UNIVERSITY FOR DEVELOPMENT STUDIES

EFFECTS OF DRIP IRRIGATION REGIMES, VELUM PRIME RATE AND NEEM PRODUCTS ON GROWTH AND YIELD OF TOMATO (*SOLANUM LYCOPERSICUM* L.) IN ROOT-KNOT NEMATODES (*MELOIDOGYNE* SPP.) INFESTED SOIL IN NORTHERN GHANA

MADJIGUENE SAMOURA

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WEST AFRICAN CENTRE FOR WATER IRRIGATION AND SUSTAINABLE AGRICULTURE

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BY

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MARCH, 2023

DECLARATION

I hereby declare that this thesis is the result of my original research and has not been submitted in whole or in part for a degree in Ghana or anywhere else, with the exception of the references to other people's work that have been properly cited.

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We hereby state that the thesis was prepared and presented in accordance with the standards for thesis supervision established by the University for Development Studies, Ghana.

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ABSTRACT

One of the most important vegetable crops widely cultivated and consumed in the world is tomato (*Solanum lycopersicum* L). However, tomato production has been decreasing at at the various irrigation sites in Ghana due to the devastating effects of root-knot nematodes (*Meloidogyne* spp.). In this study, the impact of drip irrigation regime, Velum Prime and neem extract on root-knot nematodes and yield of tomato were investigated. The experiment was carried out in a greenhouse (from May to August 2022, at the Council for Scientific and Industrial Research-Savanna Agricultural Research Institute (CSIR-SARI), Nyankpala, near Tamale, Ghana. A 3 x 2 x 3 factorial experiment laid out in a Randomized Complete Block Design (RCBD) with three replications was conducted. The treatments consisted of irrigation regimes (50% ETc, 75% ETc and 100% ETc), Velum Prime rate (0.625 and 1.25 L/ha) and neem leaf extract, neem seed extract, and neem cake, each at 5 t/ha. Each experimental pot was filled with 5 kg soil and infested with 159 ml of nematode-infected water. Results of the CROPWAT model showed that the seasonal water needs for tomato ranged from 254 mm at 50% ETc to 508 mm at 100% ETc. The soil textural class was clay loam and field capacity of the topsoil and subsoil were 31.70% and 31.90%, respectively. Application of 100% ETc with 1.25 L/ha Velum Prime plus of either 5 t/ha neem seed extract or 5 t/ha neem leaf extract increased crop growth indices such as plant height. Irrigation at 75% ETc plus Velum Prime (1.25 L/ha) and neem seed extract (5t/ha) increased number of leave per plant, whilst 100% ETc irrigation with 5 t/ha neem seed extract, 1.25 L/ha Velum Prime and neem leaf extract and 1.25 L/ha Velum Prime with neem seed extract (5 t/ha) gave the highest leaf chlorophyll content. The 75% ETc irrigation and 5 t/ha neem seed extract promoted flowering. Moreover, irrigation with 75% ETc and 1.25 L/ha Velum Prime with 5 t/ha neem seed extract gave the highest fruit set. Irrigation with 75% ETc combined with 5 t/ha neem seed extract increased number of fruits per plant. However, the greatest fruit yield of 1.7 t/ha was obtained by the application of 75% ETc irrigation with 5 t/ha neem seed extract. Fruit yield correlated positively with plant growth and reproductive indices of the plants (plant height, number of leaves, leaf chlorophyll, flower and fruit counts) showing coefficient of correlations as: r = 0.78, 0.67, 0.96, 0.85, 0.95, respectively. The study therefore revealed integration of drip irrigation, Velum Prime rate and neem extract exhibited greater potential in increasing the ???? of tomato in root-knot nematodes infestation soils at irrigation sites.

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DEDICATION

To my mother and my father, my siblings, myself and my cousins.

ABREVIATIONS AND ACRONYMS LIST

AMC	Available moisture content
BD	Bulk density
CSIR	Council for Scientific and Industrial Research
DATP	Days after transplanting
DU	Distribution uniformity
EC	Electrical conductivity
ETc	Crop water requirement
ET_0	Reference evapotranspiration
FAO	Food and agricultural organization
FC	Field capacity
g	gram
GDP	Gross domestic product
K	Potassium
Kc	Crop factor
Kg	Kilogram
L	Liter
MoFA	Ministry of Food and Agriculture
N	Nitrogen

NC	Neem cake
NL	Neem Leaf
NS	Neem seed
O.C	Organic Carbon
O.M	Organic matter
pH	Power of hydrogen
PPN	Plant parasitic nematode
PWP	Permanent wilting point
Q	Emitter discharge
RKN	Root-knot nematodes
SARI	Savanna Agricultural Research Institute
SEM	Standard Error of Means
TAW	Total available water
WATP	Weeks after Transplanting

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Across the globe, most economies are built on agriculture, which also plays a crucial and strategic role in the development of underdeveloped nations (World bank, 2020). Indeed, it is the key to economic growth, raising living standards, increasing incomes, and improving food security (Anonymous, 2011). In West Africa, agriculture is the engine of economic growth with a gross domestic product (GDP) of 40% in a country like Ghana (Wood, 2013). The size of cultivated land in Ghana increased from 28,400 ha in 1996 to 37,000 ha in 2014 (Kankam and Adomako, 2014).

One of the most common vegetable crops cultivated worldwide is tomato (*Solanum lycopersicum* L), and its output has increased significantly in 170 countries (Loeillet, 2019). In terms of volume of production, tomato is the leading vegetable in the world, ahead of watermelon and cabbage; but behind potatoes. According to Ling *et al* (2019), tomato crop is now the most important vegetable crop of commercial interest, with a world production in 2017 of about 177 million tons for a surface of 4.78 million hectares, giving an average yield of 37.02 tons per hectare (FAO, 2017a). Tomato is one of the important vegetable crops grown throughout the world and is next to potato in terms of the area but ranks first as a processing crop (Mehdizadeh *et al*., 2013).

For several years, tomato production has decreased or even totally stopped in some farms due to plant-parasitic nematodes particularly the *Meloidogyne* spp. The RKNs causes a lot of damage in vegetable farms and are therefore considered as major limiting factor (Kane, 2018).

Sikora *et al*. (2005), reported that nematodes damage, in particular root-knot nematodes, is a major challenge to Ghana's tomato production. Tomato infestation is at the origin of an enormous fruit yield loss by increasing the proliferation of plant-parasitic nematodes on the tomato crop. Indeed, it acts as an energy sink, by absorbing the photosynthates necessary to the plant for the production of fruits; hence reduction in fruit yield, poor quality of the harvest and reduction of the shelf life (Kankam and Adomako, 2013).

Giving a crop the suitable amount of water at the right time, based on the depth of its roots, is the process of irrigation. Irrigation is critical for agricultural development especially in crop cultivation. According to Jägermeyr *et al*. (2016), access to irrigation water and water security are critical factors in improving food security, increasing incomes, and in enhancing livelihoods of rural communities. The availability of plant nutrients and the characteristics of the soil are both impacted by irrigation, which may improve or decrease crop productivity. Even though there are irrigation techniques that could reduce the incidence of root-knot nematodes (Bozbuga, 2020), limited studies have been conducted in Ghana to ascertain the impact of irrigation methods on diseases attacking tomato in the field.

