

## Research Article

# Influence of Spiral Nematodes (*Scutellonema* spp.) on Maize Performance and Growth under Natural Field Infestation in Mwea, Kenya

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Maize (*Zea mays* L.) is a significant food security crop in Kenya and it serves as the main source of nutrition and calories among the small-holder farmers. The overall maize yields per hectare have been fluctuating in the past few years posing a great risk to food security. Among the stress factors associated with maize yield loss include plant-feeding nematodes. In this regard, this study was conducted to evaluate the impacts of plant-parasitic nematodes specifically *Scutellonema* spp. under field conditions on maize performance in Mwea, Kenya. The field trials were laid out in a randomized complete block design with each treatment comprising of four replicates. The treatments included maize plots without nematicide (MPWN) and control plots treated with nematicide. The experiments were conducted in two trials. Soil samples were taken at a 0–20 cm depth at monthly intervals during 2018–2019. During the two trials, MPWN recorded significantly lower plant height and number of leaves per plant. Correlation analysis revealed a significant negative relationship between *Scutellonema* abundance with leaf area index, plant height, and number of functional leaves in MPWN during the 2019 trial. This implies that high population of *Scutellonema* perhaps has the potential to affect leaf area index, plant height, number of leaves per plant, which are aspects that in turn influence maize productivity. Therefore, holistic sustainable management practices to control *Scutellonema* spp. in maize fields such as use of organic amendments, resistant maize cultivars, and antagonistic organisms are crucial in order to alleviate negative impacts linked to *Scutellonema* infestation.

## 1. Introduction

Maize (*Zea mays* L.) plays an integral role in national food security in Kenya by providing 36% and 65% of overall and staple food calories that are consumed, respectively [1, 2]. The area occupied by maize production in Kenya declined slightly from 2.12 (million hectares) MHa in 2013 to 2.1 MHa in 2014 [2]. Moreover, the overall maize yields per ha have been fluctuating in Kenya and also in other developing countries since the year 2010 [3]. Maize yield fluctuations are attributed to persistent biotic and abiotic constraints [4]. Previous studies have proposed several biotic constraints that affect maize yields which include plant-feeding nematodes such as lesion nematodes (*Pratylenchus* spp.), root-knot nematodes (*Meloidogyne* spp.), and spiral nematodes (*Scutellonema* spp.) [5–7].

Monitoring plant performance during different growth developmental stages provides valuable information in crop management. This information in combination with other relevant factors is of vital importance to farmers by helping them in implementing reliable and timely interventions [8]. Recently, it has been found that plant dynamics including growth and reproduction are strongly affected by interactions between plant roots and the microflora of ground such as plant-feeding nematodes, particularly at local spatial scales [9, 10]. Previous reported literature showed that soil diversity and its flora can impact plant growth and performance in positive and negative ways, either directly through various mechanisms such as herbivory, symbiosis, and pathogenesis [11–13] or indirectly through predation of plant grazing organisms or fluctuations in the availability of soil nutrient [9]. Therefore, understanding such interactions

between maize and parasitic nematodes can provide crucial information on their management and enhancement of crop productivity. It has been demonstrated that *Scutellonema* spp. is one of the ubiquitous polyphagous belowground herbivorous nematodes of economic importance to many food crops of economic significance including maize [14–17]. Bridge [14] reported that *Scutellonema* spp. feeds ectoparasitically on plant roots before invading the deeper cortical layers and becoming migratory endoparasites. However, such studies on interactions between plant root and belowground herbivores are scarce in Kenya despite the economic relevance of ground herbivores to crop productivity.

In order to understand the maize plants performance, this study assessed various growth parameters which included leaf area index, plant height, ear height, number of functional leaves per plant, and grain yield in plots under natural infestation by spiral nematodes particularly *Scutellonema* spp. whose economic importance on maize growth and productivity has not yet been ascertained in Kenya [5, 6]. Herein, we also looked at soil physicochemical properties, minimum temperature, and average rainfall so as to assist in understanding the prevailing conditions of the study site.

## 2. Methodology

**2.1. Site Description.** This study was performed in two trials in 2018 (October–January) and 2019 (January–April) at Nyangati, Mwea subcounty, Kenya (longitude 0°36'45.5"S and latitude 37°21'18.0"E). The region is located in agro-ecological zone 3 of the lowland altitude at 1202 m above sea level. The soil type in the area is characterized as vertisols [18] and receives two rainy seasons per year, with long rains that average about 900 mm (from March to May) while short rains average to 800 mm (from October to November). The minimum temperature and the average rainfall recorded in the area during the study period are given in Table 1, whereas soil physicochemical characteristics analyzed at the site to a depth of 25 cm are shown in Table 2.

