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Comparative Assessment of Root-Knot Nematode Infestation and Cowpea Grain Yield across Planting Seasons

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Abstract: *Root-knot nematode (RKN) is an economically important pest of cowpea. This study evaluated the relationship between planting season and RKN infestation pressure on cowpea grain yield. The study was carried out in Ibadan (Derived savannah) in the early and late rainy seasons. The RKN-infested field was laid out in a stratified design in twelve 5 × 5 m plots. Soil samples were collected at planting, and grain yield data were estimated at harvest. Data were subjected to a two-way analysis of variance, and significantly different means were separated using Tukey's HSD at a 5% probability level. Cowpea grain yield was significantly influenced by both planting season and infestation pressure, with early planting season yielding more than that of late-season plantings. These findings highlight the importance of pre-plant soil sampling for RKN enumeration and strategic planting dates. Leveraging the identified nematode density thresholds can support informed management decisions in cowpea production.*

Keywords: *Meloidogyne*, *Vigna unguiculata*, infestation, correlation, climate,

INTRODUCTION

Root-knot nematodes, *Meloidogyne* spp., are among the most economically important constraints to crop production worldwide. *Meloidogyne incognita*, *M. javanica*, *M. hapla*, and *M. arenaria* have been documented as the most destructive because of their wide distribution, broad host range, and significant impact on crop yields (Rehak Biondić et al., 2025). Collectively, RKNs have played host to more than 5,500 plant species, making them one of the most common groups of plant-parasitic nematodes (Trudgill and Blok, 2001). Their economic importance is reflected in estimated annual crop losses of about US$173 billion worldwide (Elling, 2013). In densely infested fields, plant-parasitic nematodes cause yield losses up to 80%, while in localized fields, losses can range from 10% to 15% (Nicol et al., 2011; Coyne et al., 2018).

Root-knot nematodes are important pathogens of grain legumes, including cowpea, which is regarded as a highly susceptible host in many regions of the world where it is cultivated (Huynh et al., 2015; Bui and Desaeger, 2021). The infection caused by the pathogen typically results in root galling, diminished water and nutrient uptake, stunted plant growth, and reduced grain yield. Under severe infestations, the resulting economic losses can be substantial, making cowpea production less profitable for farmers (Adegbite, 2011**;** Ndeve et al., 2018). Globally, RKNs are estimated to account for approximately 15% annual yield losses in cowpea production (Mahantheshwara et al., 2019).

Cowpea, an herbaceous annual legume belonging to the family Fabaceae, is one of the most vital food legumes produced in both tropical and subtropical regions. It is an excellent source of dietary protein for humans and as a forage crop for livestock (Tulu et al., 2023). Due to its adaptability to drought-prone environments and its high nutritional importance, it plays a critical role in ensuring food and nutritional security, especially in the semi-arid tropics of Africa, Asia, southern Europe, and Central and South America. Africa accounts for the largest share of global cowpea production. Nigeria and Niger contribute more than 66% of total world production. About 6.5 million metric tonnes of cowpea are produced annually from about 14.5 million hectares worldwide. West Africa dominate world cowpea production, accounting for more than 80% of the overall yield in the continent, led by Nigeria and Niger Republic (Kebede & Bekeko, 2020; Mekonnen et al., 2022).

Although the pathogenicity and host interactions of *Meloidogyne* species have been extensively investigated, variations in disease severity and damage thresholds may occur depending on environmental conditions and planting season (Ferris et al., 1981; Talavera-Rubia et al., 2022). Seasonal fluctuations in temperature, soil moisture, among other environmental conditions, may influence nematode population dynamics and the extent of damage to crop yield. Consequently, understanding the relationship between planting season and root-knot nematode pressure is essential for developing effective and sustainable management strategies. Therefore, this study was carried out to investigate the effects of planting season and varied levels of root-knot nematode pressure on the grain yield of cowpea.

MATERIALS AND METHODS

Experimental Site, Field Design and Soil Sampling

A field study was carried out to evaluate the relationship between levels of infestation pressure of RKN across planting seasons and their impact on grain yield of cowpea. The experiment spanned two planting seasons: early rainy and late rainy seasons. Twenty-four composite samples, with 12 plots per season, were evaluated. Multiple cores of Soil samples (500 ml per plot) were collected from each plot (0-15 cm deep) using a soil auger at planting (June for early planting and September for late planting, 2024), systematically from twelve stratified plots (5 × 5 m per plot) in a 0.5 ha RKN-infested field. Seeds were obtained from the gene bank of the Institute of Agricultural Research and Training, Ibadan, Nigeria. Planting was done at a spacing of 75 × 25 cm. A preliminary soil physical and chemical analysis was carried out in the two-trial fields. Weather data for the period of study was also retrieved from the Nigerian Meteorological Agency (NiMet).

