E-ISSN: 2618-0618
P-ISSN: 2618-060X

NAAS Rating (2025): 5.20
www.agronomyjournals.com
2025; 8(12): 1165-1173
Received: 17-10-2025
Accepted: 19-11-2025

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Effect of drip irrigation, velum prime rate and neem extract for integrated management of nematode infestation to enhance tomato production in Ghana

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DOI: https://www.doi.org/10.33545/2618060X.2025.v8.i12p.4561

Abstract
Agriculture remains the backbone of most economies, particularly in developing countries like Ghana, where it contributes significantly to GDP and food security. Tomato (*Solanum lycopersicum* L.), a widely cultivated vegetable crop on a global level, is increasingly affected by plant-parasitic nematodes, particularly root-knot nematodes (*Meloidogyne* spp.), leading to considerable yield loss, quality deterioration, and shortened shelf life. Although some irrigation strategies and botanical nematicides have been documented for nematode management. Globally, there is a knowledge gap in evaluating integrated approaches under Ghanaian conditions. This study aimed to evaluate the integrated effects of drip irrigation regimes, Velum Prime, and neem-based botanicals on the growth and yield of tomato plants under root-knot nematode infestation. A greenhouse experiment was conducted from May to August 2022 at the CSIR-Savanna Agricultural Research Institute (SARI), Nyankpala, Ghana, using a 3 × 2 × 3 factorial treatment arrangement in a Randomized Complete Block Design (RCBD) with three replications. Treatments included irrigation levels (50%, 75%, and 100% ETc), Velum Prime rates (0.625 and 1.25 L/ha), and neem treatments (leaf extract, seed extract, and neem cake, each at 5 t/ha). Results showed that 100% ETc irrigation combined with 1.25 L/ha Velum Prime and neem seed or leaf extract significantly improved plant height and chlorophyll content. Maximum fruit yield (1.7 t/ha) was obtained at 75% ETc irrigation with 5 t/ha neem seed extract. This integrated approach offers a promising strategy for managing nematodes and improving tomato productivity sustainably. These findings contribute to sustainable tomato production strategies and could inform policy and farmer practices in sub-Saharan Africa and beyond.

Keywords: Drip irrigation, velum prime, neem extract, nematode, tomato, Ghana

1. Introduction

In West Africa, agriculture contributes significantly to national economies, accounting for approximately 40% of the gross domestic product (GDP) in countries like Ghana [45]. Ghana's cultivated land area grew from 28,400 hectares in 1996 to 37,000 hectares in 2014 [22], reflecting the increasing importance of crop production to sustain its population and economy. Agriculture remains a cornerstone of global economic development, particularly in developing countries where it strategically enhances food security, raises incomes, and improves livelihoods [46]. Tomato (*Solanum lycopersicum* L.) is among the basic crops contributing to food and economic security in Ghana a widely cropped vegetable crop globally. In terms of production volume, tomatoes rank as the leading vegetable crop above watermelon and cabbage but after potatoes [26]. Global tomato production in 2017 reached 177 million tons, cultivated over 4.78 million hectares, with an mean yield of 37.02 tons per hectare [12]. Tomato is widely recognized for its nutritional value and commercial importance, ranking first among vegetable crops used for processing [2]. However, tomato production in Ghana, particularly in the northern regions, has been constrained in recent years by increasing biotic pressures, most notably the infestation of plant-parasitic nematodes, particularly root-knot nematodes (RKN) belonging to the genus *Meloidogyne* spp.

The impact of *Meloidogyne* spp. tomato productivity is severe. These nematodes are recognised as major yield-limiting pests that disrupt root systems, reduce nutrient uptake, and act as energy sinks by diverting photosynthates essential for fruit development [22]. The result is a significant decline in yield, fruit quality, and shelf life. In some cases, tomato production has been entirely abandoned due to RKN infestation [20]. RKN remains a persistent threat to tomato crops in Ghana, especially in irrigated systems where the continuous cultivation of host crops creates favorable conditions for nematode multiplication [29]. Although the damage potential of RKN has been extensively documented globally with yield losses ranging from 24 to 38% in tropical areas and, in some cases, up to 100% [1], limited research exists in Ghana concerning effective and integrated management strategies suited to local production systems. This is particularly true for the evaluation of irrigation practices, chemical nematicides, and botanical alternatives as combined control methods.