**2.2. Experimental Design.** The experiment comprised of two treatments consisting of control plots (treated with nematicide—Confidor WG 70 applied at the rate of 800 litres per hectare at planting) and maize plots without nematicide (MPWN). The field trials were set in a completely randomized block design (CRBD) with each treatment consisting of four replicates. The size of each plot was 36 m<sup>2</sup> (6 × 6 m), and each plot and block were separated by 1 m and 1.5 m buffer zone, respectively. Two maize (*Zea mays*; variety Katumani) seeds per hill were planted in rows with a spacing of 75 cm between rows and 30 cm between maize hills. Watering was done after every seven days to allow for luxuriant growth of maize foliage. All other agronomic practices including hand pulling of weeds and hoeing were done uniformly for all the treatments.

TABLE 1: Minimum temperature and rainfall data at Nyangati study site in Mwea subcounty, Kenya.

Month	Minimum temperature (°C)	Average rainfall (mm)
October	14.6	51.5
November	15.5	100.1
December	14.7	109.2
January	13.6	46.5
February	21.6	21.6
March	12.0	33
April	14.0	32

TABLE 2: Soil physicochemical characteristics at Nyangati study site in Mwea subcounty, Kenya.

Soil property	Mean	Standard error
Soil pH	5.85	0.057
Total nitrogen (%)	0.18	0.003
Total organic carbon (%)	2.03	0.050
Phosphorus (ppm)	16.67	1.667
Potassium (me%)	0.75	0.096
Calcium (me%)	6.07	0.788
Magnesium (me%)	3.63	0.135
Manganese (me%)	0.97	0.114
Copper (ppm)	2.95	0.090
Iron (ppm)	23.50	3.239
Zinc (ppm)	0.20	0.029
Sodium (me%)	0.16	0.074
Sand (%)	46.67	3.712
Clay (%)	44.00	4.000
Silt (%)	9.33	0.667

**2.3. Sampling and Data Collection.** Data were taken before planting (0 days) and 30, 60, and 90 days after planting. Plant data were recorded from five randomly selected plants per plot. In particular, leaf area index (LAI), plant height (PHt), number of functional leaves per plant (NoLP), main ear height, and grain yields were recorded. Leaf area index was estimated through digital hemispherical photography using a smartphone application (VitiCanopy) [19]. Plant height (cm) was assessed from the base of the plant to the highest point of the arch of the uppermost leaf whose tip was pointing down, while ear height was assessed from the base of the plant to the main ear using a tape measure graduated in centimeter. The number of functional leaves in each plant was evaluated by a visual count of the green leaves using the leaf collar method [20]. The LAI, PHt, and NoLP were recorded at 30, 60, and 90 days after planting while the main ear height was recorded at 60 and 90 days after planting. After 90 days, the grain yield in tons per hectare (t/ha) was computed from randomly selected cobs using a weighing balance [21]. The grain yield obtained per plot was adjusted at 12.5% moisture content as described by Badu-Apraku et al. [22] as follows:

$$\begin{aligned} & \text{yield (at 12.5\% grain moisture)} \\ &= \text{grain yield} \times \frac{100 - \text{actual grain moisture\%}}{87.5} \end{aligned} \quad (1)$$

Soil samples were taken at preplanting (0 days), 30 days, 60 days, and at maturity (90 days). Five soil subsamples per plot, each measuring 100 g, were collected randomly using an auger of diameter 3.5 cm, at a depth of 0–20 cm using a cross diagonal sampling pattern. The subsamples were then bulked into a 500 g composite sample for each plot and placed in well-labeled plastic bags and sealed [23].

**2.4. Weather Data and Soil Physicochemical Property Analysis.** Minimum temperature and average rainfall data were obtained from the Kenya Meteorological Department, Nairobi, Kenya. Soil pH, total nitrogen, total organic carbon, phosphorus, calcium, magnesium, manganese, copper, iron, zinc, sodium, sand, clay, and silt were evaluated at the Kenya Agriculture and Livestock Research Organization, Kenya.

**2.5. Nematode Extraction and Identification.** Nematodes were extracted from 250 g soil samples derived from 500 g composite sample using the modified Baermann technique [24]. After extraction, 10 ml of nematode suspension was fixed by adding an equal volume of fixative (golden solution) which was prepared as described by Hooper et al. [24]. The nematodes were counted from subaliquots of the extraction under DM750 Leica compound microscope and densities computed as described in [23]. Subsequently, nematodes were identified to genus level based on their morphological characteristics.

