# EFFECT OF BROILER LITTER APPLICATION TO SOYBEAN CROP INFESTED WITH SOYBEAN CYST NEMATODE

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## ABSTRACT

Donald, P. A., P. B. Allen, D. D. Tyler, K. R. Sistani, H. Tewolde, and E. R. Walker. 2013. Effect of broiler litter application to soybean crop infested with soybean cyst nematode. Nematropica 43:24-34.

Manipulation of the plant root zone to reduce the impact of plant parasitic nematodes has been a goal of researchers. Addition of animal manure has a long history of improved soil quality and reduced soil-borne diseases. The objective of this research was to measure the agronomic benefits of broiler litter application to a soybean (*Glycine max*) crop under no-till and disk regimes and to assess the impact of broiler litter application on soybean cyst nematode (*Heterodera glycines*) reproduction. Field treatments included two levels of broiler litter (6.7 Mg $ha^{-1}$ and 13.4 Mg $ha^{-1}$). Plots were established in a field where according to University of Tennessee soil tests no P or K were needed. Application of broiler litter at both rates significantly increased plant height in 2008 ($P = 0.0001$) and also in 2009 ($P = 0.002$). The benefits of broiler litter for soybean growth as measured by plant height was observed regardless of the litter rate. Significant grain yield differences were observed in 2008 ($P = 0.0025$). Spectral measurements among treatments were highly significant in 2008 ($P = 0.0001$). Spectral measurements were highly correlated with plant height, grain yield, and *H. glycines* egg population density at harvest in 2008. Increased levels of P, Mg and Zn were present in the soil where broiler litter was applied. We did not find a significant effect of broiler litter application on *H. glycines* reproduction in field trials.

*Key words:* broiler litter, management, soybean cyst nematode.

## RESUMEN

Donald, P.A., P.B. Allen, D.D. Tyler, K. R. Sistani, H. Tewolde, and E. R. Walker. 2013. Efecto de la aplicación de residuos de avicultura en campos de soya infestados con nematodo quiste de la soya. Nematropica 43:24-34.

La manipulación de la zona radical de la planta con el fin de reducir el daño causado por nematodos fitoparásitos ha sido objeto de investigación. Por mucho tiempo se han conocido los beneficios que la adición de estiércol de animales tienen sobre la calidad del suelo y sobre la reducción de enfermedades vegetales. El objetivo de este trabajo es evaluar los beneficios agronómicos de la aplicación de residuos de avicultura a campos de soya (*Glycine max*) arados y sin arar, y medir el impacto de estas aplicaciones sobre la reproducción del nematode quiste de la soya (*Heterodera glycines*). Los tratameintos de campo incluyeron dos niveles de residuos de avicultura (6.7 Mg $ha^{-1}$ y 13.4 Mg $ha^{-1}$). Los lotes se establecieron en un campo en donde, según análisis de suelo realizados por la Universidad de Tennessee, no se hallaban deficiencias de P ó K. La aplicación de los residuos en las dos dosis aumentó significativamente la altura de las plantas en el 2008 ($P = 0.0001$) y en el 2009 ($P = 0.002$). Los beneficios sobre el crecimiento de las plantas de soya fueron similares con las dos tasas de aplicación. Se observaron diferencias significativas en la producción de grano en el 2008 ($P = 0.0025$). La mediciones espectrales entre tratamientos fueron altamente significativas en el 2008 ($P = 0.0001$). Las mediciones espectrales estuvieron altamente correlacionadas con altura de planta, producción de grano, densidad de población del nematode quiste en el momento de la cosecha en el 2008. Se observaron niveles aumentados de P, Mg y Zn en el suelo tras la aplicación de los residuos. No encontramos efecto significativo de las aplicaciones sobre la reproducción de *H. glycines*.

*Palabras clave:* manejo, nematode quiste de la soya, residuos de avicultura.

## INTRODUCTION

Manipulation of the plant root zone to reduce the impact of plant parasitic nematodes has been a goal of researchers for years. The interest has increased with the decreased availability of nematicides due to environmental and worker hazards (Starr *et al*. 2002). Addition of animal manure has a long history to improve soil qualities and reduce soil borne diseases (Rodriguez-Kabana, 1986; Gilfillen *et al.*, 2010). Modification of the soil can lead to higher grain yield (Gilfillen *et al*., 2010). An ideal situation could be created if application of broiler litter resulted in reduction in SCN (*Heterodera glycines*) reproduction. Current management strategies for reduction of SCN egg population density, i.e. reproduction, do not eliminate risk of yield loss. Additional tools for management are needed as the nematode adapts to current sources of resistance (Faghihi *et al*., 2010) and economics of crop production limit the utility of crop rotation. The mode of action of broiler litter is thought to be based on the release of toxic levels of ammonia but this has not been demonstrated (Anonymous, 2009). Alterations in soil structure, the stimulation of antagonistic organisms, and improved plant tolerance also may be involved with the application of manures (Lazarovits *et al*., 2001). Several groups of researchers have looked at application of animal manure to reduce SCN (Tazawa *et al*., 2008; Xiao *et al*., 2007) and others have investigated application of sewage to reduce SCN (Zasada and Tenutu 2004, Zasada 2005). One of the reasons manures have not been more thoroughly investigated in suppression of SCN is that nitrogen supplementation is the common use for manures and application of nitrogen to soybean (*Glycine max*) is not a standard practice.