The use of chemical and botanicals on the management of *Meloidogyn*e spp. have been reported in literature. The synthetic nematicides are commonly used in developed cropping systems and may directly kill nematodes or by paralyzing the nematodes for a long period of time (Wen *et al*., 2017). Given the negative consequences on the environment and health of the population, farmers are beginning to apply bio-nematicides. One of the most effective ways currently used to safeguard crops against pests is the use of botanical pesticide (Singh *et al*, 2017). Several substances immobilized young root-knot nematodes at very low concentrations, and some also reduced egg hatching (Oka *et al*., 2007). In a study conducted by Kankam and co-authours, applying root-not nematodes treatment decreased nematode reproduction by 88% and tomato yield by 44% compared to the non-treated inoculated control (Kamran *et al*., 2014).

1.2. Problem Statement and Justification

The significant damage that root-knot nematodes (RKN) causes to tomato crops annually deserves special attention. RKN encounter between *Meloidogyne* spp. and tomato is centuries old. They are well recognized to result in significant economic losses across the globe. They have a diverse distribution, attacking many crops of economic importance, causing numerous losses resulting in yield reductions (Umar and Aji, 2013). However, the production and productivity of tomatoes have been greatly reduced or in some instances total crop failures are observed in some farms due to poor soil fertility and damage by plant-parasitic nematodes (PPN). Indeed, these nematodes cause a lot of damage in vegetable farms and are ranked among major limiting factors (Kane, 2018).

Many studies have been done to evaluate the root-knot nematode's potential for damage on different tomato cultivars; In the tropical area the loss is estimated between 24 to 38 % (Agbenin *et al*., 2005; Bridge, *et al*., 2005); its yield loss capacity ranges from 25 to 100% (Tileubayeva *et al*., 2021).

Nematodes that serve as parasites to crops present a serious damage, especially in light of potential financial losses. Some species of the nematodes that science is aware of exhibit great parasitic activity, which poses a serious threat to crop. However, even these genera are subject to a variety of distributional influences, the most crucial of which are the host plant and the characteristics of the soil. This study makes the assumption that the amount of water in the soil may have an indirect impact on the distribution of PPN among various tomato types and the health of these plants (Avdeenko *et al.*, 2021). The most damaging PPNs are considered to be the RKN or *Meloidogyne* spp. which are responsible for yield losses worldwide and determine the routine use of chemical pesticides (Sikandar *et al*., 2020). Other researchers who noticed that these nematode species are common in vegetables have already reported the dominance of *Meloidogyne* on vegetable crops (Altaibaeva *et al*., 2016).

The use of chemical pesticides on vegetable crops is common, and this condition poses a severe threat to global vegetable output (Sikandar *et al*., 2020). Most producers use chemicals; although, they pose serious problems including poisoning of producers, consumers and the environment, loss of soil fertility and pest resistance (Gahukar, 2012; Altaibaeva *et al*., 2016; Sikandar *et al*., 2020; Almohithef *et al*., 2020). Considering the consequences of the use of pesticides, the search for alternative ways to fight against PPNs and other insect pests is necessary. Among these alternatives, botanical extracts with nematicidal effect are one of the potential sustainable fight against root-knot nematodes (Topalović *et al.*, 2020).

Several studies have used solution substances based on neem leaves against pests. These studies have shown the effect of these extracts on the reduction of pests, their incidence and the yield of crop (Affokpon *et al*., 2012; Gahukar, 2014; Mokrini *et al*., 2018; Ayisah *et al*., 2019; Kumar *et al*., 2019). The current focus on pest management is using the combination of two or more methods for effective reduction of pests damage. Several authors (Trivedi and Barker, 1986; Deravel *et al*., 2013; Bolou *et al*., 2022) have worked on culture rotation, the use of botanical products (*Azadirachta* indica, *calotropis* procera, *Khaya* senegalensis), and products for nematodes (methyl bromide, Fosthiawate, Velum Prime), but nematodes continue to be resistant to treatment.

Unfortunately, the effect of drip irrigation, Velum Prime rate and botanicals in integrated management of the parasite was not highlighted. This study was conducted to contribute to the understanding of how watering, Velum Prime, and neem extract affect nematode infestation of tomato.

1.3. Objectives of the Study

1.3.1. General Objective

The main objective of this study was to develop an integrated management package consisting of drip irrigation, Velum Prime rate and neem extract for root-knot nematode control and improved tomato growth and yield.

1.3.2. Specific Objectives

1. Assess the interaction effect of drip irrigation, Velum Prime rate and neem extract on soil properties.
2. Measure the interaction effect of drip irrigation, Velum Prime rate and neem extract on on root-knot nematode infestation in the soil.
3. Determine the interaction effect of drip irrigation, Velum Prime rate and neem extract on growth and yield of tomato.

1.4. Research Questions

i. What is the effect of drip irrigation regime on the population of *Meloidogyne* spp. and tomato yield?

ii. What is the effect of Velum Prime rate on the management of *Meloidogyne* spp. and yield of tomato?

iii. What is the effect of neem extracts on the population of *Meloidogyne* spp. and yield of tomato?

1.5. Scope and Limitations of the Study

The study was carried out at the CSIR-SARI greenhouse located in Nyankpala, Tolon District, northern Region, Ghana, from May to August 2022. It involved testing Pectomech tomato variety under different nematode control treatments and irrigation regime. The main limitation to this study has to do with my inability to determine number of root-knot nematodes in the soil after harvest.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Introduction

One of the most significant vegetable crops in the world is tomato (*Solanum lycopersicum* L.), which is consumed by billions of people everyday (Baidya and Sethy, 2020). Tomato in terms of area occupies the first place as a processing crop and one of the main sources of income for many horticultural producers (Wossen and Berger, 2015; Ecker, 2018). Tomato production, processing and consumption are accelerating at an unprecedented rate, with more than 39.7 million tons of tomatoes produced annually in the world (Ling *et al*., 2019).

In Ghana, tomato is produced on more than 4,410 ha with an average yield of 7.2 Mt/ha and an achievable yield of 15.0 Mt/ha (Owusu *et al*., 2016). The vegetable occupies a central place in the national diet and is consumed in large quantities (Benabderrazik, 2021). In Tropical countries, such as Ghana, pests such as RNK infestations limit tomato production causing severe economic losses by reducing both the quantity and quality of marketable fruit yield (Lannoy, 2001). In Ghana, tomatoes are produced on more than 4,410 ha with an average yield of 7.2 Mt/ha and an achievable yield of 15 Mt/ha (Owusu *et al*., 2016). In hot countries, especially in Ghana, RNK infestations limit tomato production (Lannoy, 2001). In northern Ghana the loss rate in 2015 was between 73 and 100% (Saydee, 2015).

However, management strategy should focus on the early phases of the crop and should strive to safeguard the seedlings since young and sensitive seedlings of diverse crops are very much more prone to assault than older plants (Adomako *et al.*, 2017). A number of strategies have been used to reduce crop parasitic nematodes with varying degrees of success (Wabere, 2016).