**2.6. Data Analysis.** To explore statistical differences in leaf area index (LAI), plant height, number of leaves per plant, ear height, grain yield, and abundance of *Scutellonema*, data were subjected to ANOVA test using package *vegan* in R software [25]. In order to meet the assumptions of statistical analysis, transformation of data was done where necessary prior to data analysis. The treatment means separation was implemented by the Tukey HSD test using package *agricolae* [26]. To investigate how LAI, plant height, and number of leaves per plant relate to *Scutellonema* abundance, Pearson correlation analysis was performed using the package *ggpubr* [27].

### 3. Results

In the current study, the data collected during the two trials revealed that leaf area index (LAI) did not differ significantly between MPWN treatments and the control plots treated with nematicide. The lowest value of LAI ( $1.43 \pm 0.230$ ) was recorded from MPWN in 2018, whereas during 2019, the highest value ( $1.66 \pm 0.299$ ) was observed in MPWN. Data pertaining to the plant height clearly showed a significant difference between MPWN relative to the control during 2018–2019. The minimum plant height was recorded in MPWN ranged between  $112.11 \pm 22.249$  and  $92.55 \pm 21.220$  in cm during the two trials. Similarly, the lowest number of leaves per plant ranging between  $6.66 \pm 1.082$  and  $7.44 \pm 1.260$  in cm was recorded in MPWN treatments in both trials. The mean ear height in maize plants for

2018–2019 was lower in MPWN, although the data for 2018 were not statistically different at  $p = 0.255$ . Additionally, the lowest grain yields (t/ha) during 2018–2019 were also observed in MPWN, but the yield data for 2018 were not significantly different at  $p = 0.528$ . The abundance of *Scutellonema* was low in MPWN in trial one (2018), whereas during 2019 it was higher in MPWN, but there was no significant difference in *Scutellonema* abundance in 2018 ( $p = 0.634$ ) and 2019 ( $p = 0.277$ ) data. Overall, MPWN treatments showed relatively lower measures of plant height, number of functional leaves per plant, mean ear height, and grain yields compared to control amended with nematicide (Table 3).

Further analyses revealed that leaf area index (LAI), plant height, and the number of leaves per plant were positively increased but weakly correlated with *Scutellonema* density in MPWN at  $R \leq 0.37$  during trial one (2018), and the correlation was not statistically different ( $p > 0.05$ ) (Table 4 and Figures 1(a), 2(a), and 3(a)). However, during the second trial (2019), MPWN showed a significant negative correlation between LAI, plant height, and the number of functional leaves per plant with the *Scutellonema* abundance at  $R \geq -0.52$  and  $p < 0.05$  (Table 4 and Figures 1(b), 2(b), and 3(b)). For the control plots, during trial one (2018), the relationship between *Scutellonema* population and LAI, plant height, and the number of functional leaves was negative at  $R \geq -0.93$  and  $p < 0.001$  (Table 4 and Figures 4(a), 5(a), and 6(a)), while for the second trial (2019), it was negatively correlated for plant height and number of leaves ( $R \geq -0.31$ ,  $p > 0.05$ ), but for LAI it was positively correlated at  $R = 0.65$  and  $p = 0.0060$  (Table 4 and Figures 4(b), 5(b), and 6(b)).

### 4. Discussion

The current study was carried out to evaluate maize performance, as provided by different parameters, in a field infested with *Scutellonema* spp. Leaf area index (LAI) is an important plant characteristic which may affect plant productivity and is a significant indicator of plant growth, grain yield, and biomass production [21]. It also relates to the ability of the maize canopy to absorb sunlight and fix carbon. In comparison with an ideal maize LAI of 3.5 to 4.0 which indicates efficient sunlight absorption [28], our LAI values ranged between  $1.43 \pm 0.230$  and  $1.66 \pm 0.299$ . This implies that the maize plants in both MPWN and control treatments absorbed a minimal amount of solar radiation. Previous findings have concluded that leaf area index is a determinant of yield loss due to damage by nematodes [29]. In this study, the lowest and highest value of LAI in MPWN clearly corresponded with the lowest and highest density of *Scutellonema* abundance for 2018 and 2019, respectively, although they were not statistically different. In addition, during 2019, the correlation analysis showed a significant negative relationship between LAI and *Scutellonema* density in MPWN. These results collaborate the findings reported by Roderick et al. [30] and Tripathi et al. [29], who noted a significant correlation between the density of *Radopholus*

TABLE 3: Leaf area index (LAI), plant height (PHT), number of leaves per plant (NoLP), main ear height, grain yield, and *Scutellonema* density in control plots (treated with nematicide) and MPWN (maize plots with no nematicide) during trial one (2018) and trial two (2019) in Nyangati study site, Mwea subcounty.

