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# Short-term Impacts of Tillage and Fertilizer Treatments on Soil and Root Borne Nematodes and Maize Yield in a Fine Textured *Cambisol*

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## Abstract

Conservation agriculture (CA) based on the principles of minimum soil disturbance, crop residue retention, and crop rotation has been the focus of intensive research in recent years. A study was carried out to determine the effects of tillage and fertilizer on the population densities of plant-parasitic nematodes in maize. Three tillage regimes, (i) basin planting, (ii) rip line seeding, and (iii) conventional tillage, were combined with four fertilizer regimes: (i) no-fertilizer, (ii) low fertilizer rate, (iii) medium fertilizer rate, and (iv) high fertilizer rate. The experiment was arranged as a split plot in randomized complete block design, replicated three times with tillage as the main plot factor and fertilizer as the sub-plot factor. The study was conducted on fine-textured Cambisol soils at Chinhoyi University of Technology farm, Zimbabwe, over two cropping seasons between December 2014 and April 2016. Eight plant-parasitic nematode genera were observed belonging to five groups based on their feeding sites: (i) sedentary endoparasites (*Meloidogyne* and *Rotylenchulus*), (ii) migratory endoparasites (*Pratylenchus*), (iii) semi-endoparasites (*Scutelonema* and *Helicotylenchus*), (iv) ectoparasites (*Xiphinema* and *Trichodorus*), and (v) algal, lichen or moss feeders (*Tylenchus*). In both cropping seasons, semi-endoparasitic nematodes were double under rip line seeding and triple under basin planting compared to conventional tillage. Basin planting had higher plant-parasitic nematode richness than rip line seeding. Nematode densities did not have a measurable effect on maize grain yield. Maize grain yield was higher in rip line seeding (37%) and planting basins (52%) than conventional tillage during 2014/15 cropping season. On the other hand, during 2015/16 cropping season, maize grain yield was 78% and 113% higher in rip line seeding and basin planting, respectively, compared to conventional tillage. The results show that under the environmental and edaphic conditions of this specific study site, semi-endoparasitic nematodes were higher under rip line seeding and basin planting compared to conventional tillage. The authors conclude that (i) plant-parasitic nematode genera exhibited differential responses to different tillage systems but were not affected by fertilizer application, and (ii) in the present study, maize grain yield response under different tillage and fertilizer regimes was overall not related to nematode population density and composition.

### Key words

Nematode-yield relationships, Rip line seeding, Basin planting, Nematode feeding sites.

Cropping systems based on the principle of minimum tillage have been increasingly promoted as a sustainable production approach across the world (Wall et al., 2013; Kassam et al., 2015). On the other hand, the growing global food demand has necessitated the need to increase crop production per unit area through the use of crop intensification practices including application of inorganic fertilizers (Sommer et al., 2014; Vanlauwe et al., 2014). The need to strike a balance between increased crop productivity and sustainable natural resource use has led to the wide testing of cropping practices such as conservation agriculture (Kassam et al., 2009). Conservation agriculture (CA) is a crop production system that simultaneously employs three key principles: (i) minimum mechanical soil disturbance, (ii) permanent or semi-permanent plant residue cover on the soil surface, and (iii) plant diversity through crop rotation (Schier, 2006; Friedrich and Kassam, 2011; Thierfelder et al., 2015). It has been suggested that the full benefits of CA will be realized if combined with management practices such as optimum fertilizer application (Sommer et al., 2014).

Evidence suggests that minimum tillage and plant residue retention in CA enhance abundance and diversity of soil biota including nematodes (Overstreet et al., 2010; Henneron et al., 2014). A recent study in China also found that both organic and inorganic fertilizer application alters soil fauna diversity (Wang et al., 2016). Nematodes live in the soil and are more responsive to mechanical soil disturbance than surface dwelling invertebrates (Wardle et al., 1995). It is thought that tillage and fertilizer application act on nematodes through bottom-up effects by influencing food availability at the lower trophic level or top-down effects by causing direct mortality (Shennan, 2008; Wang et al., 2016).

Enhanced soil biodiversity is evidence of improved soil quality which in turn results in improved cropping system productivity (Wachira et al., 2014; Lehman et al., 2015). Practices such as tillage system, residue management, and fertilizer regime may induce shifts in abundance and composition of soil fauna, including nematodes, through influencing soil physical and chemical properties. Soil-dwelling nematodes perform different roles in the agro-ecosystem, and respond differently to ecosystem disturbance (Neher, 2001; Neher et al., 2005). Whilst most studies in agro-ecosystems have focused on the response of plant-parasitic nematodes to disturbance caused by agricultural land use (Donald et al., 2009; McSorley and Gallaher, 1993), the response and collaborative role of different nematode feeding groups in agro-ecosystems need further investigation.

Plant residue retention on the soil surface under CA, coupled with mineral fertilizer application, may influence micro fauna activity and community composition (Bot and Benites, 1992; Okada and Harada, 2007). However, the results of previous studies on the response of nematode fauna and other soil biota to tillage and fertilizer management seem to be variable, inconclusive, and contradictory (Wardle et al., 1995; Donald et al., 2009; Henneron et al., 2014). Plant-parasitic nematodes are pests of agricultural crops that can cause economic yield losses to crops (Nicol et al., 2011). In maize, nematodes can cause yield losses of 4% to 7% (Norton, 1983, 1984; Reis et al., 2008).