To minimize the pest population in the soil, tomato growers use integrated control tactics, which include preventive measures, on-farm approaches, and curative measures (cultural, biological, and chemical).

2.2. Importance of Greenhouse Tomato Production in Ghana

The use of modern greenhouse technology was introduced into Ghana in 1996 by Prof. George Oduro Nkansah (Nkansah, O. peronal communication, 2018). Ghana's tomato industry has fallen short of its potential in terms of yield when compared to nations like Niger and Burkina Faso (Vigbedor e*t al.*, 2022). Tomato yields in Ghana have increased from the national average of 7.5 t/ha to 200 t/ha as a result of the usage of this technology in greenhouses (Nkansah, O. peronal communication, 2018). However, farmers are confronted by a number of challenges such as high input costs, poor market access, high perishability of products, competition from imports, and pest and disease problems (Denny, 2019). A crucial aspect of greenhouse production is the use of drip irrigation systems and the right application of fertilizers and pesticides, which will ensure high-quality crop nutrition and boost the capacity to bear more yield. It is crucial to create the optimal microclimate for the plants (Coleguwor, 2018).

2.3. Importance of Irrigation System

Water is of paramount importance in the life of man. “The largest worldwide user of water is agriculture which accounts for 70% of total freshwater withdrawals (FAO, 2017). There has been a global water crisis for crop cultivation for many years, and drip irrigation has been one of the most popular suggestions for resolving it. It is viewed and encouraged as a strategy to use water more effectively in national and international policy texts (World bank, 2020a). Impressive statistics and measurements typically back the idea that drip irrigation can save water.

In many applications, such as the irrigation of most vegetables, cotton, sugarcane, orchards, and vineyards, drip irrigation "has the ability to at least quadruple crop yields per unit of water," according to Postel (2000). According to research from Indian research organizations, drip irrigation typically reduces water use by 30 to 60% while increasing yields by 20 to 50% for a variety of crops such cotton, sugarcane, grapes, tomatoes, and bananas. Increased crop yields and efficient water application lead to a doubling or tripling of water productivity. According to Benabderrazik, (2021), who discovered a substantial correlation between *Meloidogyne* damage and soil conditions, particularly soil water, irrigation is crucial for tomato growth.

2.3.1. Definition of Irrigation

Irrigation may be defined as the supply of water to crops through the use of techniques that meet the needs of the plant according to the climatic, agricultural and other conditions that suit the irrigation systems chosen (Benouniche *et al.*, 2014).

Irrigation is a human chain, which obliges the farmer to bring water to agricultural crops in case of water shortage (Aichouche and Amroune, 2020). Another strategy for increasing agricultural output in both commercial and subsistence farming is irrigation farming (Adongo *et al*., 2015).

Irrigation as an abiotic factor may be conducted for the following reasons:

a) To add adequate amount of water to the soil to ensure the essential humidity for the development of the plant.

b) To refresh the soil and the atmosphere to ensure an environment that support the growth of the plant.

c) To facilitate the tilling of the soil to provide good tilth for crop establishment.

d) To refresh the formation of buds through provision of the right moisture.

2.3.2. Types of Irrigation

Irrigated crop production is typically divided into 4 categories: high input, low yield and high input, high yield (Mekonnen *et al*., 2019).

2.3.2.1. Drip Irrigation

Drip irrigation is appropriate for fields with varied soil types including, shallow soils, steep slopes, and undulating terrain (Coolong, 2016). Additionally, drip irrigation techniques have been shown to considerably reduce water evaporation from soil and increase crop yield water use efficiency. Alternative cropping techniques, such as winter crops and deep-rooted cultivars that enhance the consumption of nutrients and water stored in the soil, may be used to take advantage of such benefits (Evans and Sadler, 2008). According to Zafari and Mohammadi (2019).

The drip system typically comprises:

a. A water source that supplies the system with the necessary amount of water.

b. A control valve that facilitates opening and closing the system's water supply.

c. Injection tools that are used to inject chemicals and fertilizers into the system.

d. A filtering system that removes impurities that could clog emitters.

e. Irrigation water pressure is regulated and managed via pressure gauges.

f. Water is distributed to the laterals from the sub-main lines by the main lines

According to Giordano *et al*. (2012), drip irrigation systems are a more efficient way to manage water than dug-out irrigation and furrow, basin, or border strips, which have the capacity of high percolation losses, uneven water distribution, and application efficiencies of less than 70% (Nikolaou *et al*., 2020).

2.3.3. Objectives of Drip Irrigation

Given the demographic situation, Ghana is endowed with adequate water resources for irrigation (Worqlul *et al*., 2019). Extensification and intensification of irrigation are the answers to achieving this goal given that Africa can fulfill its goals without a considerable increase in the agriculture sector due to economic expansion and the decrease of poverty. (Adongo *et al*., 2015).

At the moment, Ghana has adequate water resources given the demographics of the nation. Total water withdrawal as a fraction of all renewable water resources is 1.8%, with irrigation accounting for an estimated 66.4% of this meager drain. Both the size and makeup of Ghana's irrigation sector and its potential for irrigation are poorly recognized. Estimates of Ghana's irrigation potential, which includes floodplains and valley bottoms, range from 0.36 to 2.9 million hectares. Determining the ideal combination of interventions for enhancing performance and productivity in this sector, as well as for improving the planning of future irrigation development initiatives, would be made possible by understanding the structure of Ghana's current irrigation sector through systematic classification (Namara *et al*., 2011). The farmer is the biggest consumer of scarce water resources and irrigation is the only source of water for greenhouse tomato production. Among the irrigation systems (traditional, sprinkler, drip etc.), the drip system is the most appropriate. Drip irrigation is the most effective water and nutrient delivery adequate amounts of technology for growing crops, (Cabibel, 2020). In this system each plant receives exactly what it needs, at the proper moment, to grow effectively. It does this by delivering water and nutrients straight to the rootzone of the plant at the appropriate times. Farmers can increase yields while using drip irrigation to conserve electricity, water, fertilizer, and even plant pesticide. Water saving is the main objective of the use of drip irrigation (Benouniche *et al.*, 2014). Drip irrigation has the following advantages:

a. Reduces water loss (water saving and efficiency) or increase productivity, (Brouwer *et al*., 1990).
b. Reduces incidences of diseases (the variation of the soil water content has a considerable repercussion on the nematofauna).
c. Ease of conducting fertigation.

2.3.4. Drip Irrigation Systems in Ghana

Global, population is increasing at an alarming rate, leading to increased food insecurity (Wazed *et al*., 2018). Water is an abiotic factor in agriculture, so agricultural expansion and irrigation can put pressure on the available water resulting in competition with other sectors and ultimately scarcity of water. Agriculture must produce more while keeping environmental issues in mind. The timing and volume of rainfall are insufficient in to meet the moisture requirements of crops many parts of the world.