Parameter	Year	Control Mean $\pm$ SE	MPWN Mean $\pm$ SE	F value	p value
LAI	2018	1.51a $\pm$ 0.243	1.43a $\pm$ 0.230	0.595	0.448
	2019	1.65a $\pm$ 0.391	1.66a $\pm$ 0.299	3.619	0.069
PHT (cm)	2018	114.05a $\pm$ 21.988	112.11b $\pm$ 22.249	4.649	0.041*
	2019	112.30a $\pm$ 25.569	92.55b $\pm$ 21.220	168.135	<0.001***
NoLP	2018	7.15a $\pm$ 1.176	6.66b $\pm$ 1.082	18.909	<0.001***
	2019	8.20a $\pm$ 1.402	7.44b $\pm$ 1.260	84.552	<0.001***
Ear height (cm)	2018	82.80a $\pm$ 4.384	79.98a $\pm$ 1.768	1.428	0.255
	2019	94.60a $\pm$ 1.133	71.05b $\pm$ 3.928	48.203	<0.001***
Grain yield (t/ha)	2018	3.83a $\pm$ 0.000	3.53a $\pm$ 0.446	0.448	0.528
	2019	2.99a $\pm$ 0.000	2.28b $\pm$ 0.0713	99.249	<0.001***
<i>Scutellonema</i>	2018	71.50a $\pm$ 14.727	67.44a $\pm$ 13.542	0.233	0.634
	2019	113.75a $\pm$ 13.295	153.563a $\pm$ 42.528	1.239	0.277

Means within the same row followed by the same letters are not significantly different. \*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , and \*  $p < 0.05$ .

TABLE 4: Relationship between *Scutellonema* abundance, maize leaf area index (LAI), plant height (PHT), and number of leaves per plant (NoLP) in control plots (treated with nematicide) and MPWN (maize plots with no nematicide) during trial one (2018) and two (2019) at Nyangati study site, Mwea subcounty.

Treatment	Relationship	R-value	p value	df
<i>Trial one</i>				
Control	<i>Scutellonema</i> vs. LAI	-0.98	<0.001***	14
	<i>Scutellonema</i> vs. PHT	-0.98	<0.001***	14
	<i>Scutellonema</i> vs. NoLP	-0.93	<0.001***	14
MPWN	<i>Scutellonema</i> vs. LAI	0.37	0.155	14
	<i>Scutellonema</i> vs. PHT	0.09	0.755	14
	<i>Scutellonema</i> vs. NoLP	0.01	0.974	14
<i>Trial two</i>				
Control	<i>Scutellonema</i> vs. LAI	0.65	0.006**	14
	<i>Scutellonema</i> vs. PHT	-0.49	0.052	14
	<i>Scutellonema</i> vs. NoLP	-0.31	0.248	14
MPWN	<i>Scutellonema</i> vs. LAI	-0.54	0.032*	14
	<i>Scutellonema</i> vs. PHT	-0.52	0.038*	14
	<i>Scutellonema</i> vs. NoLP	-0.71	0.002**	14

\*df= degrees of freedom. \*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , and \*  $p < 0.05$ .