Irrigation is critical for enhancing crop performance in regions with erratic rainfall patterns [24]. It not only improves plant water availability but also affects soil properties and the behavior of soil-dwelling pests like nematodes. Access to reliable irrigation water significantly improves agricultural productivity and food security [17]. Drip irrigation, for example, has shown potential to reduce nematode incidence due to its targeted and efficient water delivery [9]. However, the adoption and evaluation of irrigation methods such as drip irrigation in Ghana's tomato systems remain understudied concerning nematode suppression. In addition to water management, the use of chemical nematicides such as Velum Prime has shown efficacy against nematodes by inhibiting their motility and reproduction [44]. However, the sustainability of chemical control is questionable due to environmental concerns, high cost, pest resistance, and health hazards [13, 5]. Inappropriate application practices, such as improper dosages and timing have also diminished their effectiveness in some West African countries (e.g., Senegal and Cameroon) [4]. Given these concerns, there is growing interest in botanical pesticides, which are more environmentally benign and can be locally produced. Among these, neem (*Azadirachta indica*) extract has been widely studied for its bio-nematicide properties, showing reduction in egg hatching and juvenile development of *Meloidogyne* spp. at low concentrations [31, 36]. Research has shown a decline in nematode reproduction and increased yields following neem application [3, 22].

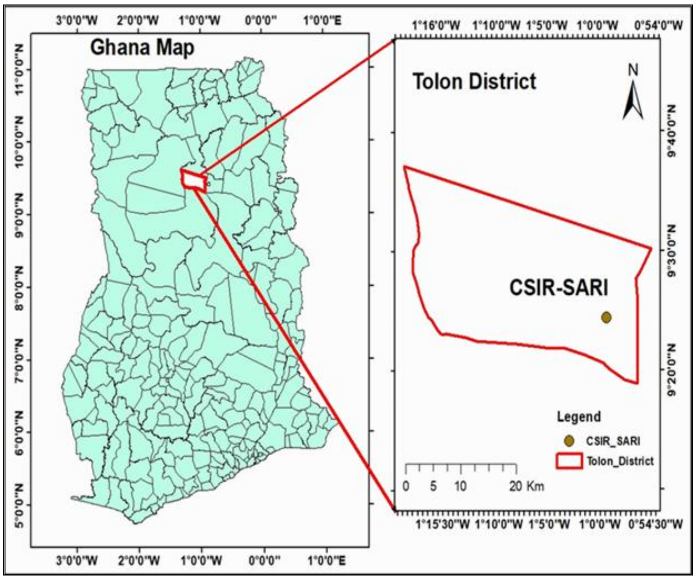
Despite these promising alternatives, integrated approaches combining water management, chemical control, and botanicals remain largely unexplored in Ghana. Therefore, the purpose of this study was to address the gap by evaluating the effect of drip irrigation, varying application rates of Velum Prime, and neem extract on nematode infestation in tomato fields under the Bontanga and Golinga irrigation schemes in Northern Ghana. Specifically, nematodes were sampled from three plots across the schemes and used to infect tomato pots in a controlled setup. The goal was to develop an integrated nematode management package suited to local growing conditions that balances effectiveness with environmental sustainability.

2. Materials and Methods

2.1. Study Area and Experimental Design

The research was conducted in a greenhouse, at the Savannah Agricultural Research Institute of the Council of Scientific and Industrial Research (CSIR-SARI) located in Nyankpala, Northern Ghana, around 17 km west of Tamale (9°40′N, 0°98′W) [24] [25] (Figure 1). The research site goes through a wet and dry season with a single rainfall peak of around 1026 mm on a annual basis and highest in August and September. The average annual temperature ranges from 23.4 ◦C to 39 ◦C [23]. The predominant vegetation is Guinean savanna with characteristic short drought-tolerant trees and grasslands.

This study followed a 3 x 2 x 3 factorial experiment in a Randomized Complete Block Design (RCBD) having 3 replications in tomato. The treatments combined three drip irrigation regimes - 100%, 75%, and 50% of crop water requirement (ETc) with two application rates of Velum Prime (0.625 L/ha and 1.25 L/ha), and three neem extract items, neem leaf extract at (5 t/ha), neem seed extract at (5 t/ha), and neem cake (5 t/ha).



(Field experiment, 2022).

Fig 1: Geographical Location of SARI Greenhouse

2.2. Nematode Sampling and Extraction

Soil samples were taken from the Northern Region of Ghana, particularly at the Bontanga and Golinga irrigation schemes, in the Kumbungu and Tolon Districts. Three plots were considered: a rice field, a fallow tomato field and an okra field. In each elemental plot, soil was taken from a depth of 20 cm using an auger following the zig-zag (Z) method. At each plot, subsamples were collected from three points, mixed thoroughly and combined into one composite sample. Each composite sample was collected in a transparent bag (well-labelled), placed in a cooler, and then transported to the CSIR-SARI pathology laboratory. The same procedure was applied across all plots.