Broiler production is currently centered in the Southeastern USA (Anonymous, 2012). Environmentally friendly ways to dispose of broiler litter generated from brooder houses have included use as plant nutrient source, soil conditioner and a compost material for the ornamental industry. The broiler litter is known to improve soil physical, biological, and other soil properties that may contribute to improved crop performance (Rodriguez-Kabana, 1986). The nitrogen (N) contribution from the application of manure on N-fixing legumes such as soybean is usually considered unneeded and as indicated by Streeter (1985) can interfere with $N_2$ fixation. However, in other crops, application of broiler litter, a combination of manure and bedding materials, is beneficial (Tewalde *et al*., 2009). This waste product has long been used as a fertilizer near the point of production, but high transportation costs has limited its use to within about 50 miles of broiler houses (Risse *et al*., 2006).

Adeli *et al.* (2005) presented the nutritional needs of soybean and documented that broiler litter at a rate of >80 kg plant available nitrogen $ha^{-1}$ was not used by the soybean plant as measured by increasing levels of nitrogen in the soil. Broiler litter application produced 3.4% more soybean grain yield for every unit of N uptake in comparison with mineral fertilization. Their study showed that yield increased linearly with increasing N uptake and was not correlated to soybean P. They came to this conclusion after comparing aboveground plant material values of 70 and 80% of total N and P uptakes by plants (Schmidt *et al*. 2001) and comparing levels of N and P in broiler-litter treated plots with those receiving either commercial fertilizer or no fertilizer. Nutrient content of litter is variable and it is advisable to have it tested for nutrient availability (Walker, 2010). Soils in the southern USA are typically low in organic matter, high in silt and sand content, and are highly erodible (Healy and Sojko, 1985). Application of manure to cropland has been shown to reduce erosion regardless of whether or not it was applied annually (Gilley and Risse, 2000).

Modifications of soil properties through application of organic matter have been shown to affect plant parasitic nematode habitats (Rodriguez-Kabana, 1986; Oka, 2010; Widmer *et al*., 2002). The addition of common wastes or byproducts of agricultural industries, such as manures, compost and plant residues with high nitrogen contents may suppress plant parasitic nematodes. Tewolde *et al*. (2009) suggest that application of broiler litter may stimulate soil microorganisms simulating the effects of crop rotation and may increase the number of years the same crop can be grown on the same soil without rotation. However, if broiler litter is applied at a rate based on nitrogen needs Cu, P, and Zn can accumulate (Gilfillen *et al*., 2010).

Soybean cyst nematode (SCN) is a serious pest of soybean in the United States and worldwide (Wrather and Koenning, 2009). Economic yield loss due to *H. glycines* in the United States varies with the growing season and the price of soybean. The loss estimate was >300 million bushels from 2003 to 2005 (Niblack and Tylka, 2008) amounting to 1,650,000 USD. The true extent of losses in the USA may be underestimated because a lack of visible stress on soybeans during the growing season often masks yield loss prior to harvest and the loss is then attributed to factors other than SCN.

Effective SCN management options are limited. Plant resistance is the primary management tool used for this pest, but lack of complete resistance to SCN, and continued development of SCN leads to selection of individuals able to reproduce on that source of resistance (Faghihi *et al.*, 2010). Crop rotation is also effective when it is economically viable. Additional SCN management strategies to supplement plant resistance and crop rotation are needed. Broiler litter may be one option since it has been suggested to induce nematode suppressive soil (Rodriguez-Kabana, 1986; Fernandez *et al*., 2001). Manure application could achieve the same effects of nematode suppression as have some cover crops but would not have the growth variability (Riegel and Noe, 2000). Additionally, cover crops are not universally suppressive of all plant parasitic nematodes (McSorley, 2009). Soil suppressiveness to plant pathogens falls into two categories, specific and general. Both types of suppressive soil change the soil microflora and microfauna. Specific suppressiveness is found when changes in soil microorganisms in the rhizosphere are limited to a specific group of microorganisms (Fernandez *et al.,* 2001). Lopez-Perez *et al*. (2005) found broiler litter was an effective biofumigant activator in greenhouse studies with root-knot nematode as long as soil temperatures were about 30°C. One previous study explored the interaction of poultry litter application and incorporation in soybean under H. glycines infestation (Morant *et al*., 1997). They concluded that a 5 Mg ha$^{-1}$ rate increased soybean yield in the presence of SCN but there was a yield reduction at the 10 t ha$^{-1}$ rate. They found no effect on the population density of SCN from application of poultry litter.