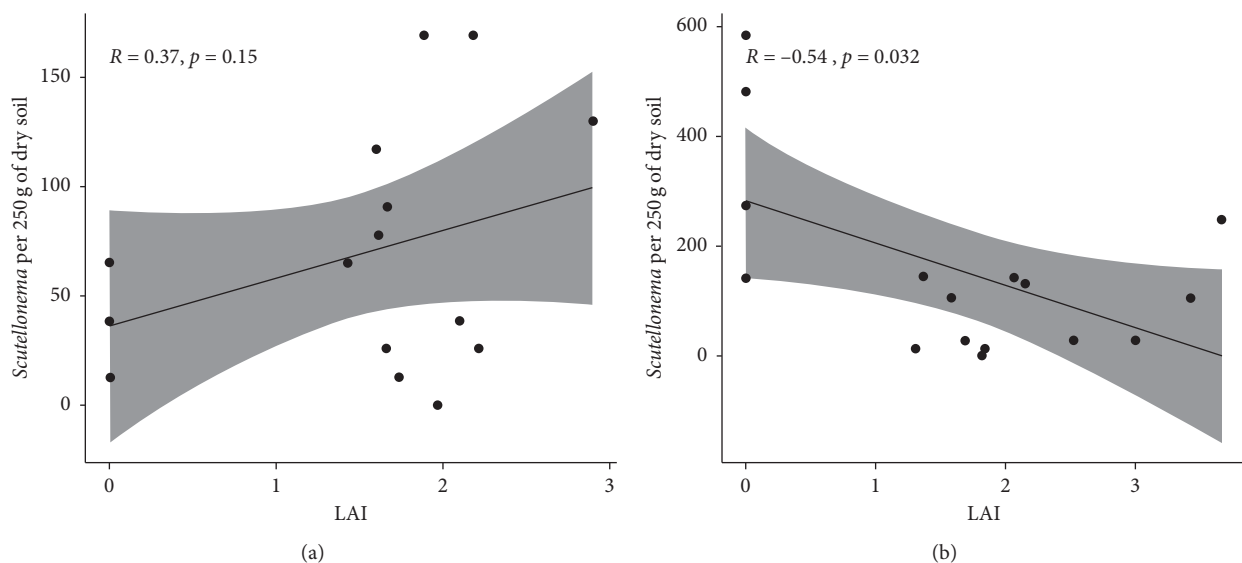


FIGURE 1: Correlation between leaf are index (LAI) and *Scutellonema* abundance during trial one in 2018 (a) and trial two in 2019 (b) in MPWN treatments. The relationship for 2018 revealed a nonsignificant positive association ( $R = 0.37$ ,  $p = 0.15$ ), while that for 2019 revealed a negative association ( $R = -0.54$ ,  $p = 0.032$ ).

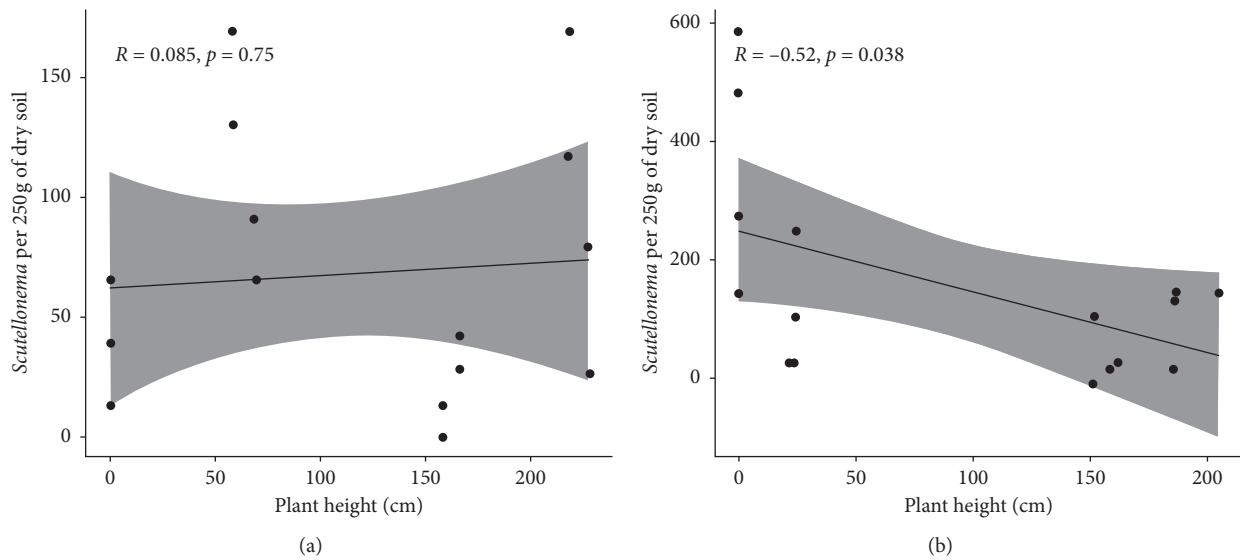


FIGURE 2: Correlation between plant height and *Scutellonema* abundance during trial one in 2018 (a) and trial two in 2019 (b) in MPWN treatments. The relationship for 2018 revealed a weak positive association ( $R = 0.085$ ,  $p = 0.75$ ), whereas for 2019 it was significantly negative ( $R = -0.52$ ,  $p = 0.038$ ).