Therefore, irrigation is essential for supplying food and fiber demands as well as enabling agriculture in semi-arid and arid areas to lessen drought. Given the decrease in overall precipitation and the rise in intermittent dry periods during the wet season cropping period in Ghana, the Ministry of Food and Agriculture (MoFA) is advocating small-scale irrigation (SSI) as a climate variability adaptation tool (Darimani *et al*., 2021). To increase agricultural productivity for Ghana's growing population, efficient use of available watering is important. Irrigation control is an important element in the control of nematodes: it is necessary to avoid excess water, which is promotes the spread of nematodes. For example: The watering with the ray by example are to be proscribed (Bertozzi, 2003; Saydee, 2015). A recent study showed that increased number of leaves per plant was observed with 100% ETc irrigation compared with 50% ETc as reported by Silva *et al*. (2021).

Studies on tomato showed maximum number of leaves per plant was observed with 100% ETc irrigation compared with 50% ETc as reported by Silva *et al*. (2021).

2.4. General Information on Root-knot nematodes (*Meloidogyne* spp).

All over the world, crop farmers are facing the menace of nematode pests, which are tiny worms that can destroy crops worth ruin billions of dollars annually (Bozbuga, 2020). *Meloidogynes* are thought to be the most destructive pests on vegetable crops, especially in nations with tropical and hot climates, like Ghana. Nematodes that parasitize plants are the primary cause of biotic stress in crops (Treonis *et al*., 2018). They are endoparasites, very polyphagous with a very wide host range grouping many cultivated or spontaneous botanical families.

About 5500 plant species infected by nematodes have been recorded (Abad *et al*., 2008).Thus Karsen (2002) discovered that this genus of species includes more than 100 80 specimen have been related in the world. The common ones from the point of view of damage and distribution have been have been reported to include *Meloidogyne arenaria*, *Meloidogyne javanica*, *Meloidogyne incognita*, and *Meloidogyne halpa* reported (Bozbuga, 2020).

2.4.1. Systematic Position

RKN are animals of the phylum Nematoda (Medel *et al*., 1976). The complete classification of *Meloidogyne* spp is presented in Table 2.1.

Table 2.1. The Systematic Position of Root-knot Nematodes, *Meloidogyne* spp.

Phylum	**Nematoda**
Class	Secernentea
Subclass	Diplogasteria
Order	Tylenchida
Sub-order	Tylenchina
Super- Family	Hoplolaimidae
Family	Meloidogynidae
Genus	*Meloidogyne*
Species	*Meloidogyne* spp.

2.4.2. The *Meloidogyne* Cycle

Biotrophic parasites or species of the genus *Meloidogyne* spp. are sedentary endoparasites.

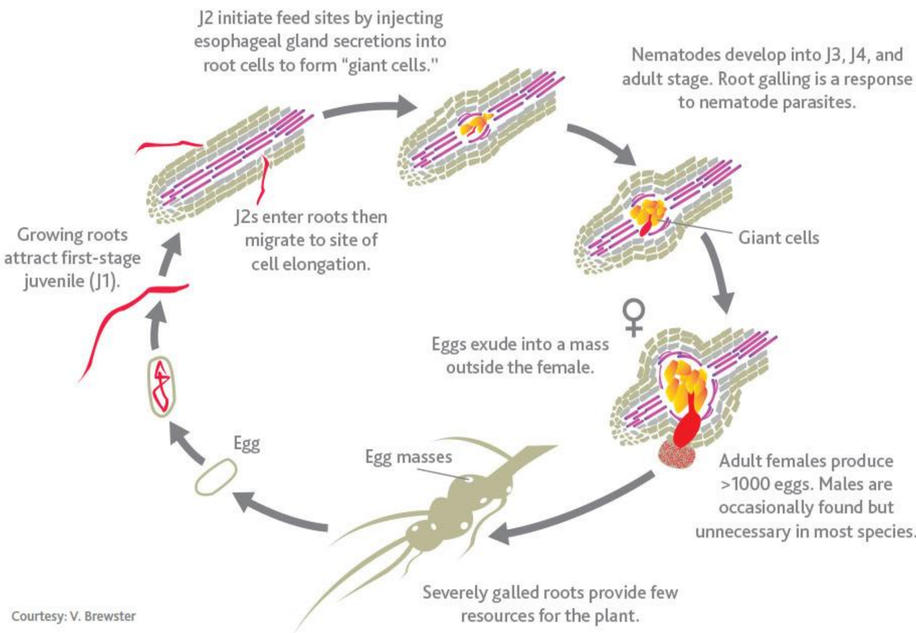

Figure 2.1. Basic Life Cycle of Root-Knot Nematode

(Source : https://www.eastman.com/Brands/Cedroz/Agronomists/Pages/Mode-of-Action.aspx)

Meloidogyne species, stationary endo-parasites with a life cycle reliant on feeding locations, are responsible for RKN. It has a straight forward life cycle with an egg, four larval stages, and an adult stage (Reddy, 2017).

2.4.3. Symptoms of *Meloidogyne* Parasitism of Tomato

Human agricultural activities have impacted the distribution of many animals. According to Edwards, (1953) during his research on RNK on weeds and crops has listed 76 host plants in Ghana. Banana, onion, bell pepper, watermelon, and tomato are the host plants that are frequently (Clerk, 1974; Saydee, 2015). It has been noted that nematode (*Meloidogyne* spp.) is responsible for the detrimental effect on tomato, which is the host plant that is most vulnerable to the disease.

Nematodes are tiny, worm-like, aquatic organisms that are widespread throughout most ecosystems. The majority of parasitic nematodes may readily live in soil, freshwater, or saltwater and feed on plants and microscopic creatures (Treonis *et al*., 2018). A few nematodes include:

I. Ecto-parasites, they remain outside the plant feeding on surface tissues by inserting their stylet into the host tissue.

II. Endo-parasites, penetrate plant tissues completely or with a large part of their body. They can be migratory in roots, stems, crown, buds and leaves.

Many plants parasitic nematodes can be discovered in the tissues of host plants when there is a lot of moisture. Reliable diagnosis is more challenging since the symptoms of nematode infection are hard to distinguish from those of many other infections and abiotic factors (Castillo and Vovlas, 2007). The primary symptom of *Meloidogyne* infection is the formation of galls on the roots. Despite variations in size and shape, these galls always have the same process of creation and fundamental structure. Stunting, chlorosis, lodging, and wilting are examples of symptoms that might appear on above-ground plant sections (Castillo and Vovlas, 2007). As soon as the parasite enters the root, the second stage larva causes the hypertrophy of the cortical cells by the secretions that it expels through its rostrum (stylet). It then migrates towards the future vascular zone along which it manages to immobilize itself, the encephalon lodged in the external part of this zone. Affected root systems may show intensely branched tips, stunted root growth and absence of root hairs and dark reddish-brown lesions (Kurniawan, 2008). Roots that have been damaged by nematodes are less efficient at uptake of soil nutrients and water. Root tissue begins to deteriorate when worms feed on it and the pace of tissue degradation accelerates as the number of nematodes feeding on the root rises (Windham and Edwards, 1999). When the swellings on the tomato roots are opened with a fine blade, small whitish beads, as big as half a pinhead, can be seen in the tissue of normal appearance and turgidity, which are the swollen adult females of the parasite.