Root-knot nematodes were extracted from the soils following the International Standard 23611-4 utilizing modified Baermann method (Whitehead and Hemming, 1965). Each sample (20g) was passed through 1mm sieve to eliminate the bigger particles; the samples were then subsequently placed on the absorbent tissue above sieve and the flat tray housing the water (240 ml). Within a day, the nematodes were at the bottom of the tray containing water after passing through the sieve. It was then accumulated in beakers (200 ml); allowing the solution in the beaker to remain standing for about 300 seconds, a hose was attached to the beaker to decrease the solution, reduced to 50 ml from 200 ml. Transfer of the solution was done into another beaker (50 ml) and finally observation was done with the binocular magnifying glass at magnification (x) 2000. Partitioning of the solution was done into 4 equal parts, spread on petri dishes and viewed with the binocular magnifier x 2000; pots were infested after that.

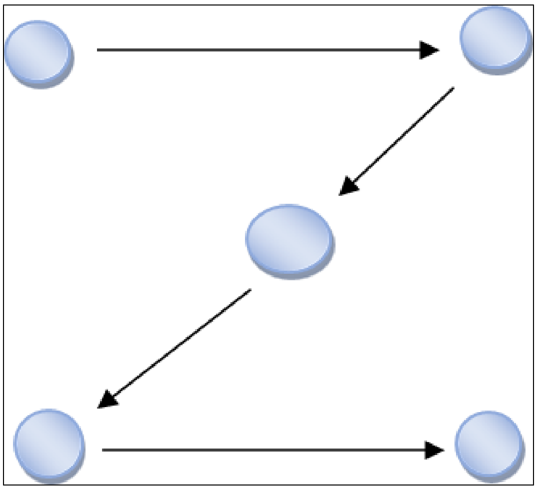


Fig 2: Soil Sampling Method at Bontanga and Golinga Irrigation Schemes (Sampling Design). *(Field experimental,2022)*

2.3. Drip System Installation and Testing

The irrigation setup included a water source, main and sub-main pipelines, lateral lines, and drip emitters. Pipe-borne water served as the irrigation source and was obtained from Tamale before it was conveyed to Nyankpala. Water was conveyed using a tanker and pumped into a 10,000-L polyvinyl chloride (PVC) storage tank, which served as the system reservoir. The irrigation network was made using 16-mm low-density polyethylene (LDPE) pipes along with appropriate connectors and fittings.

The drip irrigation assembly incorporated a screen filter to remove suspended particles and minimize emitter blockage. A one-inch diameter mainline delivered water to nine one-inch sub-main lines, which were further arranged to serve three experimental replications. Each sub-main supplied a lateral line that conveyed water directly to the plants. Drip tape emitters were installed at 40-cm intervals, enabling each emitter to irrigate an individual plant. The emitters had a nominal discharge rate of 1 L h^{-1}. Water application was controlled manually by opening and closing the storage tank outlet valve to regulate flow through the system.

Following installation, the system was evaluated to detect leakage, pressure inconsistencies, and flow non-uniformity. Flow rate assessment involved determining the volume of water discharged over a fixed time period. Distribution uniformity was assessed using a catch-can method, whereby collection containers were randomly placed across the experimental field, and the volume of water collected over a defined duration was measured. The recorded volumes were standardized by time and arranged in descending order.

In addition, catch cans were placed within each of the three replications, and the water collected per unit time was recorded. For each replication, the mean of the four lowest measured values was calculated, along with the overall average discharge rate. Distribution uniformity values exceeding 80% were considered acceptable for experimental purposes.

Estimation of Crop Water Requirement

Long-term climatic data spanning 51 years (1970-2021) were obtained from a meteorological station through the CLIMWAT 2.0 climate database. These data were subsequently integrated into the FAO CROPWAT software (version 8.0) [12]. The CLIMWAT database provides site-specific geographic information, including latitude, longitude, and elevation, along with seven long-term monthly climatic variables. These variables comprised mean and minimum air temperature (°C), wind speed (km h^{-1}), average relative humidity (%), duration of sunshine (h), total precipitation (mm), and effective rainfall (mm). Crop coefficient (Kc) values for tomato were derived in accordance with guidelines outlined in FAO Irrigation and Drainage Paper No. 56 [4, 12]. The crop coefficient (Kc) values corresponding to the initial, mid-season, and late-season growth stages were 0.90, 1.15, and 0.80, respectively. For the crop development and late-season phases, daily Kc values were obtained through linear interpolation using the stage-specific Kc values and the duration of each growth period. The lengths of the early development, mid-season, and late-season stages were 20, 30, and 40 days, respectively.