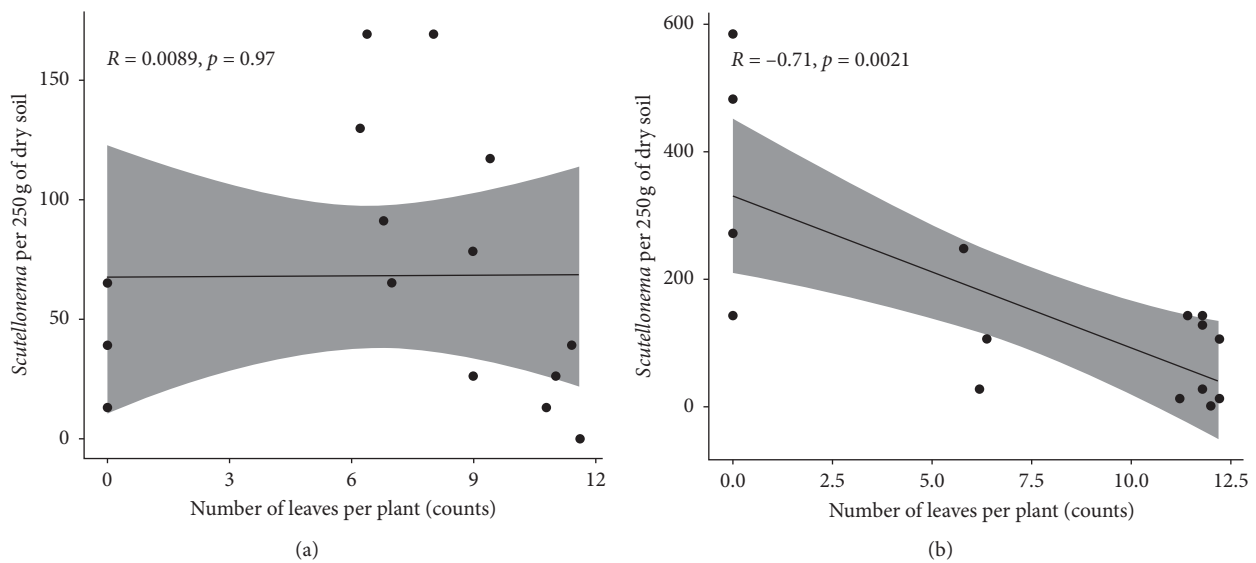


FIGURE 3: Correlation between number of leaves per plant and *Scutellonema* abundance during 2018 (a) and 2019 (b) in MPWN treatments. The association for 2018 revealed a very weak positive nonsignificant association ( $R = 0.01$ ,  $p = 0.97$ ), whereas for 2019 it was negative ( $R = -0.71$ ,  $p \leq 0.01$ ).

*similis* and *Helicotylenchus multincinctus* and a reduction in LAI.

Crop height is used to project crop yield, biomass production, and plant growth [31]. In our findings, the minimum maize height correlated to the lowest yields in MPWN in both trials. Similar results were found by Yin et al. [32], who noted that monitoring the development of maize plant height at various growth stage intervals is a very useful indicator of the potential yields. Assessment of main ear height provides useful information that can be used in breeding maize. The ideal main ear height should be neither too high nor too low [33]. Our findings showed that maize plants in MPWN exhibited not only lower plant height but

also lower ear height compared to control. The difference in these results may be associated with the use of nematicides which have been reported to improve crop growth through plant-parasitic nematodes suppression [34, 35], and alleviation of zinc deficiency symptoms [36]. Grain yield being an ultimate outcome of photosynthesis through various integrated physiological processes of the plant is affected by environmental variables, biotic and abiotic constraints [37]. In addition, it is an important measure of plant growth as it reflects the relative growth rate as net assimilation rate [38]. The lowest grain yield in this study correlated with lower *Scutellonema* density during the 2018 trial in MPWN although both grain yield and *Scutellonema* abundance data