Our hypothesis is that application of broiler litter would result in a yield increase when plants were stressed by SCN. The objectives of our study were to (i) to evaluate the agronomic benefits of broiler litter application to a soybean crop under no-till and till regimes and (ii) assess the impact of broiler litter application on SCN reproduction under these tillage regimes.

## MATERIALS AND METHODS

Two studies were conducted in the greenhouse to determine the effect of broiler litter on SCN under controlled conditions. A 3-year field study followed with agronomic measurements collected each of the 3 years.

### *Greenhouse Studies*

*Experiment 1.* Field soil (Pembroke silt loam, Fine-silty, mixed, active, mesic Mollic Paleudalfs) and broiler litter, equivalent to 2.2 and 4.5 Mg ha$^{-1}$, respectively, were placed in a plastic bag and shaken to thoroughly mix the treated soil. The mixture was placed in 9-cm diameter clay pots that were plugged to retain the soil in the pots. Ten SCN cysts/pot were placed into this mixture approximately in the center of each pot. Control pots received cysts but no broiler litter. Pots were watered and allowed to acclimate to the greenhouse conditions for one week prior to planting 2 seed of SCN-susceptible soybean cv. 'Hutcheson' in each pot.. Greenhouse air temperature was set for 27°C. Thirty days after planting seeds, roots were removed from the pots, rinsed of soil, and fresh weight was recorded. Cysts were recovered by sieving and enumerated. There were 86 observations. Nutrient analysis of broiler litter and soil (Mehlich 3) is presented in Table 1. The broiler litter was air dried prior to analysis. Analysis for P, K, and minerals used oven dried material (65°C), microwave digested with a CEM MARS-5 microwave (Matthews, NC) and further analyzed with a Varian Vista Pro Axial Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES, Walnut Creek, CA).

*Experiment 2.* Pembroke soil that was used in experiment 1 was compared with a standard potting mix used for increasing SCN in the greenhouse (3 parts sand:1 part silt loam field soil). The pH of the Pembroke soil was 5.9 and the pH of the potting mix was 6.8. Pots were filled with soil as described in greenhouse experiment 1. Ten cysts were added with the broiler litter or soil control to each pot as described in greenhouse experiment 1. Two soybean seeds cv 'Hutcheson' were planted per pot. Growing conditions were as described in greenhouse experiment 1. Cysts were recovered and enumerated 40 days after planting seed as described in greenhouse experiment 1.

### *Field Experiments*

Field plots were established at the West Tennessee Research & Education Center, Jackson, TN (35 48 52 N 089 18 16 W). The soil was a non-irrigated Memphis silt loam (fine-silty, mixed, active, thermic Typic Hapludalf). The field had a documented history of the presence of SCN at an estimated population density of 800 eggs 100 cm$^{-3}$ of soil at the initiation of the study. The experimental design was a randomized complete block design with 6 replications per treatment combination. Each plot was 9 square meters (3 x 3m) with a 6.1m border on the north and south side of each plot. Row spacing was 76 cm centers planted in the north-south direction. Glyphosate-resistant soybeans were planted 1 May 2007 and 1 May 2008 (cv. Asgrow '3906') and 29 April 2009 (cv. Cropland 'R24526' due to seed availability). All plots were sprayed with pre-emergence herbicides to control weeds. In season weed control was obtained with application of glyphosate. Treatments were a combination of tillage, litter placement, and broiler litter application rate (Table 2). Tillage treatments were no-till and disk followed by triple K for seedbed preparation. Broiler litter rates were 6.7 and 13.4 Mg ha$^{-1}$ which reflect the recommended Tennessee rate and a 2X rates (Burns *et al.*, 1999). Half of the disk tilled (DT) plots had broiler litter applied to the surface and the broiler litter was incorporated on the other half of the conventional till plots. The disk tilled (DT) and no-till (NT) controls contained adequate fertility for soybean yield without the addition of any further fertilizer, as recommended by the University of Tennessee Soil Testing Laboratory, Nashville, TN (Mehlich 1) based on soil test results from early spring samples collected as a bulk sample across the plot area borders. Grain yield was collected from the middle two rows of each plot with an Almaco plot combine. Grain weight was adjusted to 13% moisture. Harvest dates were 20 September 2007, 30 September 2008 and 1 October 2009. The location of individual plots was unchanged for the duration of the study. Broiler litter

Table 1. Nutrient composition of a composite sample of broiler litter and soil for greenhouse studies.

| | Broiler litter | Pembroke soil |
|---|---|---|
| pH | 7.7 | 6 |
| N[y] | 33 | 1.6 |
| C[y] | 359 | 16 |
| Al[z] | 5185 | 901 |
| Ca[z] | 57411 | 1382 |
| Cd[z] | 0 | 0.1 |
| Cu[z] | 920 | 1.9 |
| K[z] | 20534 | 195 |
| Fe[z] | 4669 | 139 |
| Mg[z] | 15434 | 102 |
| Mn[z] | 1398 | 327 |
| Na[z] | 5890 | 81 |
| P[z] | 34703 | 78 |
| Pb[z] | 4.2 | 2.3 |
| S[z] | 7972 | n/a |
| Zn[z] | 1248 | 8 |

[y]$gKg^{-1}$.
[z]$mgKg^{-1}$.
Analyses conducted by Animal Waste Management Research Unit, USDA ARS Bowling Green, KY. Mehlich 3.