Crop evapotranspiration (ETc) was estimated as a function of reference evapotranspiration (ET_0) and the crop coefficient using Equation (2.2):

$$ETc = ET_0 \times Kc \ldots\ldots \text{ Equation 2.2}$$

where:

ET_c is the crop evapotranspiration (mm/day)

ET_0 represents reference evapotranspiration (mm/day) and

K_c represents the crop coefficient (no unit)

For localized irrigation systems with a ground cover fraction of 95%, the method proposed by Keller and Bliesner (1990) was applied to adjust ETc to localized crop evapotranspiration (ETcrop-localized). The adjustment factor was calculated using Equation (2.3):

$$Td = Ud \times (0.1 \times (Pd)^{0.5} \ldots\ldots\ldots\ldots \text{Equation 2.3}$$

Td = ETcrop-localized

$ET_{crop\text{-}localized}$ = estimated crop evapotranspiration under localized irrigation conditions (mm/day)

U_d = conventionally estimated peak crop evapotranspiration (mm/day)

P_d = percentage ground cover (%)

2.4. Cultural Practices

Transplanting

The transplanted seedlings exhibited good vigor and uniform health. Prior to transplanting, pots inoculated with nematodes were thoroughly weeded and irrigated to field capacity. Tomato seedlings were established at an inter-plant spacing of 40 cm, with two seedlings planted per pot, resulting in a total of 36 plants per experimental plot. Transplanting was carried out during the early morning hours, with seedlings placed into planting holes approximately 10 cm deep within each pot.

Chemical Control

Velum Prime demonstrated efficacy against root-knot nematodes (RKN). For tomato crops grown under protective cover, the chemical was applied using a sprayer at rates of 0.625 and 1.25 L/ha, initially at 5 days after transplanting (DATP) and subsequently repeated at 25 DATP.

Biological Control

Plants with pesticidal properties may serve as a viable alternative to synthetic pesticides for controlling pests and pathogens in vegetable crops (Bolou *et al.*, 2022). Several botanical species, such as *Neem* (*Azadirachta indica*), can be utilized in the form of plant extracts; including aqueous extracts, essential oils, or seed cake; as foliar treatments to manage pest populations (Nahak and Sahu, 2015). *Neem* is recognized as a potent natural plant for pest and disease management, usually referred to as "the miracle of God".

2.5. Neem Leaf Extract Preparation and Application

The preparation of neem leaf extract involved the following materials: fresh *Neem* leaves (*Azadirachta indica*), 125 g of dried chili, 125 g of garlic, 250 g of grated plain soap, and ¼ L of oil. The equipment used included a grinder (mortar and pestle), basin for harvesting and processing plant materials, shears and secateurs, a sieve or fine strainer, a funnel for transferring liquids, and 20-L storage containers.

The neem leaf extract was prepared through controlled spontaneous fermentation. Fresh *Neem* leaves (broya) were ground or peeled in a basin together with 125 g of dried chili pepper, 125 g of garlic, and 250 g of grated soap. The mixture was then diluted in a 20-L container and stirred thoroughly. For seven consecutive days, the container was opened each morning for five minutes before being closed again to allow fermentation. After this period, the mixture was filtered through a fine cloth, ¼ L of oil was added, and the solution was stirred. For application, 1 L of the prepared extract was diluted with 4 L of water, and the resulting solution was sprayed on the plants starting at 5 days after transplanting (DATP) and subsequently at 10-day intervals.

2.6. Neem Seed Extract Preparation

Moldy seeds were removed, and the remaining healthy seeds were dried in a thin layer under a well-ventilated shed before being stored in bags in a dry location for future use. The seeds were gently crushed using a mortar and pestle to remove the shells without breaking the kernels. The hulls were separated from the almonds, with any moldy almonds discarded. The almonds were then crushed carefully to avoid oil extraction. A total of 1.5 kg of the resulting powder was mixed with 10 L of water and left to stand overnight. The mixture was filtered through a fine cloth to obtain the extract, which was subsequently diluted to 5% by combining 1.5 L of extract with 10 L of water. Ordinary liquid soap was added at a rate of 100 mL per 10 L of solution. Due to the solution's sensitivity to sunlight, applications were performed in the evening, starting at 5 days after transplanting (DAT) and repeated at 10-day intervals.

2.7. Neem Cake Preparation

Neem cake, a by-product of solvent extraction and cold pressing of *Neem* fruits and kernels, is considered a biotic manure. It enhances soil fertility by acting as a nitrification inhibitor, which slows the conversion of nitrogen into gaseous forms, thereby prolonging both short-term and long-term nitrogen availability for crops. Additionally, due to its limonoid content, neem cake provides protection to plant roots against nematodes. However, its application after transplanting can cause phytotoxicity, leading to stunting or dieback. The nematicidal effects and fertility benefits of neem cake manifest over time; therefore, it was applied at 5 days after transplanting (DATP) and repeated at 10-day intervals, at a rate of 5 t/ha.'

2.8. Agronomic Data

Eighteen tomato plants were randomly selected and tagged in each plot. These plants were monitored throughout the growing season, and relevant data were collected from the field.

Plant Height: Each tagged plant was measured at two-week intervals up to 8 weeks after transplanting (WATP). Plant height was determined from the base to the tip of the youngest leaf using a meter rule.

Number of Leaves: Following two-week intervals until eight (8) WATP, the leaves of each tagged plant were counted and the averages recorded.

Chlorophyll Content: From 6 weeks after transplanting (WATP), chlorophyll content was measured in three leaves per tagged plant using a SPAD meter.