The objectives of the present study were to determine plant-parasitic nematode: (i) population densities, (ii) composition, and (iii) association with maize grain yield under different tillage systems and fertilizer regimes. It was hypothesized that: (i) plant-parasitic nematode population density and diversity increase with increasing intensity of mechanical tillage and rising mineral fertilizer levels, and (ii) maize grain yield response under different tillage and fertilizer regimes is not affected by nematode population density and composition.

## Materials and methods

### Study site description

An experiment was conducted at Chinhoyi University of Technology (CUT) farm, Zimbabwe. The experimental plots were established in December 2012, and the present study commenced in December 2014. The experimental station is located in a subtropical environment (17°20′ S, 30°14′ E, 1140 m above sea level) about 5 km east of Chinhoyi town. Soils are fine-textured *Cambisols* with a pH of about 5.6, mean daily temperature is 20.6°C with mean maximum temperature during summer of 27°C and mean minimum temperature during the cold, dry season of 7°C. Rainfall is unimodal, traditionally falling between November and April with a mean annual precipitation of 850 mm. The rainfall during the study period was 844.3 mm in 2014/15 and 679.7 mm in 2015/16 (Table 1).

### Experimental design and treatments

A split plot randomized complete block design with three replications was used for this study. The main plot factor was tillage system: (i) rip line seeding (RIP), (ii) basin planting (BASIN), and (iii) conventional tillage (CONV), with fertilizer rate as the sub-plot factor

**Table 1. Monthly total rainfall (mm) at Chinhoyi of Technology farm in Zimbabwe in 2014/15 and 2015/16 cropping seasons.**

| Month | 2014/15 (Rainfall in mm) | 2015/16 (Rainfall in mm) |
|---|---|---|
| September | 0 | 0 |
| October | 3.1 | 20.9 |
| November | 22 | 90.9 |
| December | 302.8 | 184.9 |
| January | 339.2 | 53.8 |
| February | 104.9 | 61.8 |
| March | 34.3 | 173.4 |
| April | 38 | 94 |
| May | 0 | 0 |
| June | 0 | 0 |
| July | 0 | 0 |
| August | 0 | 0 |
| Total | 844.3 | 679.7 |

(Table 2). RIP and BASIN represented conservation agriculture (CA) treatments whilst plots in which disc plowing was done represented conventional tillage treatments.

## Agronomic practices

Crop residues were removed after harvesting in the CONV plots and retained at about 30% soil surface cover in CA plots. Basins were made using hand-held planting hoes; each basin measuring about 15 cm length × 15 cm width × 15 cm depth (Thierfelder and Wall, 2010). Some 5 cm of soil were added to the basin after placing the fertilizer, then another 5 cm of soil were added to cover the seed and the planting basins were about 5 cm deep after planting. Basin planting is a minimum tillage system that is commonly used by smallholder farmers who practice CA in Zimbabwe. Rip lines were made to a depth of about 10 to 15 cm using a tractor-mounted ripper. Conventional tillage was done using a disc plow as primary tillage followed by secondary tillage using a disc harrow. Basal fertilizer was applied at planting, about 5 cm below and 5 cm beside the crop seed. Nitrogen top dressing fertilizer (ammonium nitrate, 34.5% N) was applied 4 to 6 weeks after crop emergence depending on soil moisture availability. Most smallholder farmers in Zimbabwe apply 100 to 200 kg ha$^{-1}$ of basal fertilizer

**Table 2. Summary of treatments used in the study at Chinhoyi University farm, Zimbabwe, in 2014/15 and 2015/16 cropping seasons.**

| Factor | Level of factor | Explanation |
|---|---|---|
| Tillage | Basin planting | Each basin (15 × 15 × 15 cm) was done using hoes. The basins were about 10 cm below the rest of the land after planting |
| | Rip line seeding | Marked using a tractor-mounted ripper to a depth of about 15 cm |
| | Conventional tillage | Disc plowed as primary tillage followed by secondary tillage using a disc harrow |
| Fertilizer regime | Control (no fertilizer) | No fertilizer |
| | Micro dosing (low fertilizer) | 100 g of manure per plant position + 80 kg ha$^{-1}$ compound D fertilizer (8 N: 14 $P_2O_5$: 7 $K_2O$) + 80 kg ha$^{-1}$ ammonium nitrate (34.5% N) (total rate: 35.2 kg ha$^{-1}$ N: 12.2 kg ha$^{-1}$ $P_2O_5$: 6.6 kg ha$^{-1}$$K_2O$) |
| | Medium fertilizer rate | 100 kg ha$^{-1}$ compound D fertilizer (8 N: 14 $P_2O_5$: 7 $K_2O$) + 100 kg ha$^{-1}$ ammonium nitrate (34.5% N) (total rate: 41.5 kg ha$^{-1}$ N: 14 kg ha$^{-1}$$P_2O_5$: 7 kg ha$^{-1}$$K_2O$) |
| | High fertilizer rate | 200 kg ha$^{-1}$ compound D fertilizer (8 N: 14 $P_2O_5$: 7 $K_2O$) + 200 kg ha$^{-1}$ ammonium nitrate (34.5% N) (total rate: 83 kg ha$^{-1}$ N: 28 kg ha$^{-1}$ $P_2O_5$: 14 kg ha$^{-1}$ $K_2O$) |

(7% N: 14% $P_2O_5$: 7% $K_2O$) and 80 kg $ha^{-1}$ of ammonium nitrate fertilizer (Kamanga et al., 2001). Both tillage and fertilizer treatments were applied on the same plots from the time the experiments were set up in 2012 and during each maize-growing season. Weeding was done four times during each cropping season using a hand-held hoe – no herbicides were used for weed control. Most farmers who practice CA in Zimbabwe use the hand hoe for controlling weeds (Muoni and Mhlanga, 2014).