Table 2. Tillage treatment summary for field study at West Tennessee Research and Education Center, Jackson, TN, 2007-2009.

| Tillage | Litter Application | Litter Rate ($Mg\ ha^{-1}$) |
|---|---|---|
| No-till | Surface | 6.7 (low) |
| | | 13.4 (high) |
| | | No litter |
| Disk followed by Triple K | Surface | 6.7 (low) |
| | | 13.4 (high) |
| | | No litter |
| | Incorporated | 6.7 (low) |
| | | 13.4 (high) |

was obtained from local broiler facilities in Tennessee (2007 and 2008) and Kentucky (2009) and subsamples analyzed at the USDA-ARS facility in Bowling Green, KY for nutrient content on a fresh weight basis using an Elementar Vario Max Carbon Nitrogen analyzer (Hanau, Germany). The nitrogen composition for the poultry litter was 28.5g/Kg, 23.1 g/Kg, and 20.4 g/Kg for 2007, 2008 and 2009, respectively. The carbon composition of the poultry litter was 352.8 g/Kg, 242.9 g/Kg, and 302.7 g/Kg for 2007, 2008 and 2009, respectively.

*Data collected*

Plant height at midseason, transmittance/absorbance chlorophyll meter readings (CI) and leaf area index (LAI) at monthly intervals, and normalized difference vegetation index (NDVI) data at approximately two week intervals were collected from the center two rows of each plot to measure the response of the plants to broiler litter application. The SPAD-502 chlorophyll meter (Minolta Corp., Ramsey, NJ) was used to measure CI and the AccuPAR model PAR-80 ceptometer (Decagon Devices, Pullman, WA) was used to estimate LAI. The Greenseeker hand-held red/NIR NDVI sensor (Model 505, NTech Industries, Ukiah, CA) equipped with a data logger was used for data collection. All data for NDVI measurements were initiated at 9 am CDT. The sensor was suspended by a telescoping boom over the center of each row, oriented vertically and adjusted to a height of 64 cm above the top of the canopy. Soybean grain yield was collected from the two middle rows 20 September 2007, 30 September 2008, and 1 October 2009. SCN egg population density was estimated each year at planting and harvest by collecting 8 soil cores (2.5 cm dia x 20 cm deep) combined into a single bag for each plot, and stored at 4°C until processed. A subsample of 120 $cm^3$ from each bag was screened through 1 cm hardware cloth to remove extraneous material and thoroughly mixed prior to processing with a University of Georgia semi automatic elutriator (Byrd, 1976). Cysts were collected on 250 µm sieves, ground (Faghihi and Ferris 2000), and eggs collected on a 25 µm sieve. The eggs were stained with acid fuchsin (Hooper, 1970) and enumerated under a dissecting microscope at 40X. The remaining soil sample collected at harvest and after processing for SCN was submitted to the University of Tennessee Soil, Plant, Pest Center, Nashville, TN for soil nutrient content (macro and micro nutrients, pH, organic material). Weather data was collected at the West Tennessee Agriculture Experiment Station 1.6 km from the field. Precipitation data presented are from the years of the study and the 30 year average (Table 3).

*Data analysis*

Pearson correlation coefficients were calculated for all response variables using SAS (SAS Institute, Cary, NC). A strong anisotropic trend in several plant and nematode response variables was evident within blocks across the field. Since the blocking did not account for this variation a spatial trend variable, incremented from 1 to n across the field, was regressed with the dependent variable during Mixed Model Analysis of Variance

Table 3. Monthly precipitation (cm) recorded at West Tennessee Research and Education Center Jackson, TN weather station 1.6 km from research area. Data presented are study years (2007-2009) and the 30 year average.

| | 2007 | 2008 | 2009 | 30 Year |
|---|---|---|---|---|
| January | 14.5 | 10.4 | 10.4 | 11.0 |
| February | 4.6 | 9.7 | 5.6 | 10.6 |
| March | 3.0 | 24.9 | 12.4 | 13.7 |
| April | 8.4 | 20.8 | 14.2 | 12.2 |
| May | 2.2 | 17.4 | 19.1 | 14.7 |
| June | 6.9 | 7.1 | 9.2 | 12.7 |
| July | 4.4 | 16.0 | 18.7 | 12.1 |
| August | 2.0 | 6.5 | 7.6 | 7.5 |
| September | 16.0 | 2.0 | 18.4 | 10.0 |
| October | 22.8 | 8.0 | 0 | 8.7 |
| November | 7.6 | 5.3 | 0 | 13.0 |
| December | 14.0 | 20.3 | 0 | 13.6 |

Table 4. Average plant height (cm) for each treatment at West Tennessee Research and Education Center, 2007-2009.