Number of Flowers per Plant: The number of flowers per tagged plant was counted and the average number of flowers per plant was recorded.

Fruit Set Rate Per Plant: This rate was calculated as the percentage of total flowers using the formula below:

$$\text{Set rate} = \frac{\textit{Total number of flower} - \text{aborted } \textit{flower}}{\text{Total number of flowers}} \times 100\%$$

Equation 2.4

Number of Fruits per Plant: The number of fruits per plant was determined by counting fruits for each treatment.

Yield (t/ha): Fruit weight (kg) was multiplied by the plant population per hectare, and the result was divided by 1,000 to obtain yield per hectare.

2.9. Statistical Analysis of Data

The acquired data was organized in Microsoft Excel (2019) and subjected to Analysis of Variance (ANOVA) using the GenStat 12th edition statistical package. A factorial combination of irrigation level, Velum Prime, and neem extract was implemented within a randomized complete block design (RCBD) as the general treatment structure and used to assess, yield, yield components and plant growth data. The different treatment averages were compared using the least significant difference (LSD) at the 5% probability. Where necessary values were transformed using square root (SQRT) for normality.

3. Results and Discussion

3.1. Plant Height

At 6 WATP, plant height was significantly affected by all main effects and interactions ($P < 0.001$), except for the interaction between Velum Prime rate and neem extract, which was significant at $P < 0.01$. Similarly, at 8 WATP, plant height was significantly affected by all main effects and interactions ($P < 0.001$), with the Velum Prime × neem extract interaction significant at $P < 0.01$. At both 6 and 8 WATP, plants receiving full irrigation (100% ETc) combined with 1.25 L/ha Velum Prime and 5 t/ha neem seed extract recorded the highest plant heights of 80.67 cm and 90.70 cm, respectively (Table 1). Conversely, the lowest plant heights of 47.60 cm and 54.00 cm were observed under 50% ETc with 0.625 L/ha Velum Prime and 5 t/ha neem cake at 6 and 8 WATP, respectively.

Table 1: Effect of Irrigation Regime, Velum Prime rate and Neem Extract on Plant Height per Plant at 6 WATP and 8 WATP.

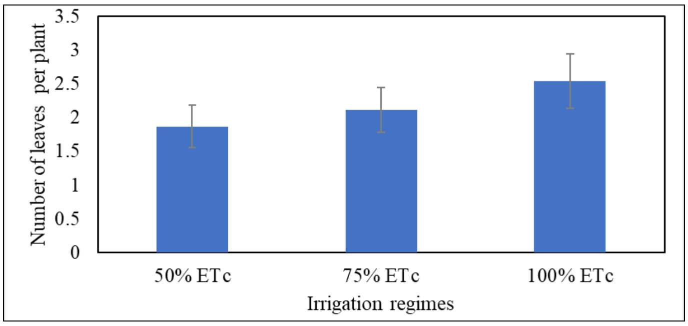
Irrigation Regime (% ETC)	Velum Prime (L/ha)	6 WATP			8WATP		
Neem Extract (t/ha)							
		NC	NL	NS	NC	NL	NS
50%	0.625	47.60fg	66.70f	57.00fg	54.00f	62.67f	60.00fg
75%		54.00g	69.00cd	62.00d	61.00g	73.67cd	69.00d
100%		62.00bc	53.00cd	72.00bc	73.00cd	77.33bc	78.00bc
50%	1.25	54.00f	54.00f	56.00fg	59.00fg	61.00f	63.00ef
75%		61.30de	71.00bc	73.60b	68.00de	78.00bc	80.67b
100%		70.00d	79.30a	83.60a	69.00d	86.33a	90.67a
LSD (5%)		5.334			5.315		
p-value		0.001			0.001		
CV (%)		1.9			1.7		

(Experimental Field, 2022).

3.2. Number of Leaves

At 4 WATP, analysis of variance showed that the interactions of irrigation level × Velum Prime rate × neem extract, Velum Prime rate × neem extract, irrigation level × neem extract, and irrigation level × Velum Prime rate, as well as the main effects of Velum Prime rate and neem extract, did not significantly affect the number of leaves per plant ($P > 0.05$). However, the irrigation regime alone had a significant effect ($P < 0.001$), with full irrigation (100% ETc) producing more leaves per plant than 50% ETc, while 75% ETc resulted in a similar number of leaves (Figure 3).

At 6 and 8 WATP, the interactions of irrigation × Velum Prime rate × neem extract, irrigation × neem extract, and the main effects were all significant ($P < 0.001$) on leaf number. In contrast, the interactions of irrigation × Velum Prime rate and Velum Prime rate × neem extract were not significant ($P > 0.05$). The combination of full irrigation (100% ETc), 1.25 L/ha Velum Prime, and 5 t/ha neem seed extract produced the highest number of leaves per plant, with 4.94 and 5.29 leaves at 6 and 8 WATP, respectively, whereas 50% ETc with 0.625 L/ha Velum Prime and 5 t/ha neem cake extract resulted in the lowest values of 3.43 and 4.18 leaves per plant at 6 and 8 WATP, respectively (Table 2).



