IST	3,351 a (123.7)a	1,354 a (72.2)a
	$P > F$	0.02	0.65

Means within a column and state followed by the same letter are not significantly different, $P < 0.05$.

Table 4. ANOVA table for soybean yields and net economic returns across the Mid-South for each year (2005–2014)

Year		Yield	Returns
2005	*F*-value	7.2	1.48
	df	1, 32.9	1, 32.8
	P-value	0.01	0.23
2006	*F*-value	20.14	5.62
	df	1, 183	1, 183
	P-value	0.01	0.01
2007	*F*-value	8.17	3.88
	df	1, 63.3	1, 63.4
	P-value	0.01	0.05
2008	*F*-value	18.62	11.74
	df	1, 211	1, 211
	P-value	0.01	0.01
2009	*F*-value	0.15	0.34
	df	1, 92.7	1, 92.5
	P-value	0.70	0.56
2010	*F*-value	1.71	0.28
	df	1, 202	1, 202
	P-value	0.19	0.60
2011	*F*-value	6.90	3.41
	df	1, 159	1, 158
	P-value	0.01	0.06
2012	*F*-value	10.06	7.34
	df	1, 199	1, 199
	P-value	0.01	0.01
2013	*F*-value	0.27	1.78
	df	1, 125	1, 125
	P-value	0.61	0.18
2014	*F*-value	2.97	1.74
	df	1, 68	1, 68
	P-value	0.08	0.19

Table 5. Mean (SEM) yields and net economic returns of soybean treated with a neonicotinoid seed treatment compared with those not treated with insecticide for each year across the Mid-South region from 2005–2014

Year	Treatment	Kg ha^{-1}	US$/ha^{-1}
2005	Untreated	3,212 b (313.5)	694 a (63.6)
	Neonicotinoid IST	3,360 a (312.9)	709 a (63.5)
	$P > F$	0.01	0.23
2006	Untreated	2,945 b (199.2)	669 b (45.7)
	Neonicotinoid IST	3,112 a (198.4)	689 a (45.5)
	$P > F$	0.01	0.01
2007	Untreated	2,931 b (396.4)	943 b (109.1)
	Neonicotinoid IST	3,146 a (394.6)	990 a (108.3)
	$P > F$	0.01	0.05
2008	Untreated	2,559 b (180.4)	890 b (62.4)
	Neonicotinoid IST	2,800 a (178.0)	956 a (61.6)
	$P > F$	0.01	0.01
2009	Untreated	3,537 a (178.0)	1,239 a (66.7)
	Neonicotinoid IST	3,560 a (176.2)	1,227 a (66.1)
	$P > F$	0.70	0.56
2010	Untreated	3,094 a (190.7)	1,212 a (73.4)
	Neonicotinoid IST	3,165 a (188.2)	1,223 a (72.4)
	$P > F$	0.19	0.60
2011	Untreated	3,040 b (302.9)	1,353 a (135.9)
	Neonicotinoid IST	3,168 a (301.8)	1,393 a (135.4)
	$P > F$	0.01	0.06
2012	Untreated	3,180 b (206.6)	1,691 b (110.6)
	Neonicotinoid IST	3,396 a (204.4)	1,790 a (109.4)
	$P > F$	0.01	0.01
2013	Untreated	3,234 a (207.8)	1,555 a (98.6)
	Neonicotinoid IST	3,212 a (206.9)	1,528 a (98.2)
	$P > F$	0.61	0.18
2014	Untreated	2,949 a (368.2)	1,406 a (175.5)
	Neonicotinoid IST	3,097 a (365.8)	1,460 a (174.4)
	$P > F$	0.08	0.19

Means within a column and year followed by the same letter are not significantly different, $P < 0.05$.

responses to neonicotinoid seed treatments compared with untreated soybean seed. Buehring et al. (2015) investigated the yield response of three different soybean maturity groups at three different planting dates to insecticide seed treatments and found that there was no interaction between seed treatments and planting date. Averaged across locations, planting dates, and maturity groups, soybean with an insecticide seed treatment resulted in yields that were significantly greater than the fungicide-only treatment. Their results were similar to the current study with a reported 222 kg/ha^{-1} difference.

Out of the 170 neonicotinoid insecticide seed treatment trials conducted across the Mid-South, 67% displayed a positive yield response when a neonicotinoid seed treatment was used from 2005–2014. The overall average soybean yield response to neonicotinoid seed treatments was 132.0 kg ha^{-1} and ranged from a loss of

−742.6 kg ha^{-1} to an increase of 2,527 kg ha^{-1}. The 2,527 kg ha^{-1} advantage at one location was due to pea leaf weevil, *S. lineatus*, damage in the fungicide-only plots. When net returns were calculated across the Mid-South region, 60% of the trials had a positive net return from using neonicotinoid seed treatments with an average increased return of US$94.00 per hectare.

This metaanalysis was conducted on previous research with neonicotinoid insecticide seed treatments throughout the Mid-South with the goal of determining the value of neonicotinoid insecticides as a seed treatment in soybean. These 170 experiments were analyzed from the production years of 2005 to 2014 and data indicate that neonicotinoid seed treatments may provide a yield and economic benefit in soybean production systems throughout the Mid-South region a majority of the time. However, significant differences in net economic returns were only observed in Louisiana and Mississippi when analyzed by state and in 4 out of the 10 years when analyzed by year. Neonicotinoid seed treatments are currently used on >50% of soybean production in the Mid-South region (Musser et al. 2013). This high adoption rate can be attributed to better stand establishment, more vigorous seedling growth, yield advantages, and risk management aversion. Many producers report more uniform emergence, less stand loss, and fewer replants as adoption of insecticide seed treatments in the Mid-South region. Our results demonstrate significant yield and economic increases in some situations resulting from the use of neonicotinoid seed treatments in Mid-South soybean production. Because these benefits are likely the result of management of a complex of multiple pest species that usually occur at subthreshold levels individually and because those complexes are difficult to predict at the time of planting, at-planting insecticides (including seed treatments) are broadly recommended for soybean integrated pest management in the Mid-South. As such, producers may elect to use or not use seed treatments based on commodity prices, tillage, and cover crop practices, previous field history, or personal preference.

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