| Treatments | 2007 | 2008 | 2009 |
|---|---|---|---|
| DT low Li[s] | 20 | 135 bc[r] | 91 bc |
| DT low L[t] | 20 | 131 cd | 93 bc |
| DT high Li[u] | 18 | 128 cd | 92 bc |
| DT high L[v] | 18 | 135 bcd | 98 ab |
| DT[w] | 19 | 114 e | 86 bc |
| NT low[x] | 20 | 146 ab | 107 a |
| NT high[y] | 17 | 156 abcd | 105 a |
| NT[z] | 19 | 119 de | 82 c |

[r]Means with the same or no letter are not different (P = 0.05) according to the least significant difference procedure (LSD).
[s]DT low Li = disk tilled 6.7 Mg $ha^{-1}$ litter incorporated.
[t]DT low L = disk tilled 6.7 Mg $ha^{-1}$.
[u]DT high Li = disk tilled 13.4 Mg $ha^{-1}$ litter incorporated.
[v]DT high = disk tilled 13.4 Mg $ha^{-1}$.
[w]DT = disk tilled control with no additional fertility needed as established by University of Tennessee recommendations.
[x]NT low = no-till 6.7 Mg $ha^{-1}$.
[y]NT high = no-till 13.47 Mg $ha^{-1}$.
[z]NT = no-till control with no additional fertility needed as established by University of Tennessee recommendations.

(MMAOV) to capture the spatial drift. The SCN egg count data were transformed to log $10_{(x + 1)}$ prior to analysis and only non-transformed means are reported. Contrast analysis was done on CI, LAI and also on SCN data and soybean yield.

## RESULTS

Greenhouse studies showed a reduction in number of cysts recovered from soybean roots when dried broiler litter was applied to pots in comparison to the untreated control containing no broiler litter but there was no statistical difference in the treatments. The number of cysts recovered in the soil without broiler litter averaged 57/100 $cm^3$ of soil. The number of cysts recovered from the high broiler litter level (13.4 Mg $ha^{-1}$) was 26/100 $cm^3$ of soil and the number recovered from the low level (6.7 Mg $ha^{-1}$) was 36/100 $cm^3$ of soil. Data were not statistically different between soil types (Pembroke and Memphis).

### *Field studies*

The most observable effect of broiler litter addition to soil planted to soybean was the increased height especially in successive years. Plant height and grain yield in 2007 were uniformly low which we attribute to low level of precipitation during the growing season (Table 3). No significant differences were found in plant height in 2007 (Table 4). Plant height ranged from 17 to 20 cm. However, plant height was significantly different (P = 0.0001) among treatments in 2008. The average values ranged from 114 cm in the disk treatment with adequate fertility (DT) treatment to 156 cm in the no-tillage high litter (NT high L) treatment. The range in plant height in 2009 was from 82 cm in the no-tillage with adequate fertility (NT) to 107 cm in the no-tillage low litter (NT low L) treatment (P = 0.002). Incorporation of the litter, although thought to improve release of nutrients to the plants, had no significant difference on plant height. Likewise, there were no significant differences in plant height between the two rates of broiler litter.

Spectral Measurements of CI and LAI readings were highly correlated with NDVI readings (Tables 5 and 6). Plots receiving broiler litter (L) had higher biomass than plots with adequate soil fertility (F) regardless of the tillage regime. The differences in biomass reflected by NDVI readings were statistically different (P = 0.0001) in collections on 12 and 27 June and 9 July 2008 (Table 7). Statistical differences in row closure were seen in collections on 12 and 27 June and 9 July 2008 (Table 7).

Grain yield in 2008 differed among treatments (P = 0.0025). Yield ranged from 1211 to 2095 kg $ha^{-1}$. The lowest yield was in the DT treatment followed by the NT treatment. The highest yields were in the NT high L plots. Litter incorporated (Li) in the disk tillage (DT) plots did not consistently increase the yield. In 2009, yield was higher than the previous year and differences in treatments were significant at the P = 0.03 level. The range in yield was from 1944 to 2387 kg $ha^{-1}$. As in the previous year, the lowest yields were in the DT and NT treatments. Higher yields were seen in DT Li treatments (Table 6).

### *SCN reproduction*

Due to wide environmental variability, data across years was not combined. However, despite low precipitation during the growing season in 2007, SCN reproduction was higher than in other years for most treatments (Table 6). There was no significant difference in SCN reproduction due to specific treatment in any of the three years. However, contrast analysis of those treatments with litter versus those that received no litter showed that the final population densities and Rf's of SCN were significantly higher in plots treated with litter in 2007 and 2009.

### *Soil nutrition*

Soil nutrient data was collected in 2008 and 2009 on selected plots prior to application of litter. There was no difference in P in plots without broiler litter regardless of the tillage regime in either year. Increased levels of P, Mg, and Zn were present where broiler litter was applied which is consistent with other data (Gilfillen *et al.*, 2010). Lower P, K., Mn, Fe, and Ca levels were observed in 2009 than in 2008 across all treatments.