Nematode Extraction

Root-knot nematodes, second stage juveniles (J2) were extracted using a modified Baermann technique, following the procedure of Van Bezooijen (2006). A 200 mL thoroughly mixed soil sample was placed on a double layer of facial tissue supported by a sieve over a tray containing clean water, and adjusted to ensure that the tissue was in contact with the water level and the soil was unsubmerged. The setup was left undisturbed at room temperature (25-28°C) for 48 hours, allowing the nematodes to migrate from the soil into the water. After the extraction, the suspension was collected in a beaker, concentrated, and sieved through a 25-µm mesh. The concentrate was transferred into a counting dish, where the nematodes were identified and counted under a stereomicroscope or compound microscope at appropriate magnification. Population densities were expressed as the number of nematodes per 200 mL of soil. To meet the assumptions of normality and homogeneity of variance, raw nematode counts (n) were $\log_{10}$-transformed. Based on these population densities, plots were categorized into High (41-100) or Moderate (≤40) infestation classes.

Crop Yield Assessment

At physiological maturity, cowpea pods were harvested per plot. Grains were threshed, cleaned, and sun-dried to a constant weight. Grain yields were standardized and recorded in kg/plot to determine crop productivity against seasonal variations and nematode infestation levels.

Statistical Analysis

Data were subjected to a two-way analysis of variance, evaluating the main and interactive effects of Season (Early-season vs. Late-season) and Infestation Class (Moderate vs. High) on nematode populations and grain yield. Treatment means were separated using Tukey's Honestly Significant Difference (HSD) test at 5% probability level. The relationships between RKN density and grain yield were determined using Pearson correlation (r), Spearman rank correlation (ρ), and simple linear regression (R^2) analyses across the pooled dataset, individual seasons, and infestation classes. All statistical analyses were performed using SAS software.

RESULTS

A total of 24 composite soil samples collected across early (n = 12) and late (n = 12) planting seasons were evaluated for RKN density and categorized into high and moderate infestation classes. Two-way analysis of variance (ANOVA) indicated that the main effect of planting season on nematode density was not significant. However, nematode density varied significantly by infestation class and exhibited a significant Season × Class interaction effect (Table 1). Mean comparisons using Tukey's Honestly Significant Difference (HSD) test ($\alpha = 0.05$) revealed that plots classified under high infestation in the early-season harbored the highest mean nematode density (1.789±0.052), which was significantly greater than the high class in the late-season (1.670±0.025, $p = 0.0001$). Conversely, moderate infestation plots in the early-season exhibited the lowest mean nematode population density (1.344±0.000), whereas moderate infestation plots in the late-season recorded a significantly higher mean density (1.552±0.051, $p < 0.0001$) (Table 2).

The result also established that grain yield was significantly affected by both planting season and infestation class. The Season × Class interaction effect on grain yield was non-significant. Across main effects, cowpea yield was significantly higher in the early-season (3.913±2.845 kg/plot) compared to the late-season (1.637±0.427 kg/plot). Regarding infestation classes, plots falling into the high category supported greater average grain yield (3.619±2.579 kg/plot than moderate category plots (1.369±0.261 kg/plot, $p = 0.0169$). Mean separation tests indicated that the early-season high class combination achieved significantly higher grain yields (5.095±2.817 kg/plot) than all other treatment combinations ($p < 0.05$), while yields among late-season high, late-season moderate, and early-season moderate treatments did not differ significantly from one another ($p > 0.05$) (Table 1).