2.5. Methods of Controlling *Meloidogyne* spp

Wilting and yellowing, wilting, root and tuber galling, stunted growth, root damage, and yield loss are all common signs of nematode infection. A sizable portion of food production depends on the efficient management of worms that parasitize plants. While plant illness can be controlled with a single operation, most infections require the use of numerous control measures and typically entail the manipulation and combination of cultural, chemical, biological, and environmental components (Singh, 2001).

The major problem with tomato production in the world is the harmful effect of RKN on the crop, which decreases yield and sometimes forcing farmers to abandon their farmlands. Since young, sensitive seedlings of different crops are significantly more vulnerable to attack than older plants, management strategy should focus on the early crop stages and attempt to safeguard the seedlings (Adomako *et al.*, 2017). A number of management methods have been used to reduce crop parasitic nematodes with varying degrees of success (Wabere, 2016).

2.5.1. Cultural Practices

Cultural practices reduce the pest population in tomato crops without the use of chemicals, such as crop rotation with resistant cultivars or non-host crops. According to (Kankam and Adomako, 2014), the implementation of these management measures may also be hindered due to the vast host range of root-knot nematodes. The use of these tactics is hampered by rising tomato production costs and consumption. Root-knot nematode populations in the soil could be decreased, for instance, by rotating or intercropping tomato and cucumber with non-host crops like garlic (Allium sativum), marigolds (Tagetes sp.), lettuce, radish, cabbage, and cauliflower (Griffith, 2000).

2.5.2. Chemical Control

In West Africa, Ghana was the second largest importer of insecticide and nematicides from the United Kingdom (Lutuf, 2015). There are no nematicides that have been approved for protected cultivation use in India as of yet. As a result, gardeners using polyhouses rely on other integrated pest management techniques to handle nematodes. Combining all preventive and curative methods is a successful tactic that local growers utilize to manage nematodes under polyhouses. Synthetic substances have long been used to control PPN. Nematicides, a chemical technique frequently employed in crop production systems, can either kill nematodes immediately or paralyze them for some times (Wen *et al*., 2017). Usually, two main groups of nematicides are used: contact nematicides (fumigants) and systemic nematicides (non-fumigants) based on their volatility in the soil.

Systemic nematicides include a variety of chemical compounds that directly affect the biology of the nematode. The most widely developed and used nematicides were carbamates and organophosphates that directly affect the nervous system of the nematode (Noling, 2014; Hajihassani *et al*., 2018; Sikora *et al*., 2018). In vegetable production, chemical nematicides have played a key role in managing nematodes. These chemical products used by farmers are quite efficient, but the current evolution of legislations compromises the future of chemical nematicides because of the problems they can cause at the sanitary or environmental level (Seid *et al*., 2015). However, most growers prefer broad-spectrum fumigants because they are less expensive and have more consistency in reducing nematode populations (Bosques, 2020). Nematicides are harmful not only to nematodes but also to humans. Connection with some chemicals during combining, employment, cleaning and storage causes certain diseases in humans. Given the negative consequences on the nature and the health of the citizens, farmers are beginning to practice biological control.

Effect of Velum Prime on Root-knot nematodes

Velum prime is a revolutionary nematicide that offers long lasting protection against root-knot nematodes (Devindrappa *et al*., 2022). According to Seshweni (2016), numerous studies have shown that Velum Prime action is efficient against nematode. However, any nematode population may contain individuals who are naturally resistant to Velum Prime (Alheyalee and Aljuboori, 2020). If this nematicide is applied regularly, the resistant individuals may eventually dominate the worm population. Velum Prime might not be able to control these hardy nematodes. By using excellent farming techniques, it is possible to keep Velum Prime effective against the resistance of nematodes.

2.5.3. Biological Control

The accumulated knowledge of farmers, combined with access to modern techniques, will be the key to sustainable agriculture (FAO, 1993). Agricultural and horticultural crops are suffering significant losses as a result of PPN. In order to control nematodes in an environmentally acceptable way, biopesticides of botanical origin have thus come to the forefront of attention today. Today, one of the most effective ways to preserve crops is through the use of botanical pesticides. Since many of them are still undiscovered, extensive research and testing are needed to find the botanical pesticides that are present in many plants in India (Singh and Prasad, 2017). In the management of nematodes, botanicals have drawn a lot of attention. There are four major ways to employ them: directly as a component of the plant, as extracts from plant parts, as compounds with nematicidal activity, and as oil seed cakes or mature crop leftovers. The indegenous knowledge of farmers, combined with access to modern techniques, will be the key to sustainable agriculture (FAO, 1993). According to Saydee (2015), botanicals also tend to protect the plant from soil-borne diseases which has been researched for several decades. This management strategy uses one or more beneficial organisms to control a pathogen. Biocontrol is more effective as a preventive treatment than as a curative method and should not be used as a stand-alone technique (Kiewnick and Sikora, 2006; Panpatte *et al*., 2016). A better understanding of the complex interactions between the microbial agent, the soil, the plant, the pathogen and the environment will lead to greater commercialization of microbial products against RKN. Several substances immobilized young RKN at very low concentrations, and some also reduced egg hatching capacity (Oka *et al*., 2007). In tomato microplot studies, reduction in nematode reproduction by 88% and increased in yield by 44% compared to the non-treated inoculated management (Kamran *et al*., 2014). Botanical products are easy to prepare, available in some places and often cheaper than chemical product. However, the level of natural control is rarely sufficient to stop the harm nematodes cause to plants.

Biopesticides, living organisms or products derived from such organisms having the characteristic of limiting or suppressing crop pests have been used for centuries by farmers (Agbenin *et al*., 2005). In recent times, they are classified in three main categories according to their origin (microbial, vegetable or animal) and present multiple advantages. They can be applied in twain conventional and organic agriculture, some of them allows plants to resist abiotic stresses and in general, they are less toxic than their chemical counterparts. Biopesticides are required for increased profit from farmers, especially in the context of integrated pest management techniques, despite their common reputation for being less effective than the latter. The future development of biopesticides depends on many constituents, such as government policies in terms of research support and regulation, the tactics of the major crop protection companies, and the evolution of consumer choices according to (Deravel *et al*., 2013).

Insecticidal properties of neem

Neem (*Azadirachta* indica) is an attractive green pant with a multitude of leaves. A "God's miracle" tree, "universal", "with a thousand virtues" (Assouma and Yacoubou, 2021), native to Southeast Asia, it has been used for thousands of years, particularly in India, for its extraordinary insecticide, medicinal and cosmetic properties. For more than 5,000 years, Indian pharmacopoeia has used its seeds, bark and leaves, and texts indicate dozens of recipes and traditional prescriptions (such as therapeutic, insecticides, antiviral, etc. (Jean, 2009). Numerous studies have shown that its phytosanitary action is efficient against over 300 species harmful organisms including (insects, nematodes, mites, fungi and bacteria) (FAO, 1993; Bélanger & Musabyimana, 2005).