## DISCUSSION

Glenn *et al.* (2008) reviewed the relationship between vegetation indices and plant physiology. Plant height, LAI and NDVI can be used as estimates of yield and in this study were highly correlated with yield. Adeli *et al.* (2005) found that application of broiler litter increased aboveground dry matter yields more than commercial fertilizer. They theorize that there are yield-enhancing factors other than N and P present in broiler litter. Plant height in this study was significantly different by year; however, there were no significant differences in plant height by treatment whether or not broiler litter was applied or under different tillage regimes in 2007. In 2008 the DT and NT treatments were significantly shorter than all the broiler litter treated plots suggesting that benefits of broiler litter application may not be seen in the initial year of application. In 2009 the differences in height were only seen between the NT 6.7 Mg $ha^{-1}$ litter rate and 13.4 Mg $ha^{-1}$ litter rate vs the NT treatment. NDVI readings were significantly different by tillage with significant differences between NT low, NT high and the NT treatment in four of the six sampling dates. This suggests that canopy closure was faster when broiler litter was applied in no-tillage (NT) than when the litter was applied to DT either with or without incorporation (Li or L). In most sample collection times there were significant differences between the DT and

Table 5. Leaf area index (LAI) and chlorophyll index (CI) of soybean fertilized with broiler litter or standard inorganic fertilizer in a soil infested with soybean cyst nematode.

| | Leaf area index | | | | Chlorophyll index | | | |
|---|---|---|---|---|---|---|---|---|
| | 2007 | | 2008 | | 2007 | | 2008 | |
| Treatment | July 3 | Aug 7 | June 26 | July 9 | July 3 | Aug 7 | June 26 | July 9 |
| DT low Li[o] | 1.13 | 1.23 | 1.15 b[n] | 2.74 b | 37.4 | 44.4 | 39.9 | 47.2 |
| DT low L[p] | 1.24 | 1.20 | 1.02 b | 2.63 b | 35.7 | 43.4 | 39.3 | 46.4 |
| Dt high Li[q] | 1.26 | 1.04 | 1.04 b | 2.47 bc | 36.5 | 43.4 | 39.0 | 46.2 |
| DT high L[r] | 1.28 | 1.21 | 1.16 b | 2.70 c | 38.2 | 43.3 | 39.6 | 46.3 |
| DT[s] | 1.22 | 1.29 | 0.71 b | 1.64 d | 36.7 | 44.8 | 40.0 | 46.3 |
| NT low[t] | 1.21 | 1.49 | 1.93 a | 2.94 ab | 35.6 | 44.0 | 39.8 | 46.1 |
| NT high[u] | 1.06 | 1.18 | 2.04 a | 3.49 a | 38.4 | 43.6 | 39.9 | 46.4 |
| NT[v] | 0.92 | 1.04 | 0.78 a | 1.88 cd | 38.0 | 42.6 | 38.7 | 45.8 |
| **Avg** | **1.16** | **1.21** | **1.23** | **2.56** | **37.07** | **43.67** | **39.53** | **46.34** |
| ANOVA | | | | | | | | |
| Year (Y) | 0.478 | 0.000 | | | 0.000 | 0.000 | | |
| Treatment (T) | 0.001 | 0.017 | | | 0.360 | 0.278 | | |
| Y*T | 0.001 | 0.016 | | | 0.090 | 0.796 | | |
| CONTRASTS | | | | | | | | |
| DT vs NT | 0.047 | 0.688 | 0.001 | 0.077 | 0.426 | 0.321 | 0.834 | 0.319 |
| low vs high | 0.624 | 0.761 | 0.008 | 0.000 | 0.214 | 0.784 | 0.947 | 0.572 |
| F[w] vs L[x] | 0.039 | 0.436 | 0.047 | 0.111 | 0.157 | 0.648 | 0.589 | 0.596 |
| Li[y] vs LS[z] | 0.829 | 0.799 | 0.308 | 0.019 | 0.648 | 0.219 | 0.968 | 0.846 |

[n]Means within a column followed by the same letter or with no letter designation are not significantly different at $P < 0.05$.
[o]DT low Li = disk tilled 6.7 Mg ha$^{-1}$ litter incorporated.
[p]DT low L = disk tilled 6.7 Mg ha$^{-1.}$
[q]DT high Li = disk tilled 13.4 Mg ha$^{-1}$ litter incorporated.
[r]DT high = disk tilled 13.4 Mg ha$^{-1.}$
[s]DT = disk tilled control with no additional fertility needed as established by University of Tennessee recommendations.
[t]NT low = no-till 6.7 Mg ha$^{-1}$.
[u]NT high = no-till 13.47 Mg ha$^{-1}$.
[v]NT = no-till control with no additional fertility needed as established by University of Tennessee recommendations.
[w]F = adequate fertility as establish by University of Tennessee recommendation.
[x]L = broiler litter (6.7 and 13.4 Mg ha$^{-1}$).
[y]Li = broiler litter incorporated.
[z]LS = broiler litter surface.