Table 1. Analysis of Variance for Nematode Density and Cowpea Yield

Dependent Variable	Source of Variation	Df	Mean Square	p-Value
Log_{10}-RKN Density	Season	1	0.0001	0.8235
	Infestation Class	1	0.4194	< 0.0001***
	Season × Class	1	0.1487	< 0.0001***
	Error	20	0.0017	
	Total	23		
Cowpea Grain Yield	Season	1	26.3836	0.0061**
	Infestation Class	1	23.7553	0.0087**
	Season × Class	1	11.2165	0.0593
	Error	20	2.8044	
	Total	23		

Means within the same factor column sharing a common letter exponent are not significantly different at α = 0.05 according to Tukey's Honestly Significant Difference (HSD) post-hoc test. **p < 0.01, ***p < 0.001

Table 2. Effect of Season and Infestation Class on Root-Knot Nematode Density and Cowpea Yield

Treatment	Log_{10}-RKN Density (Mean±SD)	Cowpea Grain Yield (Kg/plot) (Mean±SD)
Season × Class		
Early Season — High Class	$1.789±0.052^{a}$	1.224±0.277b
Early Season — Moderate Class	$1.344±0.000^{d}$	1.931±0.198b
Late Season — High Class	$1.670±0.025^{b}$	1.550±0.000b
Late Season — Moderate Class	$1.552±0.051^{c}$	5.095 ±2.817a
Main Effects: Season		
Early Season	$1.640±0.223^{a}$	$3.913±2.845^{a}$
Late Season	$1.621±0.071^{a}$	$1.637±0.427^{b}$
Main Effects: Infestation Class		
High Class	$1.733±0.073^{a}$	$1.369±0.261^{b}$
Moderate Class	$1.460±0.116^{b}$	$3.619±2.579^{a}$

Standard deviation (SD) is presented alongside each mean value. Means within the same factor column sharing a common letter exponent are not significantly different at α = 0.05 according to Tukey's Honestly Significant Difference (HSD) post-hoc test.

Bivariate correlation and linear regression analyses were performed to evaluate the relationship between root-knot nematode population densities and cowpea yield (Table 3). Across the entire dataset (n = 24), a strong negative linear relationship was observed between RKN density and cowpea yield (r = -0.71, p = 0.000; ρ = -0.85, p = 0.000). Simple linear regression established that nematode density accounted for 50.0% of the total variance in cowpea yield (R^2 = 0.50, p = 0.000). When partitioned by planting season, strong and significant negative associations persisted in both periods. In the early season, nematode counts and cowpea yield showed a significant negative relationship (r = -0.78, p = 0.003; ρ = -0.90, p = 0.000), with nematode levels explaining 61% of the variation in yield (R^2 = 0.61). In the late rainy season, the negative relationship was remarkably strong and highly significant (r = -0.88, p = 0.000; ρ = -0.95, p = 0.000), with nematode levels accounting for 77% of the variation in crop grain yield (R^2 = 0.77). The relationship between nematode levels and cowpea yield differed significantly. Plots with high nematode levels showed a significant negative relationship with cowpea yield (r = -0.65, p < 0.008; ρ = -0.75, p = 0.001), with nematode density explaining 42% of the variation in grain yield (R^2 = 0.44). Conversely, plots with moderate nematode levels showed a non-significant negative relationship (r = -0.55, p = 0.122; ρ = -0,60, p = -0.0088), with nematode density accounting for only 30% of the yield variation (R^2 = 0.30).

Table 3. Correlation and Linear Regression Between Nematode Populations and Yield by Season and Nematode Class

Partition	Pearson r	p-Value	Spearman ρ	p-Value	R²	Regression p-Value
Complete Dataset	-0.71***	0.000	-0.850***	0.000	0.50***	0.000
Early Season	-0.78**	0.003	-0.90***	0.000	0.61**	0.003
Late Season	-0.88***	0.000	-0.95***	0.000	0.77***	0.000
High Class	-0.65**	0.008	-0.75***	0.001	0.42**	0.008
Moderate Class	-0.55	0.122	-0.60	0.088	0.30	0.122

**p < 0.01, ***p < 0.001

Table 4. Weather conditions of the study area during the period of study

Month	Max Temp (°C)	Min Temp (°C)	Rainfall (mm)	Relative Humidity (%)
June	29°C – 30°C	22°C – 23°C	190 – 210 mm	85% – 88%
July	28°C – 29°C	22°C	170 – 190 mm	87% – 90%
August	27°C – 28°C	21°C – 22°C	120 – 150 mm	86% – 88%
September	28°C – 29°C	22°C	210 – 240 mm	88% – 90%
October	30°C	22°C – 23°C	140 – 160 mm	84% – 86%
November	32°C – 33°C	22°C – 23°C	20 – 40 mm	70% – 78%
December	33°C – 35°C	20°C – 21°C	< 10 mm	45% – 60%

Nigerian Meteorological Agency (NiMet)