Individual sub-plots measured 7.2 m (8 rows) × 8 m (32 plants per row) separated by 1.8 m pathways. Planting was done with the first effective rains in December of each maize-growing season. In all treatments, a medium maturity (130 d to maturity) commercial maize variety ZAP61 was used as the test crop, planted at four seeds per plant position and thinned to two plants per plant position three weeks after crop emergence at a plant spacing of 0.9 m inter-row by 0.5 m intra-row to give a target plant population of 44,444 plants $ha^{-1}$. Maize was grown on the same plots during the two cropping seasons of this study. Measurements were taken from the four central rows of 6 m in length.

## Sampling procedure

Five soil sub-samples from a soil depth of 0 to 20 cm were randomly taken from each sub-plot using a 7.4-cm-diameter field core sampler to make one representative composite soil sample (250 $cm^3$). Sampling was done at planting in December, then at 60 (February) and 120 d (April) after crop emergence (DAE). Three maize plants were also dug and uprooted from each sub-plot at 60 and 120 DAE and the stem cut off at the root crown level. The roots from these three maize plants were used to extract root borne nematodes whilst the above ground plant parts were discarded. Both soil and root samples from each sub-plot were bulked and thoroughly mixed, sealed in a plastic bag and stored in a refrigerator at 4°C until processed for nematode extraction. Sampling was done on the same set of plots during the crop growing season between November and April in 2014/15 and 2015/16 cropping seasons.

## Nematode extraction and identification

Nematodes were extracted from 100 $cm^3$ of soil using the modified sugar centrifugation procedure and from 10 g of root tissue using the maceration centrifugation procedure (Southey, 1986) within two weeks of sampling. Plant-parasitic nematodes were identified to genus level and counted at 40 times magnification with a microscope. Non-plant-parasitic nematodes were all classified as “non-parasitic nematodes” without further assigning them to taxonomic groups. Classification was based on taxonomic characteristics, mainly from morphology and comparative anatomy (Bird and Bird, 1991). The main morphological characteristics used were: (i) body size and death posture, (ii) shape of head and cephalic region, (iii) stylet shape and size, (iv) esophagus and its overlap on the intestines, (v) position of vulva and number of ovaries in case of female nematodes and shape and position of bursa in case of male nematodes, and (vi) shape of tail. The plant-parasitic nematodes were further assigned to feeding site groups based on Yeates et al. (1993).

## Yield determination

Maize grain was harvested from the sub-plot after physiological maturity and dried down in the field, in April, in each maize-growing season. Maize was harvested from 10 randomly selected samples of two rows, each 5 m long, collected from the middle of each plot and grain yield adjusted to 12.5% moisture content and expressed per hectare. All maize stalks and leaves without cobs were weighed at harvest; 10 sub-samples per plot were air dried at least four weeks before the final dry weights were taken and biomass was calculated on an area basis. The rest of the biomass was returned to the field as surface mulch.

## Statistical analysis

Residuals were tested for normality and homogeneity of variances using Shapiro–Wilk’s test for normality and Bartlett’s test for homogeneity of variances, respectively, and were found to require transformation. Nematode count data were therefore log $(x + 1.5)$ transformed to normalize the variances before being subjected to statistical analyses. Plant-parasitic nematode richness, diversity, and evenness (Shannon, 1948; Shannon and Weaver, 1949) were calculated using Paleontological Statistics (PAST) package version 3.14 (Hammer et al., 2001) and used as measures of community composition. Repeated measures in a split plot design were used to analyze the two-year nematode data using the residual maximum likelihood (REML), linear mixed model procedure using GenStat Release for Windows Version 10 (VSN International, 2011). The model included the two treatments and their respective interactions as fixed effects (Fixed model: Constant + Block + Sampling time + Tillage + Fertilizer + Sampling time × Tillage + Sampling time × Fertilizer + Tillage × Fertilizer + Sampling time × Tillage × Fertilizer). The sampling time and all its interactions were considered as random effects, and the results presented in this study are the estimated average values for each year. Yield data for each year were subjected to the split plot analysis of variance using GenStat Release for Windows Version 10 (VSN International, 2011). Nematode counts were used as a covariate in order to better estimate treatment effect on maize grain yield. Treatment means were compared using Fisher's least significant difference (LSD) test at 95% level of significance. Plant-parasitic nematode composition data for each season were subjected to principal component analysis (PCA) using CANOCO 5 (ter Braak and Smilauer, 2012). Nematode populations recovered from soil samples at planting and combined soil and root samples at 120 d after crop emergence were subjected to correlation analyses using PAST version 3.14 (Hammer et al., 2001).