Table. 6 Measurement of soybean cyst nematode population density at planting (Pi), harvest (Pf), and reproduction (R) and soybean grain yield in response to application of broiler litter or standard inorganic fertilizer in a soil infested with soybean cyst nematode.

| | Soybean Cyst Nematode | | | Yield | Soybean Cyst Nematode | | | Yield | Soybean Cyst Nematode | | | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2007 | | | | 2008 | | | | 2009 | | | |
| Treatment | Pi[l] | Pf[m] | R[n] | $Kgha^{-1}$ | Pi[l] | Pf[m] | R[n] | $Kgha^{-1}$ | Pi[l] | Pf[m] | R[n] | $Kgha^{-1}$ |
| DT low Li[o] | 2.4 | 2.3 | 0.9 | 1600 | 2.9 | 3.3 | 1.2 | 1573 | 2.6 | 2.5 | 1.0 | 2279 |
| DT low L[p] | 2.5 | 2.4 | 0.8 | 1569 | 2.8 | 3.4 | 1.3 | 1476 | 2.8 | 2.1 | 0.8 | 2218 |
| DT high Li[q] | 2.0 | 2.2 | 0.8 | 1453 | 2.8 | 3.2 | 1.2 | 1358 | 2.3 | 1.5 | 0.6 | 2087 |
| DT high L[r] | 1.8 | 2.5 | 0.8 | 1416 | 2.9 | 3.3 | 1.2 | 1563 | 2.0 | 2.3 | 1.1 | 1895 |
| DT[s] | 2.1 | 1.8 | 0.6 | 1228 | 3.0 | 3.3 | 1.1 | 1126 | 2.3 | 1.5 | 0.4 | 1806 |
| NT low L[t] | 1.8 | 2.0 | 0.7 | 1666 | 2.8 | 3.3 | 1.2 | 1707 | 1.5 | 1.6 | 0.5 | 2123 |
| NT high L[u] | 2.1 | 2.4 | 0.8 | 1664 | 3.0 | 3.2 | 1.1 | 1946 | 1.7 | 1.5 | 0.6 | 2081 |
| NT[v] | 2.0 | 1.5 | 0.6 | 1344 | 2.9 | 3.4 | 1.2 | 1249 | 2.4 | 0.3 | 0.2 | 1942 |
| **Avg** | **2.1** | **2.1** | **0.8** | **1492** | **2.9** | **3.3** | **1.2** | **1500** | **2.2** | **1.7** | **0.7** | **2054** |
| ANOVA | | | | | | | | | | | | |
| Year | 0.000 | 0.000 | 0.001 | 0.000 | | | | | | | | |
| Treatment | 0.107 | 0.012 | 0.332 | 0.011 | | | | | | | | |
| Y*T | 0.132 | 0.044 | 0.076 | 0.121 | | | | | | | | |
| CONTRASTS | | | | | | | | | | | | |
| DT vs NT | 0.138 | 0.095 | 0.263 | 0.118 | 0.751 | 0.594 | 0.539 | 0.062 | 0.036 | 0.008 | 0.010 | 0.913 |
| low vs high | 0.084 | 0.484 | 0.958 | 0.176 | 0.521 | 0.504 | 0.592 | 0.770 | 0.316 | 0.302 | 0.978 | 0.033 |
| F[w] vs L[x] | 0.572 | 0.000 | 0.015 | 0.001 | 0.567 | 0.732 | 0.809 | 0.002 | 0.486 | 0.004 | 0.004 | 0.007 |
| Li[y] vs LS[z] | 0.723 | 0.297 | 0.808 | 0.709 | 0.789 | 0.121 | 0.874 | 0.725 | 0.963 | 0.592 | 0.496 | 0.223 |

[l]Number of nematode eggs (transformed $log10_{(x+1)}$ at planting).
[m]Number of nematode eggs (transformed $log10_{(x+1)}$ at harvest).
[n]Reproductive factor =( Pf/Pi x 100) (transformed $log10_{(x+1)}$).
[o]DT low Li = disk tilled 6.7 Mg $ha^{-1}$ litter incorporated.
[p]DT low L = disk tilled 6.7 Mg $ha^{-1}$.
[q]DT high Li = disk tilled 13.4 Mg $ha^{-1}$ litter incorporated.
[r]DT high = disk tilled 13.4 Mg $ha^{-1}$.
[s]DT = disk tilled control with no additional fertility needed as established by University of Tennessee recommendations.
[t]NT low = no-till 6.7 Mg $ha^{-1}$.
[u]NT high = no-till 13.47 Mg $ha^{-1}$.
[v]NT = no-till control with no additional fertility needed as established by University of Tennessee recommendations.
[w]F = adequate fertility as establish by University of Tennessee recommendation.
[x]L = broiler litter (6.7 and 13.4 Mg $ha^{-1}$).
[y]Li = broiler litter incorporated.
[z]LS = broiler litter surface.