2.6. Integrated Pest management (IPM)

Integrated Pest Management (IPM) is a practical and environmentally responsible method of pest control that combines a number of methods for pest and disease management (Domingues *et al*., 2015). IPM programs make use of up-to-date, thorough data on pest life cycles and how they interact with the environment. Using this knowledge in conjunction with existing pest control techniques, pest damage is managed in the most cost-effective manner, while posing the fewest risks to people, property, and the environment (Abrahamsson *et al*., 2010). IPM makes use of all effective pest control methods, including but not limited to the prudent application of pesticides.

Integrated management strategies for *Meloidogyne* spp. parasite of tomato are the preventive strategies and on-farm techniques or curative combined with chemical and/or botanical methods adopted by farmers to reduce the parasite population below economic threshold. For example, a study conducted on tomato by Aminisarteshnizi (2021) found that neem extract maximized plant height compared to the Velum Prime. Similarly, Javed *et al.* (2007) and Sekanjako (2021) reported that the application of pesticides, neem extract and Velum Prime prevented RKN eggs from hatching and stopped development of embryo inside the egg by killing the embryo or young adults of the first stage. Hadian *et al*. (2011) and Waisen *et al*. (2021) also reported that the number of tomato leaves per plant obtained with neem seed extract (5 t/ha) was higher than observed for neem cake extract (5 t/ha), neem leave extract (5 t/ha) and Velum Prime.

2.7. Overview of Tomato

2.7.1. Origin and History of Tomato

Tomato (*Solanum lycopersicum* L.) is a climacteric plant, native to the fertile valleys of Mexico. The plant with produces very small fruits was first domesticated in Mexico and improved by Aztecs. It was first cultivated and improved by the Indians of Mexico who adopted the Aztec name "tomatl", before being brought to Europe by the Spanish conquistadors. The *lycopersicon* genus includes only nine (9) wild species of which only two are edible, the "currant tomato" (*Solanum pimpinellifolium)* and the "cherry tomato" (*Solanum lycopersicum var cesariforme*) which is the ancestor of the current tomatoes (Bénard, 2009; Broglie *et al*., 2005). *Solanum* *lycopersicum var cesariforme*, could be the direct origin of the varieties currently cultivated (Idrenmouche, 2011). The cultivated tomato is diploid (2 n = 24), autogamous, of recent introduction, phenotypically quite diversified but with a very reduced genetic diversity (Philouze, 1993). According to Schumann, 1996 ; Degioanni, 1997 cited by (Bénard, 2009) claims that "as early as the 16th century, Italians were the first to consume tomatoes, especially in sauces, and so it arrived in France through Provence in the 17th century, before being popularized in Paris during the revolution". Due to its resemblance to the mandrake, the tomato has long been considered poisonous, and was associated with all kinds of evil virtues. It was therefore first used as an ornamental plant, until 1778 when it joined the catalog of vegetable seeds of Vilmorin-Andrieu According to Degioanni, 1997 ; Mikanowski, 1999 cited by (Fall, 2018). In the 19th century, the consumption of tomatoes increased when the fruits and vegetables grown in the south of France were transported to the north by rail. One variety of tomato is called PLM: Paris-Lyon-Marseille. At the same time, tomato became popular by being cultivated in family and workers' gardens. The first varietal researches will begin in the 20th century, for a more regular production of tomatoes, more resistant to diseases, and more fruitful. Production methods are also evolving, with year-round greenhouse tomato production, particularly in the Netherlands, gaining popularity. On the other hand, in the United States, the crops are still grown in open fields in a mechanized way.

The production and consumption of tomatoes have become very important, and since the 1990s, consumers have complained about the standardization of this product and the loss of taste of tomato. Currently, research is directed more towards characterization and improvement of the organoleptic quality of tomato fruit.

2.7.2. Botanical Description of Tomato

Tomato is an annual herbaceous plant from the herbaceous family; creeping port, hairy and with rather climbing stems. It is cultivated by its citrus fruit, is aromatic when crumpled. This vegetable plant size varies from 40 to 5 according to the species and the mode of culture (Fall, 2018).

The seed is hairy and small (0.003 to 0.004 g per seed); its germination is epigeous. The plant produces 7 to 14 compound leaves after the cotyledonary stage before flowering (Chaux and Foury, 1994).

Tomato can have roots that can reach 1 m in depth (Chaux and Foury, 1994), with a strong taproot that can produce a high density of lateral and adventive roots.

Tomato stem can tigernate between 2 to 4m depending on the varieties and growing conditions (Naika *et al*., 2005). Two kinds of hairs are distributed on the stem and leaves: glandular hairs that contain an essential oil, which gives the smell of the tomato and green coloration and simple hairs.

Leaves are simply arranged in spiral and they are compound, alternate, without stipules, measuring 10 to 30 cm wide and 15 to 50 cm long. Elliptical leaflets are oblong covered with glandular fur (Naika *et al*., 2005). The glandular leaflets are sometimes pinnatifid at the base. The inflorescence is a cyme of 6 to 12 flowers. The petiole measures between 3 and 6 cm.

The flower is bisexual, regular with a diameter of 1.5 and 2 cm. They grow opposite to the leaves or between them. The tube of the calyx is short and hairy, the sepals are sometimes persistent. The corolla is made up in general of six petals which can reach a length of 1 cm. Flowers are of yellow color. The androecium is formed by four stamens, the anthers have a bright yellow color and surround the stylet which has an elongated sterile end (Broglie *et al*., 2005). They are of pentameric type:

5 Sepals + 5 Petals + 5 Etamines + 2 Carpels

Tomato fruits are flattened, oval or globular in shape with a diameter that varies from 2 to 15 cm (Fall, 2018). Its color varies from yellow to red to orange when ripe. The tomato citrus can weigh from a few grams to nearly two kilograms (Naika *et al*., 2005).

2.7.3. Economic Importance and Nutritional Value of Tomato

Tomato is cultivated almost everywhere in the world, in all climatic zones and in relatively cold regions. Its volume of production on the global scale the second most important vegetable crop after the potato. In fact, a hatch of 182,258,016 million tons and an average yield of 3.83 kilos/m^2 and an amount of 4,762,129 million hectares are kept annually to this crop (FAO, 2018).

The consumption of tomato fruits contributes to a healthy and balanced diet. It is rich in vitamin C, vitamin A, B carotene, organic acid, sugar, and its richness in lycopene pigment makes it a vegetable with anti-cancerous properties (Blancard *et al*., 2009). Tomatoes are eaten fresh in salads or cooked in relish, soups etc. They can be processed into pate, puree, juice and ketchup. Canned fruits are processed products that also have an economic importance (Naika *et al*., 2005).

2.7.4. Fertilization of Tomato

A mineral fertilizer amendment was introduced to enhance soil physical characteristics and maintain soil moisture by better retaining irrigation water (Kane, 2018).