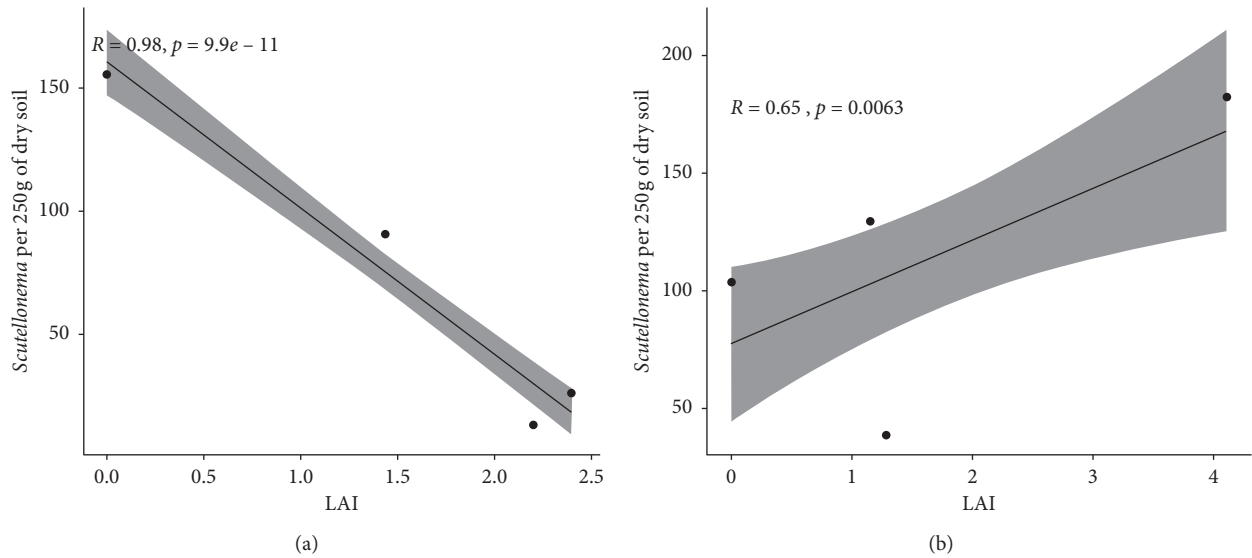


FIGURE 4: Correlation between leaf area index (LAI) and *Scutellonema* density during 2018 (a) and 2019 (b) in control plots. The relationship for 2018 showed a significant negative association ( $R = -0.98$ ,  $p \leq 0.001$ ), while for 2019 it was positive ( $R = 0.65$ ,  $p < 0.05$ ).

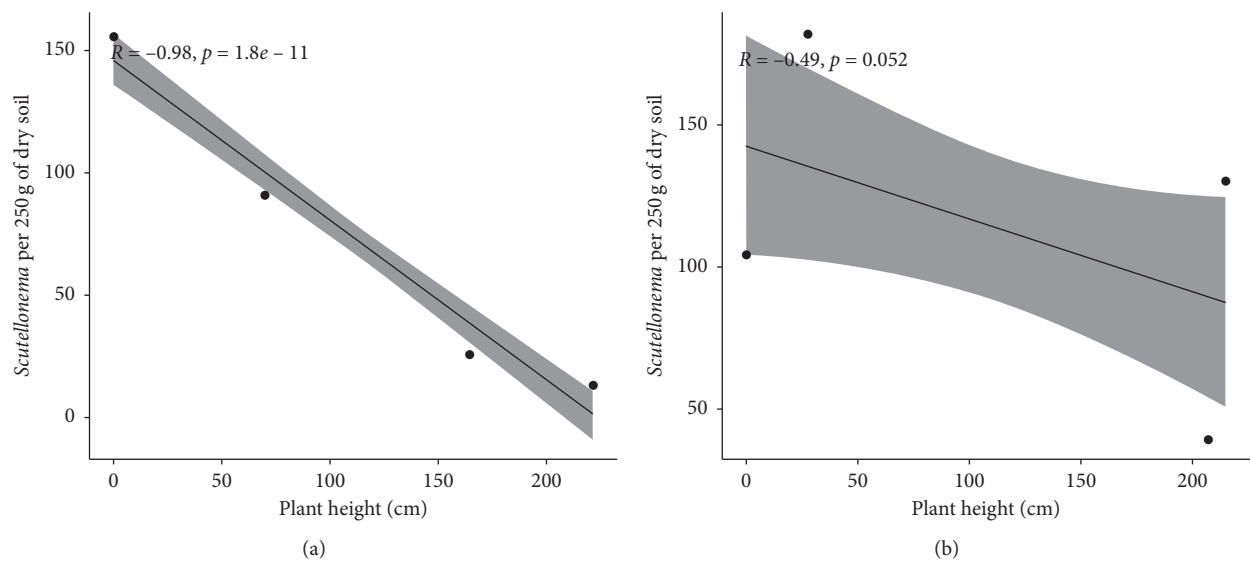


FIGURE 5: Correlation between plant height and *Scutellonema* density during 2018 (a) and 2019 (b) in control plots. The relationship for 2018 and 2019 showed a significant negative association ( $R = -0.98$ ,  $p \leq 0.001$ , and  $R = -0.49$ ,  $p = 0.052$ , respectively).

were not significantly different relative to the control. In contrast, during 2019, lower significant yields in MPWN were correlated to a higher population of *Scutellonema*, whose abundance was not statistically different compared to the control. These observations imply that it is often complex under field conditions to quantitatively link nematode population abundances with yield loss since nematodes closely interact with other factors including nutrient availability, water, and other secondary pathogens such as fungi and bacteria which may exacerbate the situation [5, 39, 40]. Moreover, the correlation analysis between plant height and the population density of *Scutellonema* revealed a significant negative relationship in MPWN (2019), while in 2018 the association was not significant. This, therefore,

suggests that *Scutellonema* abundance could probably have affected maize plant height negatively in MPWN under natural infestation where lower plant height was noted. High density of spiral nematodes, *Helicotylenchus* spp., was correlated with reductions of plant height, root masses, and chlorophyll content in maize fields in India [41]. Elsewhere, plant-feeding nematodes particularly root-lesion nematodes have been found to cause significant reduction in plant height in maize fields through impaired root systems, thereby causing stunted growth and yield loss [5, 42, 43].