## Results

### Nematode density and composition

About 79,775 nematode specimens were identified combined for all seasons, years, and treatments. These nematodes were composed of non-plant-parasitic nematodes (5,662 specimens) and eight genera of plant-parasitic nematodes (74,113 specimens). Plant-parasitic nematodes recovered in the present study belonged to five groups according to feeding site: sedentary endoparasitic (*Meloidogyne* and *Rotylenchulus*), migratory endoparasitic (*Pratylenchus*), semi-endoparasitic (*Scutellonema* and *Helicotylenchus*), ectoparasitic (*Trichodorus* and *Xiphinema*) and algal, lichen and moss feeding (*Tylenchus*). The root lesion nematodes (*Pratylenchus* spp.) were most predominant (70.5%) followed by *Scutelonema* (14.6%), *Helicotylenchus* (7.3%), and non-plant-parasitic nematodes (7.1%) whilst combined abundances of *Rotylenchulus*, *Tylenchus*, *Meloidogyne*, *Trichodorus*, and *Xiphinema* were only 0.4% of total nematode abundance (Fig. 1).

### Tillage effects on nematode population density

There were no treatment-by-sampling time point interactions. Mean densities of nematodes that were extracted from the soil were significantly affected by tillage while those recovered from maize roots did not respond to tillage treatments (Table 3) in both cropping seasons. In 2014/15 cropping season, population densities of *Helicotylenchus* were higher under rip line seeding and basin planting where crop residues were left on the soil surface compared to conventional tillage where maize residues were removed before plowing (Table 3). In the same cropping season, total nematode (plant-parasitic and non-parasitic combined) population densities in the soil were higher under basin planting compared to rip line seeding and conventional tillage. However, tillage had no effect on *Helicotylenchus* and total nematode population densities in 2015/16 cropping season. Also, in 2015/16 cropping season non-plant-parasitic nematodes were the lowest under rip line seeding but were not affected by tillage in 2014/15 season (Table 3). Population densities of *Scutellonema* in the soil were consistently higher in basin planting and rip line seeding compared to conventional tillage in both 2014/15 and 2015/16 cropping seasons (Table 3). Based on specimens recovered from both soil and root samples, the effects of tillage on the populations densities of *Pratylenchus*, *Rotylenchulus*, and *Tylenchus* were not significant (Table 3).

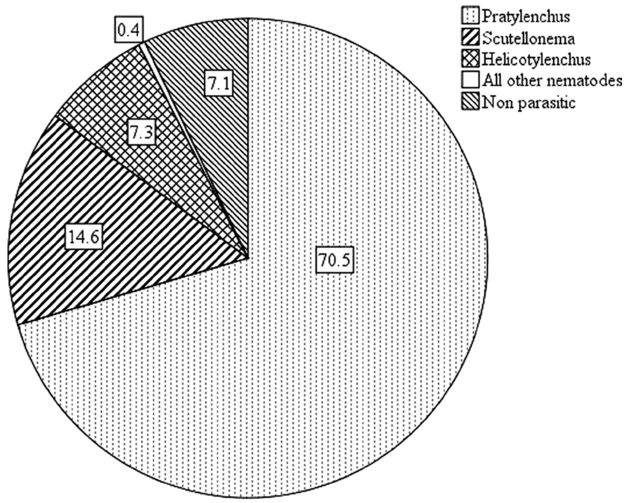


Figure 1: Percentage composition of total soil and root borne nematodes from soils and roots collected in tillage and fertilizer split plot experiment at Chinhoyi University of Technology farm, Zimbabwe, combined for all time points and treatments in the 2014/15 and 2015/16 seasons.

When nematodes were classified into feeding site groups, semi-endoparasites were almost double in rip line seeding and triple in basin planting compared to conventional tillage in both 2014/15 and 2015/16 cropping seasons (Table 4). However, tillage

**Table 3. Tillage and fertilizer effects on population density of nematodes recovered from 100 cm³ of soil and 10 g of maize root tissue at Chinhoyi University farm, Zimbabwe, in 2014/15 and 2015/16 cropping seasons.**

| | Tillage treatments | | | | Fertilizer treatments | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Basin | Rip | Conv | SED | NF | LF | MF | HF | SED |
| 2014/15 season | | | | | | | | | |
| *Soil* | | | | | | | | | |
| *Helicotylenchus* sp. | 55[b] | 30[b] | 22[a] | 12.20 | 27 | 42 | 27 | 45 | 14.09 |
| *Pratylenchus* sp. | 22 | 35 | 40 | 13.59 | 37 | 41 | 28 | 23 | 15.69 |
| *Rotylenchulus* sp. | 1 | 0 | 0 | 0.32 | 1 | 0 | 0 | 0 | 0.37 |
| *Scutellonema* sp. | 112[b] | 78[b] | 37[a] | 17.90 | 81 | 78 | 75 | 68 | 20.67 |
| Non- parasitic | 44 | 39 | 38 | 4.583 | 41 | 35 | 40 | 46 | 5.292 |
| Total nematodes | 233[b] | 182[a] | 137[a] | 24.97 | 186 | 197 | 171 | 182 | 28.84 |
| *Root* | | | | | | | | | |
| *Pratylenchus* sp. | 255 | 302 | 494 | 122.90 | 334 | 428 | 411 | 229 | 141.90 |
| 2015/20 season | | | | | | | | | |
| *Soil* | | | | | | | | | |
| *Helicotylenchus* sp. | 27 | 37 | 19 | 15.73 | 21 | 31 | 36 | 22 | 18.17 |
| *Pratylenchus* sp. | 19 | 23 | 25 | 6.47 | 23 | 17 | 31 | 19 | 7.47 |
| *Rotylenchulus* sp. | 3 | 4 | 4 | 3.71 | 4 | 6 | 3 | 1 | 4.28 |
| *Scutellonema* sp. | 74[b] | 52[b] | 21[a] | 14.58 | 37 | 54 | 54 | 49 | 16.83 |
| *Tylenchus* | 1 | 0 | 0 | 0.47 | 1 | 0 | 1 | 1 | 0.55 |
| Non- parasitic | 23[b] | 10[a] | 21[b] | 4.91 | 14 | 12 | 23 | 22 | 5.67 |
| Total nematodes | 148[b] | 126[ab] | 88[a] | 29.04 | 1001 | 120 | 147 | 115 | 33.53 |
| *Root* | | | | | | | | | |
| *Pratylenchus* sp. | 889 | 354 | 917 | 284.40 | 643 | 779 | 638 | 820 | 328.40 |