The following chronogram was adopted in the fertilization trials:

Before transplanting: a thorough fertilization with 200 kg/ha of fertilizer grade 10 – 10 - 20 (10% Nitrogen (N), 10% Phosphorus (P_2O_5) and 20% Potassium (K_2O)). 15, 30, 50 and 80 days after transplanting (DATP) maintenance fertilization with 200 kg/ha of N-P-K fertilizer (10 – 10 - 20) and 150 kg/ha of urea.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1. Description of the Study Area

The trial was conducted at the Savannah Agricultural Research Institute of The Council of Scientific and Industrial Research (CSIR-SARI) in Nyankpala, in Ghana's Northern area, in a greenhouse. Nyankpala is at latitude 9° 407532‟N and longitude 0°987150‟W, 17 kilometers west of Tamale (Figure 3.1). The area has a wet and dry season with a monomodal rainfall distribution of about 1026 mm from May to October, with peaks in August and September. The mean annual minimum temperature is 23.4 ˚C and the maximum is 39˚C (Lawson *et al*., 2013). The vegetation cover is predominantly Guinean savanna with short drought-resistant trees and grasslands.

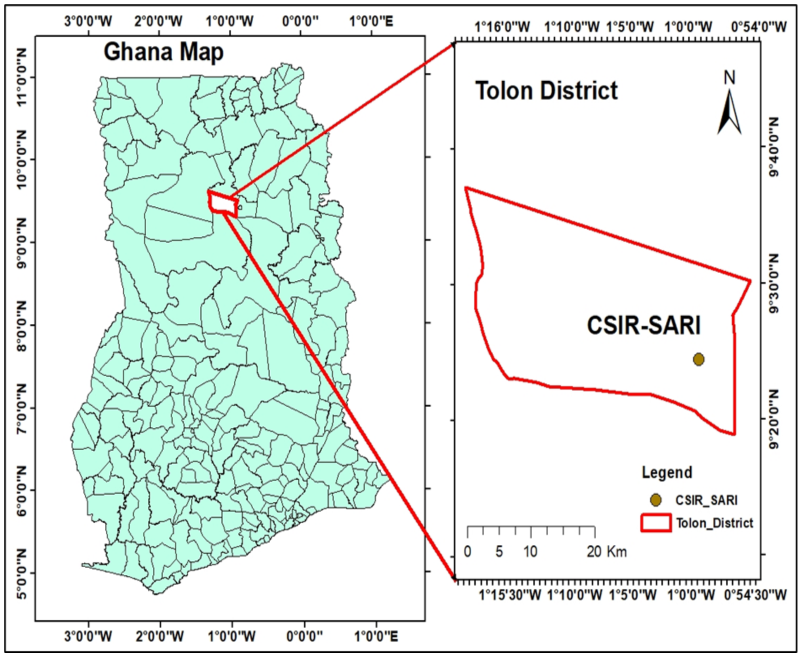

Figure 3.1. Geographical Location of SARI Greenhouse

(Field experiment, 2022).

3.2. Experimental Design and Treatments

The experiment was a 3 x 2 x 3 factorial laid out in Randomized Complete Block Design (RCBD) with 3 replications. The treatments included a drip irrigation regime of 100% crop water requirement (ETc), 75% ETc, and 50% ETc combined with Velum Prime rate of 0.625 L/ha and 1.25 L/ha and neem treatments including, as neem leaf extract at (5 t/ha), neem seed extract at (5 t/ha), and neem cake (5 t/ha).

3.2.1. Tomato Variety

The Tomato variety utilized for this experiment was Pectomech. This variety was chosen because it was commonly used by farmers in the area due to its adaptability to the weather conditions prevalent in Tamale.

3.2.2. Nursery Preparation and Practice

The nursery was carried out under the glass in plates of one hundred and four cells in order to obtain good germination and emergence of seedlings, quality plants and to reduce the duration of the nursery, which is 25 days after sowing.

3.2.3. Area Preparation

Pots were installed in the greenhouse. Plot size included nine (9) line of 3.32 m long and 2.80 m wide, giving 9.30 m^2, and the diameter of pots was 33.00 cm.

3.2.4. Soil Sampling and Analyses of Soil Physico-Chemical Properties

In order to predict the water needs of the crop, the irrigation schedule, and the application rate of neem leaf extract, neem oil, and neem cake, soil studies were undertaken to ascertain the physical and chemical characteristics of the soil. Soil samples were collected at random from four different locations on the experimental field in a zigzag pattern at depths of 0 - 20 cm, 20 - 40 cm, and a composite sample was taken for analysis. Following air drying, mixing, and sieving with a 2 mm sieve, the soil samples sub were subjected to laboratory analysis for physical and chemical characteristics in terms of soil texture, initial soil moisture content, saturation, bulk density, total amount of water available, organic matter, soil pH, porosity, and saturated hydraulic conductivity.

i. Infiltration Test

Pots of 50 cm in diameter were utilized for the experiment with four perforations which made water drainage possible. Before the commencement of the test, the bottom of the pots was filled with about 3 cm of gravels, this further eased the drainage process and prevented soil loss during the test. Water was added to the soil so that it reached a moisture content of about 6 % on a gravimetric basis. The pots were then gradually filled with the soils to the height of about 20 cm. The rate of infiltration was then determined making use of a mini - disk infiltrometer. This was done at a pressure of 2 bar (Libutti *et al*., 2021). Readings of soil water was taken every minute until total infiltration was achieved. This process was done for each of the pots. The cumulative infiltration (IC) over time was measured whereas the rate of infiltration (IR, cm / min) was obtained from the difference between two cumulative infiltration data against time (t) (equation 1).

$$Ir = \frac{(IC)2 - (IC)1}{t2-t1} \quad \text{Equation 3.1}$$

ii. Soil Texture

The soil textural class was determined using the USDA textural triangle and the hydrometer method for assessing the soil particle size distribution (Beretta *et al*., 2014).

iii. Bulk Density

To accurately determine the bulk density at the experimental plot at two (2) distinct depths (0 – 20 cm and 21 – 40 cm), core samples of undisturbed soil were taken from two (2) points. The soil samples were uniformly weighted after being oven dried for 24 hours at 105°C to determine the dry weight. The bulk density was calculated using the Callo-Concha *et al*. method (Bd) as presented in Equation 3.2.

$$Bd = \frac{Ms}{Vc} \quad \text{Equation 3.2}$$

where, Bd = bulk density (g/cm^3)

Ms = dry weight of soil (g) and

Vc = total volume of soil in the sampler (cm^3).

iv. Saturated Conductivity

$SC = \frac{M1-M2}{M2-M3} \times 100$ ……………………………...………………………………Equation 3.3

where, M1 = mass of saturated soil core (g)

M2 = mass of oven dried soil core (g)

M3 = mass of empty core (g)

v. Field Capacity

The moisture content at Field Capacity was determined using the pressure plate apparatus method, the collected soil samples were saturated in water for a day (24 hours), before placing in the apparatus. Moisture extraction was done at a pressure at 0.33 bars (Protocol for Analysis, 2021).

vi. Permanent Wilting Point (PWP)

The minimum point at which a plant may access water is when the quantity of water in soil is held by forces greater than 15 bars, and is referred to as the PWP (Ewaid *et al.*, 2019). The membrane device was used to determine this Permanent Wilting Point. The semi-disturbed sample was soaked in this arrangement and put inside a metal. After the samples were saturated for 24 hours, a 15-bar compressor high-pressure was achieved in the pressure membrane extractor. When the samples reached equilibrium, they were taken out, weighed (W_1), oven-dried at 105° C, and weighed (W_2) once again as presented in aquation 3.4.