Table 7. NDVI readings of center two rows of soybean crop for each broiler litter treatment at West Tennessee Research and Education Center, Jackson, TN in 2008.

| | 6/12/2008 | 6/27/2008 | 7/9/2008 | 7/23/2008 | 8/6/2008 | 8/27/2008 |
|---|---|---|---|---|---|---|
| DT low Li[s] | 0.33 bc[r] | 0.65 cd | 0.73 bc | 0.82 ab | 0.69 abc | 0.47 |
| DT low L[t] | 0.33 bc | 0.62 cd | 0.71 c | 0.78 ab | 0.66 abc | 0.47 |
| DT high Li[u] | 0.34 bc | 0.63 cd | 0.69 c | 0.76 bc | 0.63 bc | 0.44 |
| DT high L[v] | 0.36 b | 0.67 bc | 0.73 bc | 0.79 ab | 0.65 abc | 0.47 |
| DT[w] | 0.28 c | 0.48 e | 0.56 d | 0.69 c | 0.59 c | 0.43 |
| NT low[x] | 0.47 a | 0.75 ab | 0.8 ab | 0.84 a | 0.69 ab | 0.45 |
| NT high[y] | 0.51 a | 0.77 a | 0.83 a | 0.84 a | 0.72 a | 0.44 |
| NT[z] | 0.34 bc | 0.57 d | 0.67 a | 0.77 b | 0.65 ab | 0.46 |

[r]Means with the same or no letter are not different (P = 0.05) according to the least significant difference procedure (LSD).
[s]DT low Li = disk tilled 6.7 Mg $ha^{-1}$ litter incorporated.
[t]DT low L = disk tilled 6.7 Mg $ha^{-1}$.
[u]DT high Li = disk tilled 13.4 Mg $ha^{-1}$ litter incorporated.
[v]DT high = disk tilled 13.4 Mg $ha^{-1}$.
[w]DT = disk tilled control with no additional fertility needed as established by University of Tennessee recommendations.
[x]NT low = no-till 6.7 Mg $ha^{-1}$.
[y]NT high = no-till 13.47 Mg $ha^{-1}$.
[z]NT = no-till control with no additional fertility needed as established by University of Tennessee recommendations.

NT treatments indicating that there were differences in canopy closure between tillage treatments. The LAI data followed the similar pattern further indicating that there was a tillage treatment effect that overrode the level of broiler litter application. Greater yield in NT vs tillage treatments has been documented but also can depend on a number of factors such as soil type, and environmental conditions (Hussain and Olson, 2012). This pattern was also seen in yield measurements. Higher yield was seen in this study with the application of broiler litter despite soil tests indicating that inorganic fertilizer was not needed to meet yield potential. Each year of the study there were significantly higher yield in all broiler litter treated plots from 2007 through 2009 with the exception of the NT 13.4 Mg $ha^{-1}$. This suggests that although major nutrients N, P, and K were not limiting, application of broiler litter did increase grain yield. Increased fertility has been shown to reduce impacts of plant parasitic nematode (Melakeberhan *et al*., 1988); however, increased plant growth due to fertilizer can provide additional feeding sites and increased number of plant parasitic nematodes (Schmitt and Riggs, 1989). This effect may explain the higher numbers of SCN in plots receiving litter in 2007 and 2009. Examination of the soil nutrient analysis for 2008 and 2009 suggests that higher nutrients were present in the broiler litter obtained in 2008 than in 2009. The 2008 broiler litter was composted and was relatively dry. The 2009 broiler litter had been recently removed from the broiler houses and the moisture level was relatively high. Nutrient release from poultry litter varies from facility to facility and even over time at a single operation. Factors which influence nutrient availability are the number of animals, composition of the animal feed ration, design of the waste management system, bedding material and the environmental conditions (Hochmuth *et al.,* 2007). Effects of broiler litter application on soil pH and percent organic matter was unchanged over the course of this study across treatments and tillage regimes. One could anticipate that more applications would be necessary to see an effect on these characteristics. However, due to build up of heavy metals where broiler litter has been applied, it is not a standard practice to apply litter annually.

Kaplan and Noe (1993) and Kaplan *et al*. (1992) also found that broiler litter reduced root-knot nematode in greenhouse studies, and that suppression was not observed in an *in-vitro* sterile soil environment. Zasada's (2005) laboratory study ruled out soil microbes as a major player in reduction of SCN when N-Viro (sewage) was applied to soil. She also demonstrated that pH greatly affected the response. Sumner *et al.* (2002) conducted field studies to reduce *Meloidogyne incognita, Paratrichodorus christiei,* and *Helicotylenchus dihystera* in vegetable production systems and found that reduction in nematodes was species specific for broiler litter treatment and tillage systems. Everts *et al.* (2006) conducted field studies using broiler litter to reduce *M. incognita*, and *Pratylenchus penetrans* in potato production. They found that nematode population density could be achieved through a multiyear application of broiler litter with cover crops. Previous research on application of broiler litter to fields where SCN was present also found an effect on plant growth with application of broiler litter without a corresponding effect on the nematode (Morant *et al*., 1997). Their application rates were almost twice the rates used in our study and were high enough to reduce grain yield presumably due to effects on nitrogen fixation based on their observations with nodulation.

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