Means with the same letter within the same row for the same factor (tillage or fertilizer) are not significantly different at $P \leq 0.05$ (mean ± standard error of difference (SED) between means); rip line seeding (rip lines); basin planting (basins); conventional tillage (conv) ); no fertilizer (NF); low fertilizer (LF); medium fertilizer (MF); high fertilizer (HF). Mean separation is only shown if treatment effect was significant based on analysis of variance ($P \leq 0.05$). Means are estimated average values for each cropping season.

had no effect on algal feeders, ectoprasites, sedentary endoparasites and migratory endoparasites. In 2014/15 cropping season, plant-parasitic nematode richness was significantly lower under rip line seeding compared to basin planting, but was not affected by tillage in 2015/16 season (Table 5). In contrast, tillage had no effect on plant-parasitic nematode evenness and Shannon indices.

## Effects of fertilizer on nematode population density

Fertilizer had no effects on densities of nematodes at both generic and feeding site group levels. Furthermore, fertilizer had no effect on all the three diversity parameters (richness, evenness, and Shannon–Weaver indices) during the two cropping seasons of

**Table 4. Tillage and fertilizer effects on population density of different nematode feeding site groups recovered from 100 cm³ of soil and 10 g of maize roots at Chinhoyi University farm, Zimbabwe, in 2014/15 and 2015/16 cropping seasons.**

| | Tillage treatments | | | | Fertilizer treatments | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Basin | Rip | Conv | SED | NF | LF | MF | HF | SED |
| 2014/15 season | | | | | | | | | |
| *Soil* | | | | | | | | | |
| Sedentary endoparasites | 1 | 0 | 0 | 0.31 | 1 | 0 | 0 | 0 | 0.36 |
| Migratory endoparasites | 22 | 35 | 40 | 13.59 | 37 | 41 | 28 | 23 | 15.69 |
| Semi-endoparasites | 167[b] | 108[b] | 59[a] | 25.42 | 108 | 121 | 103 | 114 | 29.35 |
| Ectoparasites | 0 | 0 | 0 | 0.18 | 0 | 0 | 0 | 0 | 0.21 |
| *Root* | | | | | | | | | |
| Migratory endoparasites | 255 | 302 | 494 | 122.90 | 334 | 428 | 411 | 229 | 141.90 |
| Semi-endoparasites | 1 | 0 | 1 | 1.04 | 12 | 0 | 0 | 0 | 1.20 |
| 2015/16 season | | | | | | | | | |
| *Soil* | | | | | | | | | |
| Algal feeders | 1 | 0 | 0 | 0.47 | 1 | 0 | 1 | 1 | 0.55 |
| Sedentary endoparasites | 3 | 4 | 4 | 3.71 | 4 | 6 | 3 | 1 | 4.28 |
| Migratory endoparasites | 19 | 23 | 25 | 6.47 | 23 | 17 | 31 | 19 | 7.471 |
| Semi-endoparasites | 105[b] | 92[b] | 43[a] | 24.58 | 63 | 91 | 93 | 73 | 28.38 |
| *Root* | | | | | | | | | |
| Migratory endoparasites | 889 | 354 | 917 | 284.40 | 643 | 779 | 638 | 820 | 328 |

Means with the same letter within the same row for the same factor (tillage or fertilizer) are not significantly different at $P \leq 0.05$ (mean ± standard error of difference (SED) between means); rip line seeding (rip lines); basin planting (basins); conventional tillage (conv); no fertilizer (NF); low fertilizer (LF); medium fertilizer (MF); high fertilizer (HF). Mean separation is only shown if treatment effect was significant based on analysis of variance ($P \leq 0.05$). Means are estimated average values for each cropping season.

this study. There was no tillage × fertilizer interaction in both 2014/15 and 2015/16 cropping seasons.

## Maize grain yield

In general, maize grain yield increased with decreasing intensity of mechanical soil disturbance in both seasons (Table 6). Maize grain yield was higher under BASIN (85%) and RIP (74%) than CONV during 2014/15 cropping season. In 2015/16 cropping season, maize grain yield was higher in BASIN (111%) and RIP (63%) than CONV. Fertilizer application had no effect on maize grain yield in both 2014/15 and 2015/16 cropping seasons (Table 6).