(Field Experiment,2022).

Fig 3: Effect of Irrigation Regime on Number of Leaves at 4 WATP. Bar = SEM

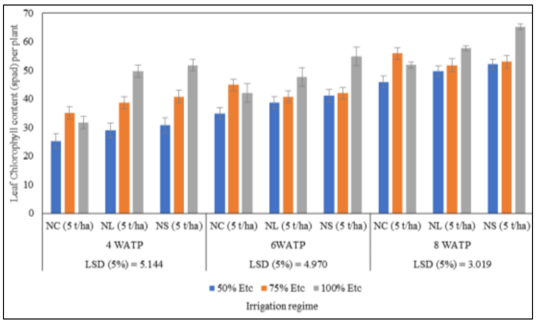
Table 2: Effect of Irrigation, Velum Prime rate and Neem on Number of Leaves per Plant ($\sqrt{(x+0.5)}$) at 6 and 8 WATP.

Irrigation Regime (% ETC)	Velum Prime (L/ha)	6 WATP			8WATP		
Neem Extract (5 t/ha)							
		NC	NL	NS	NC	NL	NS
50%	0.625	3.44g	3.80f	3.80f	4.18h	4.29fgh	4.45efg
75%		3.39g	4.18de	4.06ef	4.26gh	4.78bcde	4.71cde
100%		4.63bc	4.14e	4.56bc	5.03abc	4.63defg	4.09bcd
50%	1.250	3.43g	3.80f	3.80f	4.22h	5.30a	4.41efgh
75%		4.18de	3.49g	4.42cd	4.67cdef	4.14h	5.12ab
100%		4.02ef	4.74ab	4.94a	4.45efgh	5.14ab	5.29a
LSD (5%)		0.2438			0.3508		
p-value		0.001			0.001		
CV (%)		1.2			0.3508		

(Field Experiment,2022).

3.3. Chlorophyll Content

At 4 WATP, leaf chlorophyll content of tomato was significantly influenced by the interactions of Velum Prime rate × neem extract and irrigation × neem extract ($P < 0.001$), while all other interactions and main effects were not significant ($P > 0.05$). Similarly, at 6 and 8 WATP, the interactions of Velum Prime rate × neem extract, irrigation × neem extract, and the main effect of neem extract significantly affected leaf chlorophyll content ($P < 0.001$) (Table 3). The highest chlorophyll content was recorded in plants receiving full irrigation (100% ETc) combined with 5 t/ha neem seed extract, with SPAD readings of 52, 55, and 65 at 4, 6, and 8 WATP, respectively (Figure 4).



(Field Experiment,2022).

Fig 4: Effect of Irrigation and Neem Extract on Tomato Chlorophyll at 4, 6 and 8 WATP. Bar = SEM

Table 3: Effect of Velum Prime rate and Neem Extract on Tomato Chlorophyll at 4, 6 and 8 WATP

Irrigation Regime (% ETC)	4 WATP		6 WATP		8 WATP	
	Velum Prime rate (L/ha)					
	0.625	1.250	0.625	1.250	0.625	1.250
NC (5 t/ha)	26.11b	26.98b	36.00b	45.21a	71.78c	73.28c
NL (5 t/ha)	37.73a	35.21a	47.73a	36.98a	77.52c	83.00a
NS (5 t/ha)	35.52a	35.82a	45.84b	46.02a	76.89b	85.44a
LSD (5%)	2.971		2.869		3.117	
p-value	0.001		0.001		0.001	
CV (%)	2.00		2.50		5.40	

Field Experiment, 2022).

3.4. Flower Count (√(x+0.5)) Per Plant

At 6 WATP, the interactions of irrigation regime × Velum Prime rate × neem extract, irrigation level × neem extract, Velum Prime rate × neem extract, and all main effects significantly influenced flower count ($P < 0.001$), whereas the interaction of irrigation regime × Velum Prime rate did not have a significant effect ($P > 0.05$). At 8 WATP, the interaction of irrigation regime × Velum Prime rate × neem extract and all main effects significantly affected flowering ($P < 0.001$). Plants treated with 75% ETc in combination with 1.25 L/ha Velum Prime and neem seed extract produced the highest number of flowers per plant, with 5.15 and 5.43 flowers at 6 and 8 WATP, respectively. In contrast, the lowest flower counts of 1.56 and 3.08 were observed under 50% ETc with 0.625 L/ha Velum Prime and 5 t/ha neem leaf extract at 6 and 8 WATP, respectively (Table 4).