The increase or decline in the number of functional leaves in each plant has a significant impact on the crop yields [21]. Leaves are important plant organs through which plants interact with the external environment and they are

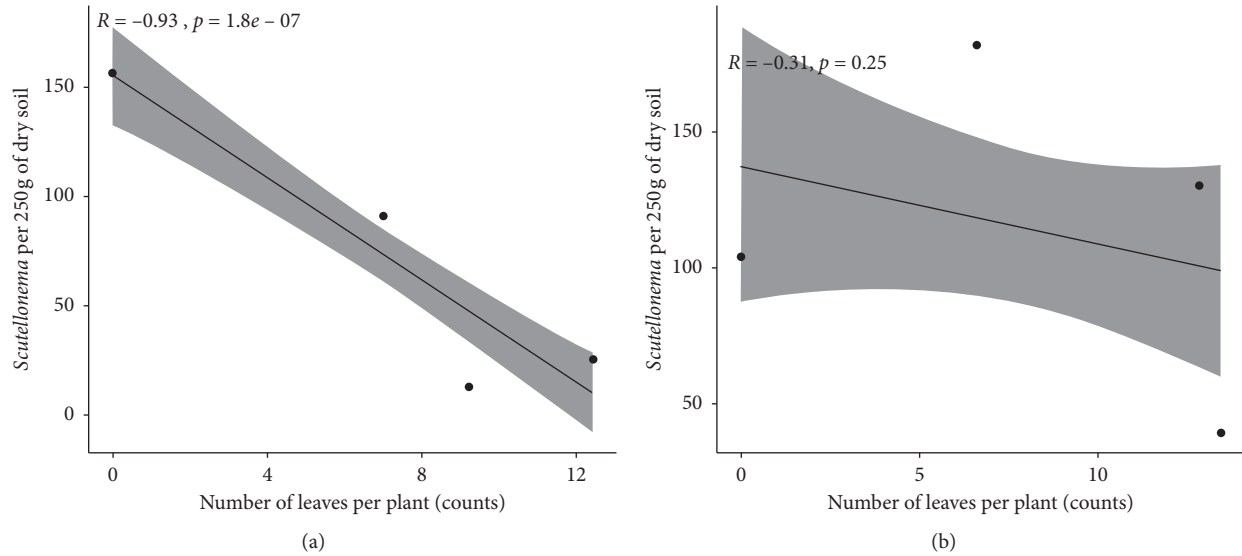


FIGURE 6: Correlation between number of leaves per plant and *Scutellonema* density during 2018 (a) and 2019 (b) in control plots. The relationship for 2018 showed a significant negative association ( $R = -0.93$ ,  $p \leq 0.001$ ), while for 2019 it was nonsignificant ( $R = -0.31$ ,  $p = 0.25$ ).

sites for photosynthesis. The lower number of leaves in this study was in parallel with lower yields recorded in MPWN treatments during both trials, but the yields for 2018 were not statistically different. Additionally, a significant negative association between the number of leaves per plant with *Scutellonema* density was observed in 2019, whereas the relationship for 2018 was not statistically different. This may be explained by the fact that *Scutellonema* spp. attack plant roots ectoparasitically and then invade the deeper cortical layers, resulting in reduction in the efficiency of root systems to uptake water and nutrients [14]. The damage in plant roots caused by *Scutellonema* spp. influences the translocation of photosynthates from the leaves to infected root tissues while in turn leaves will also experience a shortage of water, minerals, and nutrients [15]. Due to poor supply of water and nutrients, the development of leaf tissues and chlorophyll pigments is strongly affected [41, 44], consequently reducing the number of functional leaves per plant leading to lower yields.

## 5. Conclusion

This study provides an insight on the impacts of *Scutellonema* spp. density on maize plants in Mwea subcounty under natural field infestation. The high population of *Scutellonema* spp. has the potential to negatively affect maize leaf area index, plant height, number of functional leaves per plant, and grain yields. This information will be useful in implementing reliable and timely interventions that will ensure optimal maize production. Based on this, we recommend that holistic sustainable management practices against *Scutellonema* spp. in maize fields such as use of organic amendments, resistant maize cultivars, and antagonistic organisms are put in place in order to mitigate potential losses.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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