## Association between management practices and response variables

Projection of the principal component analysis (PCA) showed some association among most nematode genera except *Pratylenchus* (Figs. 2,3). Axis 1 explained 54.33% and 72.5% variability in 2014/15 and 2015/16 cropping seasons, respectively. On the other hand, Axis 2 explained 28.18% and 16.17% variability in 2014/15 and 2015/16 cropping seasons, respectively. In both PCA diagrams, the first axis separates conventional tillage (CONV) plots from minimum tillage (BASIN and RIP) plots. The second axis distinguishes unfertilized (NF) plots

**Table 5. Mean plant-parasitic diversity across different tillage and fertilizer treatments at Chinhoyi University farm, Zimbabwe, in 2014/15 and 2015/16 cropping seasons.**

| | Basin | Rip | Conv | SED | NF | LF | MF | HF | SED |
|---|---|---|---|---|---|---|---|---|---|
| 2014/15 season | | | | | | | | | |
| Evenness index | 0.62 | 0.65 | 0.60 | 0.03 | 0.62 | 0.63 | 0.64 | 0.61 | 0.03 |
| Richness index | 5.08[b] | 4.64[a] | 4.97[ab] | 0.13 | 4.74 | 5.04 | 4.82 | 5.00 | 0.15 |
| Shannon index | 1.12 | 1.07 | 1.06 | 0.05 | 1.04 | 1.12 | 1.10 | 1.08 | 0.06 |
| 2015/16 season | | | | | | | | | |
| Evenness index | 0.66 | 0.66 | 0.71 | 0.02 | 0.67 | 0.66 | 0.68 | 0.68 | 0.03 |
| Richness index | 5.33 | 5.21 | 5.17 | 0.19 | 5.17 | 5.11 | 5.28 | 5.39 | 0.22 |
| Shannon index | 1.23 | 1.21 | 1.29 | 0 | 1.2 | 1.2 | 1.3 | 1.3 | 0 |

Means with the same letter within the same row for the same factor (tillage or fertilizer) are not significantly different at $P \leq 0.05$ (mean ± standard error of difference (SED) between means); rip line seeding (rip lines); basin planting (basins); conventional tillage (conv) ); no fertilizer (NF); low fertilizer (LF); medium fertilizer (MF); high fertilizer (HF). Mean separation is only shown if treatment effect was significant based on analysis of variance ($P \leq 0.05$). Means are estimated average values for each cropping season.

**Table 6. Mean maize grain yield in kg ha$^{-1}$ as affected by tillage and fertilizer treatments at Chinhoyi University farm, Zimbabwe, in 2014/15 and 2015/16 cropping seasons.**

| | Tillage treatments | | | | Fertilizer treatments | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Cropping season | Basins | Rip | Conv | SED | NF | LF | MF | HF | SED |
| 2014/15 | 6,846[b] | 6,449[b] | 3,697[a] | 1,041.84 | 5,022 | 6,200 | 5,459 | 5,975 | 709.90 |
| 2015/16 | 9,672[c] | 7,463[b] | 4,580[a] | 635.33 | 5,945 | 7,755 | 7,842 | 7,412 | 1,048.66 |

Means with the same letter within the same row for the same factor (tillage or fertilizer) are not significantly different at $P \leq 0.05$ (mean ± standard error of difference (SED) between means); rip line seeding (rip lines); basin planting (basins); conventional tillage (conv) ); no fertilizer (NF); low fertilizer (LF); medium fertilizer (MF); high fertilizer (HF). Mean separation is only shown if treatment effect was significant based on analysis of variance ($P \leq 0.05$). Means are estimated average values for each cropping season. Nematode counts were used as a covariate.

from fertilized (LF, MF, and HF) plots. The association between fertilizer application rate and nematode genera was not consistent during the two cropping seasons. In both seasons, most nematodes, except *Pratylenchus*, showed an affinity for the basin planting treatment, with semi-endoparasites (*Helicotylenchus* and *Scutellonema*) and non-plant-parasitic nematodes being more closely associated with the treatment. Correlation analysis showed that during 2014/15 cropping season, maize grain yield was significantly and positively correlated with pre-planting populations of *Helicotylenchus* and total

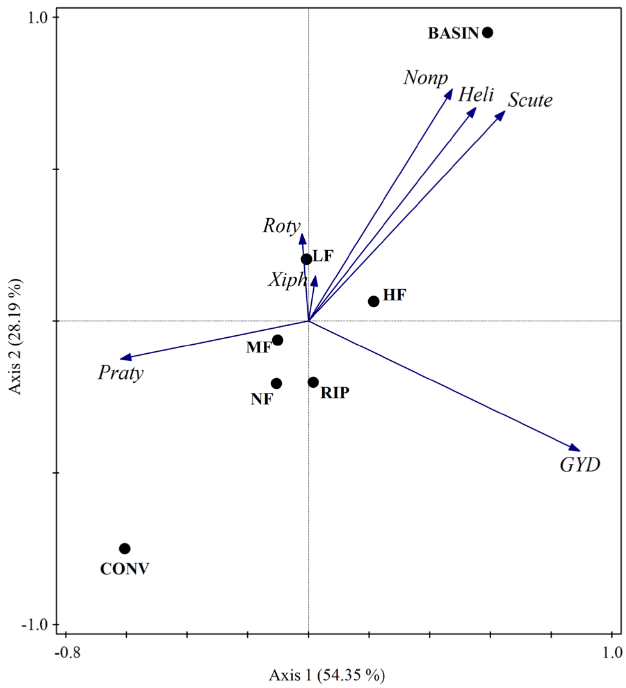


Figure 2: Biplot representing the principal component analysis (PCA) performed on nematodes assemblages (Heli (*Helicotylenchus*), Nonp (non-plant-parasitic nematodes), Scute (*Scutellonema*), Roty (*Rotylenchulus*), Xiph (*Xiphinema*), Tyle (*Tylenchus*), Trich (*Trychodorus*), Melo (*Meloidogyne*), and Praty (*Pratylenchus*)) and maize grain yield (GYD) collected from 36 plots that were subjected to three tillage systems (basin NT (BASIN), rip line NT (RIP), and conventional tillage (CONV)) and four fertilizer regimes (no-fertilizer (NF), micro dosing (LF), medium fertilizer (MF), and high fertilizer (HF)) at Chinhoyi University farm, Zimbabwe, in 2014/15 cropping season. Treatments are depicted using arrows while nematodes are depicted with dots.