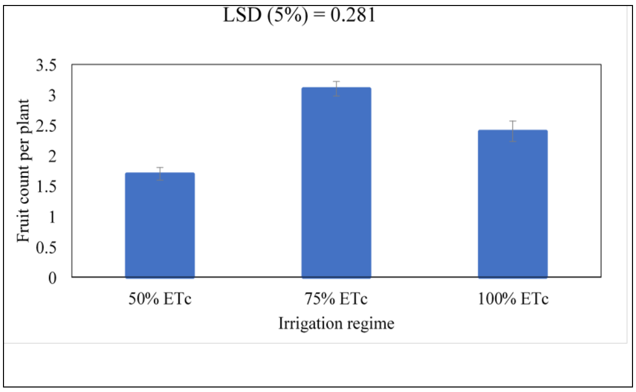
Table 4: Effect of Irrigation Regime, Velum Prime rate and Neem Extract on Tomato Flower Count (√(x+0.5)) per Plant at 6 and 8 WATP

Irrigation Regime (% ETC)	Velum Prime (L/ha)	6 WATP			8WATP		
	Neem Extract (5 t/ha)						
		NC	NL	NS	NC	NL	NS
50%	0.625	2.12i	1.56j	4.75a	3.39i	3.08j	4.14f
75%		3.08fg	3.67c	4.41a	4.06fg	4.53c	5.15b
100%		2.91g	3.08fg	3.42ef	3.94gh	4.06fg	4.18ef
50%	1.250	2.91gh	2.91gh	3.19f	3.94gh	3.94gh	4.14f
75%		2.79h	4.30b	4.75a	3.85h	5.05b	5.43a
100%		4.02ef	3.53cd	3.39de	4.42cd	4.30de	4.42cd
LSD (5%)		0.184			1.398		
p-value		0.001			0.001		
CV (%)		1.60			0.80		

(Field Experiment,2022).

3.5. Fruit count

At 9 WATP, fruit count was not significantly affected ($P > 0.05$) by irrigation regime, Velum Prime rate, neem extract, the interactions of irrigation × Velum Prime, irrigation × neem extract, Velum Prime × neem extract, or the main effect of Velum Prime. However, crops treated with both irrigation and neem extract showed a significant effect on fruit count ($P < 0.05$). The results indicated that plants under 75% ETc recorded the highest fruit count, while application of 5 t/ha neem seed extract resulted in maximum fruiting (Figure 5).



(Field Experiment,2022).

Fig 5: Effect of Irrigation Regime on Fruit Count at 9 WATP. Bar = SEM

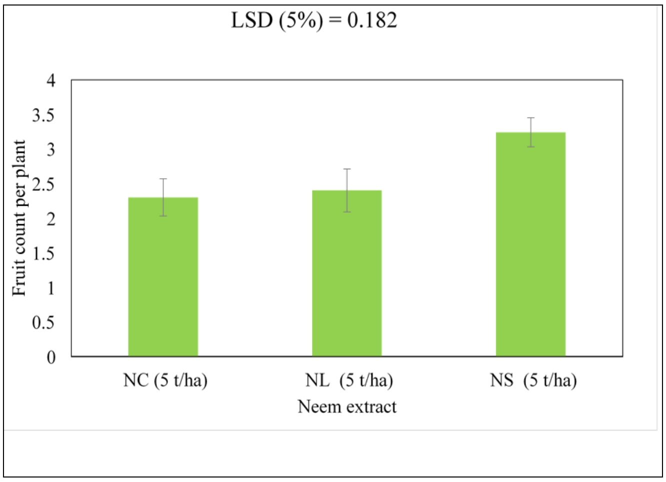
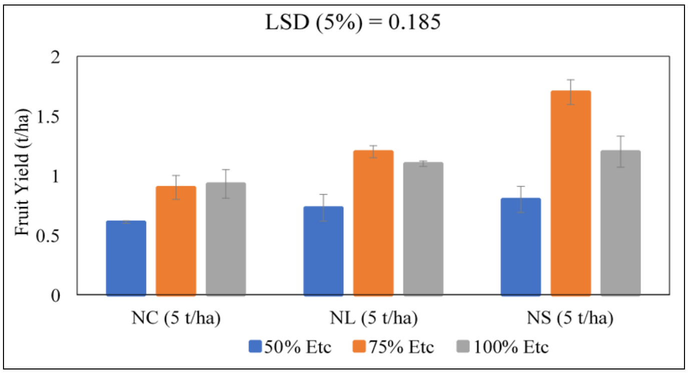


Fig 6: Effect of Neem Extract on Fruit Count at 9 WATP. Bar = SEM *(Field Experiment,2022).*

3.6. Tomato Fruit Yield

Analysis of variance indicated that fruit yield was significantly influenced by the interaction of irrigation regime × neem extract and by the main effect of neem extract ($P < 0.001$). Tomato plants irrigated at 75% ETc combined with 5 t/ha neem seed extract achieved the highest fruit yield of 1.7 t/ha, whereas the lowest yield of 0.6 t/ha was observed under 50% ETc with 5 t/ha neem cake extract (Figure 7).