Table 5. Soil physicochemical properties of the study areas

Soil property	Early-season	Late-season
Sand (%)	63.4	63.4
Clay (%)	20.9	18.9
silt (%)	15.7	17.7
pH	5.71	4.89
Ca (cmol/kg)	3.72	5.05
Mg (cmol/kg)	2.51	2.98
Na (cmol/kg)	0.19	0.11
K (cmol/kg)	0.53	0.24
H+ (cmol/kg)	0.02	0.13
ECEC (cmol/kg)	6.97	8.51
Cu (mg/kg)	1.2	1.3
Zn (mg/kg)	12.3	7.4
Fe (mg/kg)	35	48
Av. p (mg/kg)	25.67	5.41
Mn (mg/kg)	97	21
Org C (%)	3.11	1.56
Total N (%)	0.31	0.16

DISCUSSION

The present study investigated the relationship between planting season, nematode infestation class, and their interactive effects on RKN density and cowpea grain yield. While the impact of RKN on cowpea is well-documented, studies have shown that the damage threshold also depends on the pest pressure and the prevailing environmental conditions. Root-knot nematodes are highly sensitive to soil temperature and moisture, and their life cycles are often inhibited under sub-optimal conditions (GC et al., 2025). The prevalence of RKN populations and egg masses in the soil between cropping seasons depends on the microclimatic conditions such as temperature and moisture. Extreme weather conditions may impose a physiological constraint on nematode survival. Prolonged anaerobic conditions have been reported to deplete dissolved soil oxygen (Bozbuğa et al., 2026). Also, excessive rainfall and low temperatures have been documented to have restrained J2 root invasion. On the other hand, reports have shown that elevated temperatures (30°C–33°C) enhance nematode multiplication, leading to a significant yield loss (Tsai et al., 2010; Daramola et al., 2021). In tropical agro-ecosystems, early-season conditions typically provide optimum moisture and beneficial rhizosphere temperatures that stimulate egg hatching and second-stage juvenile (J2) mobility (Ghosh et al., 2021). This reveals why early-season high nematode density plots supported high population densities (1.789). Conversely, early-season moderate class plots recorded lower RKN densities (1.344). This is likely due to slower initial population increase in the nematode infestations before the root system was well established (Das et al., 2008).

Across the collective data, RKN populations exerted a strong, highly significant negative impact on cowpea yield (Pearson $r = -0.71$, $p < 0.001$; $\rho = -0.85$, $p = 0.000$). The linear regression analysis revealed that 50% of the variance in cowpea yield can be directly attributed to the nematode population density. This establishes RKN pressure as a primary yield-limiting factor in cowpea cropping systems. Olowe (2004) reported that root-knot nematodes are a general constraint to cowpea production in Nigeria, causing substantial harvest loss. These results are consistent with the findings of Thakur et al. (2023), who showed that *Meloidogyne incognita* infestation leads to a significant 15.78% yield loss in cowpea crops.

The findings from the present study show that RKN pressure varies primarily based on changes in the prevailing environmental factors. Studies by Khanal and Land (2023) indicated that while rising soil temperatures reduce the reproduction rates of RKNs, it also increases their virulence and overall yield loss. Their investigation established that higher temperatures, precisely up to 34°C, significantly increased root galling and disease severity. Also, Pollok et al. (2023) demonstrated that environmental factors like soil temperature, specifically, temperatures between 24°C and 30°C, can raise host resistance. Changes in rainfall patterns and soil moisture directly impair nematode survival, mobility, and infection success (Parvatha, 2026).

The findings from this study established how different groupings of nematode populations influence cowpea grain yield, highlighting the significance of pest pressure assessment. The current study showed that the disparity in Log_{10}-RKN density between high and moderate infestation classes was significant during the early-season (1.79 vs. 1.34, respectively) and the late-season (1.67 vs. 1.55). The present study showed that while the initial nematode population density grouped as moderate class did not cause a significant difference in yield, except for those of high class. This suggests that the critical damage for RKN on this cowpea cultivar is above 40 J2 larvae per 100 ml of soil, below which the plant tolerates the infestation but above which severe root damage significantly impairs grain yield. According to Shi et al. (2024), the specific initial population density required to cause significant crop damage is a minimum of 50 J2 per 200 grams of soil. This suggests that late-season environmental factors such as declining soil temperatures and reduced soil moisture may have suppressed the reproductive potential of the nematode typically observed in high infestation categories

CONCLUSION

This study emphasized that root-knot nematodes represent an important constraint in cowpea production. Managing the pathogen may require monitoring the pre-plant soil population densities before making management decisions in cowpea production.

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