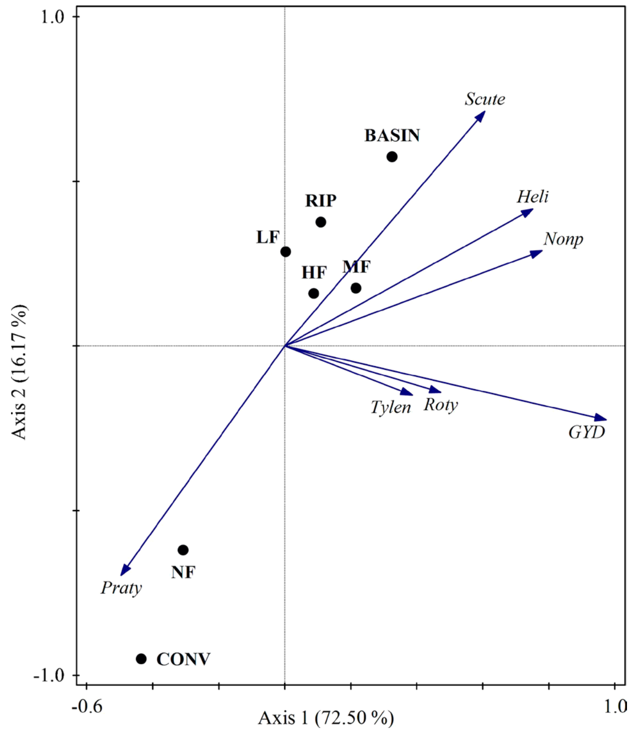


Figure 3: Biplot representing the principal component analysis (PCA) performed on nematodes assemblages (Heli (*Helicotylenchus*), Nonp (non-plant-parasitic nematodes), Scute (*Scutellonema*), Roty (*Rotylenchulus*), Tylen (*Tylenchus*), and Praty (*Pratylenchus*)) and maize grain yield (GYD) collected from 36 plots that were subjected to three tillage systems (basin NT (BASIN), rip line NT (RIP), and conventional tillage (CONV)) and four fertilizer regimes (no-fertilizer (NF), micro dosing (LF), medium fertilizer (MF), and high fertilizer (HF)) at Chinhoyi University farm, Zimbabwe, averaged across all sampling points in 2015/16 cropping season. Treatments are depicted using arrows while nematodes are depicted with dots.

plant-parasitic nematodes ($r$ = 0.51 and $r$ = 0.37, respectively; Table 7). However, these correlations were not evident 120 DAE (2014/15) and throughout 2015/16 cropping season. Maize grain yield was not significantly correlated with *Pratylenchus* and *Scutellonema* in both 2014/15 and 2015/16 cropping seasons (Table 7).

## Discussion

We found consistently higher densities of *Scutellonema* under rip line seeding and basin planting compared to conventional tillage but the effect of tillage on *Helicotylenchus* and total nematodes was not consistent between the two cropping seasons. Drier

**Table 7. Correlation (Pearson *r*) between maize grain yield and plant-parasitic nematode population in the soil and on roots (log (*x* + 2.5)–transformed) before planting and 120 d after crop emergence at Chinhoyi University farm, Zimbabwe, in 2014/15 and 2015/16 cropping seasons.**

| Sampling time point | *Pratylenchus* | *Scutellonema* | *Helicotylenchus* | Total nematode |
|---|---|---|---|---|
| 2014/15 cropping season | | | | |
| Pre-planting | −0.19 | 0.23 | 0.51** | 0.37* |
| 120 DAE | 0.04 | 0.19 | 0.03 | 0.27 |
| 2015/16 cropping season | | | | |
| Pre-planting | −0.14 | 0.24 | 0.19 | 0.26 |
| 120 DAE | −0.03 | 0.06 | −0.11 | −0.03 |

Values are correlation coefficients between maize grain yield and plant-parasitic nematode density. Days after crop emergence (DAE). *, **Represent significance at $P \leq 0.05$ and 0.01, respectively.

conditions that prevailed in 2015/16 cropping season probably masked the effects of tillage on *Helicotylenchus* and total nematodes. The presence of plant residue on the soil surface in minimum tillage plots (basin planting and rip line seeding) regulates soil temperature and conserves moisture (Neher, 2010; Thierfelder and Wall, 2009, 2010). On the other hand, the survival rate of the *Scutellonema* has been shown to be enhanced by increased soil temperature conditions (Demeure et al., 1980; Baujard and Martiny, 1995). In line with the above understanding, our results suggest that basin planting and rip line seeding create a favorable microhabitat for growth and development of both host plants and plant-parasitic nematodes, leading to increased population densities of certain genera such as *Scutellonema*. Both *Scutellonema* and *Helicotylenchus* have some species that are able to switch from endo- to ecto-parasitism and vice versa (Demeure et al., 1980). The two genera are important parasites of some agricultural crops such as cowpea (*Vigna unguiculata*), sunflower (*Helianthus annuus*), cassava (*Manihot esculenta*), and sweet potatoes (*Ipomoea batatas*). Soil biota microhabitats are more stable under minimum tillage conditions than CONV, enabling sustained nematode activity and perpetuation.