(Field Experiment,2022).

Fig 7: Effect of Irrigation Regime and Neem Extract on Fruit Weight. Bar = SEM

4. Discussion

Nematodes are soil borne plant pathogens; they initially infect root epidermis after which the fungi invade the vascular tissue of the plant.

These results of amount of nematodes per water volume encountered in the soils sampled was more than that reported by [23] and [8]. The results from this study depicted an increasing population of nematodes in the Northern Ghana soils, which is a signal for serious management response.

The results indicated the potential of Velum Prime, water and neem seed extract to enhance tomato plant growth. Plants with 100% water and neem seed recorded the highest plant height, as compared to 50% ETc with 0.625 L/ha Velum Prime and neem cake extract (5 t/ha). Pesticide (neem extract and Velum Prime) can affect the hatching ability of RKN eggs and halt the growth of the embryo inside the egg by eliminating the embryo or young adults of the first stage before their hatching and the second egg explodes are also consistent [18] and [36]

The present results, however contradict findings, which show that the maximum number of leaves was attained at 100% ETc as compared to 50% ETc [38]. The number of leaves per plant was higher in crops treated with 5 t/ha neem seed extract compared to those treated with 5 t/ha neem cake extract, 5 t/ha neem leaf extract, or Velum Prime at 0.625 and 1.25 L/ha [16, 46]. The present results partially align with previous findings, as the lowest leaf production was observed in plants treated with neem cake under 50% ETc combined with 0.625 L/ha Velum Prime. It is possible that neem cake releases allelopathic compounds that inhibit tomato growth, a phenomenon that warrants further investigation. Given the limited reports on leaf chlorophyll content, these findings provide a benchmark for future research on treatments aimed at enhancing leaf chlorophyll in tomatoes, particularly in the context of nematode management.

The observed increase in flower number may be attributed to the effect of neem seed extract in enhancing plant nutrient status and suppressing nematodes, in combination with Velum Prime and irrigation, thereby supporting optimal flowering. Overall, the combination of 75% ETc, 1.25 L/ha Velum Prime, and 5 t/ha neem seed extract produced the highest number of flowers per plant, with 5.43 and 5.15 flowers recorded at 6 and 8 WATP, respectively. These results highlight the potential of this treatment for integrated nematode management to improve flower production, which could subsequently enhance fruit yield. Given the limited literature on this topic, the present findings provide a benchmark for future research on strategies aimed at increasing flower count in tomatoes through nematode management.

At 8 and 9 WATP, neem seed extract recorded the largest fruit number of 2 and 3 fruit count per plant respectively; neem cake showed the fewest fruits. Neem seed extract produced the most fruits [40]. According to the results of the present investigation, using neem extract might have largely alleviated the negative effect of the nematode infestation that could impair the tomato fruit count drastically.

The effects of 75% irrigation and 5 t/ha of neem seed extract were noted to achieve the ultimate parameter of interest, fruit production of tomato. The findings from this research depicted that the moderate irrigation regime in combination with neem extract could have double effects, by cementing availability of nutrients to plants and, more importantly, responsible for controlling the root-knot nematodes (Meloidogynes spp.) for good tomato growth and fruit production. Neem extract could enhance nutrient uptake by crops [15]. The findings align with research carried out by Oke *et al*. (2020), who reported that applying 75% ETc with neem seed extract improved plant flowering and yield

5. Conclusion

In order to effectively manage nematodes in tomato in northern Ghana, the study evaluated the impact of drip irrigation regime, Velum Prime rate, and neem extract in production of the crop. The current research was therefore designed to examine the effects of drip irrigation regime, Velum Prime rate and neem extract in integrated management of root-knot nematodes in tomato in northern Ghana. Improving tomato productivity represents a critical problem for the management of agricultural nematodes and as a result, sustainable crop production. Further studies are needed to refine the interactions between the different explanatory parameters. This study will enable the strengthening of sustainable management strategies for tomato nematodes by taking into account the combination of irrigation, velum prime and neem extract that influence the proliferation of soilborne pests.

Acknowledgment

This study was supported by the World Bank's African Centre of Excellence for Development Impact (ACE Impact) initiative and funded by the Government of Ghana through the West African Centre for Water, Irrigation and Sustainable Agriculture (WACWISA) at the University for Development Studies, Ghana. Funding for this research was provided by WACWISA, Ghana.

Author contributions

Conceptualization, M.S.; Methodology, M.S.; Investigation, M.S.; writing - original draft preparation, M., O.O.O, M.O.K; Writing - review and editing, I.K.Z, F.K.; Visualization, I.K.Z.; Supervision, I. K.Z, F.K.

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