The main effects of tillage on *Pratylenchus*, *Tylenchus, Rotylenchulus*, and non-parasitic nematode densities are somewhat contrary to Govaerts et al. (2006) and Brmez et al. (2006) who observed increased populations of *Pratylenchus* under minimum tillage. Conventional tillage (CONV) uproots and sometimes fragments plant roots, destroying the feeding substrates for root-feeding nematodes and is therefore expected to reduce these plant parasites. *Pratylenchus* are, however, reported to be capable of successfully surviving on fragmented plant roots and maintain stable populations in the soil (Okada and Harada, 2007). This attribute of *Pratylenchus* may be one of the reasons for the lack of difference in their density between minimum tillage and CONV treatments. This can also be seen as resilience of lesion nematode to thrive in CONV and low nutrient soils. Considering that lesion nematodes are a serious problem in agriculture then moving to a minimum tillage system could be more beneficial. Results of the effect of tillage treatments on the Shannon–Weaver and evenness indices agreed with the findings by Mazvimavi and Twomlow (2009) which showed a similar trend on nematode community structure. Increased species richness in minimum tillage plots during the 2014/15 cropping season was probably due to recruitment of new species under stable and undisturbed sites as opposed to highly disturbed microhabitats under conventional tillage. However, this trend disappeared in 2015/16 presumably because of the drier conditions which prevailed during this season compared to the preceding cropping season.

Non-plant-parasitic nematodes are composed of a large number of nematode taxonomic and feeding groups such as fungivores, bacterivores, and predators. It is therefore difficult to make meaningful conclusions without further classifying non-parasitic nematodes into relevant taxonomic and feeding functional groups and then determining their response to management practices. This study found no effect of fertilizer on plant-parasitic nematode taxonomic and feeding site groups. Contrary to Walker (1969), Andren and Lagerlof (1983), and Rahman et al. (2007) who reported reduction in plant-parasitic nematode populations with fertilizer application, our results suggest that fertilizer has no effect on nematode taxonomic and feeding site groups under the environmental and edaphic conditions of this specific study.

The effect of tillage on maize grain yield corroborates observations previously made by other researchers who found higher maize grain yield under CA than conventional tillage (Thierfelder and Wall, 2012; Thierfelder et al., 2015, 2016; Mupangwa et al., 2016). The results of principal component analysis (PCA) suggest that fertilizer application and basin planting are associated with plant-parasitic nematode assemblages compared to CONV and NF. This observation contradicts Govaerts et al. (2006) who found more nematodes under CONV than minimum tillage. Fertilizer application probably influences nematode population densities through bottom-up effects, by enhancing food availability at the lower trophic level. Fertilizer application enhances nutrient provision for primary producers which will in turn have a cascading effect on organisms higher up the soil food web including nematodes (House and Brust, 1989).

Furthermore, the principal components analysis revealed that there was no association between grain yield and plant nematode population densities, and this result agreed with Govaerts et al. (2006). Positive correlations between maize grain yield and both *Helicotylenchus* and total plant-parasitic nematodes during 2014/16 cropping season are suggestive that these nematodes caused increased maize grain yield but these effects are not explainable. These results were contrary to Youssef (2013) who reported negative correlation between maize grain yield and population densities of *Helicotylenchus* and other nematodes. However, no meaningful conclusion can be made from this inconsistent observation without further investigation. Interestingly, whilst *Pratylenchus* have been shown to cause grain yield reductions in maize (Kagoda, 2010), our results found no correlation between this genera and maize grain yield.

Minimum tillage is practiced in different forms including direct drilling, dibbling, basins, and/or rip lines. Our results revealed that the effect of minimum tillage cannot be generalized since these minimum tillage planting methods seem to have different impacts on plant-parasitic nematode populations with most nematodes expressing a high affinity for basin planting. It is important to note that even though our study site represents a system in the transitional stages (3-4 years) of CA, the results agree with studies previously conducted on older cropping cycles, for example Govaerts et al. (2006). We can therefore suggest that the impact of tillage and fertilizer management practices on plant-parasitic nematodes can be traced back to the so-called initial cropping cycles that were proposed by Yeates et al. (1999).

We conclude that under the environmental conditions and the specific results obtained in this study: (i) nematode population density responds differently to different levels of tillage but is not affected by fertilizer management, (ii) the effect of tillage on plant-parasitic nematode richness is not consistent whilst neither tillage nor fertilizer has an effect on plant-parasitic nematode evenness and Shannon–Weaver indices, and (iii) maize grain yield was not correlated with population densities of some important plant-parasitic nematodes, such as *Pratylenchus* whilst the positive correlation between maize gain yield and *Helicotylenchus* population density was observed in one out of two seasons. Further research is required to determine (i) the impact of tillage and fertilizer management on the abundance of non-parasitic nematode functional groups and their subsequent suppression of plant-parasitic groups, and (ii) the short- and long-term impacts of tillage and fertilizer on antagonistic nematode faunae.

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