$W1-W2 = PWP$ ……………………………………………………………... Equation 3.4

Where:

Permanent wilting point (PWP) (%)

W1 = Soil's initial weight before drying in the oven (g)

W2 is the soil's final weight following 105° C. drying (g)

3.2.5. Soil Chemical Analysis

Soil samples were collected from the WACWISA field at depths of 0 – 20 cm and 0 – 40 cm in the soil profile. The entire field was laid in blocks and the soil samples were taken from each block, and composite samples was obtained for the analysis at the UDS Nyankpala soil laboratory to determine pH, EC, and organic carbon (OC).

3.2.6. Soil Sampling and Nematodes Extraction

i. Soil Sampling

In the Northern Region of Ghana, at the Kumbungu and Tolon Districts, respectively, soil sampling was done at the Bontanga and Golinga irrigation schemes; three (3) plots were sampled: a rice field, an old tomato field (not cultivated) and an okra field. In each elementary plot, the sample was taken at a depth of 20 cm with an auger using the Z method (Figure 3.2). The auger is driven into the ground and then carefully removed to leave the soil in its place as it was in the field. Thus, 3 sub-samples per elementary plot were taken and mixed in a bag to form a composite sample. This composite sample was collected in a well-labelled transparent plastic bag and stored in a cooler for transport to the CSIR-SARI pathology laboratory. The procedure is the same for all elementary plots.

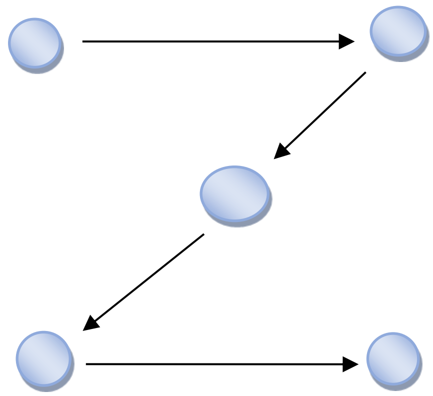

Figure 3.2. Soil Sampling Method at Bontanga and Golinga Irrigation Schemes (Sampling Design). *(Field experimental,2022)*

ii. Nematodes Extraction from the Soil

Soil nematodes were extracted according to International Standard 23611-4 using modified Baermann method (Whitehead and Hemming, 1965). 20 g of each sample was sieved (1 mm mesh) to get rid of the gravel and then placed on the double-ply tissue paper on top of the sieve and the tray containing 240 ml of water. Within 24 hours the nematodes passed through the sieve into the water in the tray. This was collected in 200 ml beakers and allowed to stand for 5 minutes, a rubber hose was introduced into the beaker to reduce the solution from 200 ml to 50 ml. The solution was transferred to a 50 ml beaker then observed and with the binocular magnifying glass at magnification (x) 2000.

The solution was divided into 4 equal parts, poured on petri dishes and observed with the binocular magnifier x 2000; after which pots were inoculated.

3.3. Drip System Installation and Testing

3.3.1. Installation of Drip Irrigation System

The system includes a water supply, main and sub main lines, laterals, and drip emitters. Pipe water served as the irrigation system's water supply. This was acquired at Tamale, after which it was transported to Nyankpala. A tanker was used to pump water into a 10,000 L PVC polytank that was used as a storage reservoir. Low-density polyethylene pipes measuring 16 mm (LDPEP) and the corresponding fittings were used to install the system. The drip irrigation system included a screen filter that was used to filter impurities out of the water to prevent emitter clogging, a mainline of one inch that supplied water to nine sub-mains of one inch, nine (9) sub-mainlines that supplied water to three replications, and nine lateral that carried water inside the plant. The drip tape's emitters were positioned 40 cm apart so that each emitter could feed water to a single plant. One emitter's discharge rate was 1 L/h. The polytank had to be manually opened and closed in order to regulate how much water was emitted from each emitter.

3.3.2. Testing of Irrigation System

After installation, the system was checked for leaks, pressure variations, and non-uniformity. This involved estimating the volume of water flow per period, a distribution uniformity test was conducted. Catch cans were positioned at random over the entire experimental site, and the water volume was measured against time. After which amount of water collected from each catch can against time was noted and arranged in descending order. Additionally, catch cans were positioned in each of three replications, with the amount of water collected per unit time being recorded. The four lowest values from each replication were averaged and average of all the values in each replication was noted. Distribution uniformity of more than 80% were considered acceptable (equation 3.5).

$$DU = \frac{\text{Average of the all lowest} * \frac{1}{4}}{\text{Total Aerage}} \quad \text{...Equation 3.5}$$

Where: DU = Distribution uniformity (%)

3.4. Irrigation Water Requirement (IWR)

The following estimations were used to determine how much water the plant will require throughout the growing season.

- **Estimation of Crop Water Requirement**

The Meteorological Station provided the climatic database and for the 51 years (1970 - 2021), which were taken from the CLIMWAT 2.0 climatic database to be used in conjunction with the CROPWAT program (FAO, version 8.0). This which enables the calculation of irrigation for various crops for a variety of climatological stations around the world (Ewaid *et al*., 2019). CLIMWAT includes the location's coordinates and altitude together with seven long-term monthly climatic characteristics. The monthly average and minimum temperatures (degrees Celsius), wind speed (kilometers per hour), mean relative humidity (percent), sunshine hours (hours), rainfall data (millimeters), and effective rainfall (mm) where used as the metrics. The FAO Irrigation and Drainage Paper 56 was used to determine the crop coefficient (Kc) for tomatoes (Allen *et al*., 1998; Ewaid *et al*., 2019). The beginning, mid-season, and end-season Kc values are 0.90, 1.15, and 0.80, respectively. Daily crop coefficients for development and late season were interpolated based on the Kc values of the crop and the length of each growth stage. The growth stages are 20 days, 30 days, and 40 days, respectively, for early development, midseason, and late season) (equation 3.6).

$ET_c = ET_0 \times K_c$ .... Equation 3.6

where:

ET_c = It is the ratio of the crop ETc to the ET_0

ET_0 = is the evapotranspiration

K_c = is the crop coefficient

For localized irrigation systems with a ground cover (Pd) of 95%, the equation by Keller and Bliesner (1990) was used to convert the ETc to ETcrop-loc. The adjusted ETc was then determined using aquation 3.7:

$T_d = U_d \times (0.1 \times (P_d)^{0.5}$ …………………………………………………………… Equation 3.7

$T_d = ET_{crop-localized}$

$ET_{crop-localized}$ = estimated ET_{crop} at peak demand for localized irrigation (mm/day)

U_d = conventionally estimated peak ET_{crop} (mm/day)

P_d = percentage ground cover (%)

- **Estimation of the Net Irrigation Requirement (IRn)**

Improved irrigation management in the field is determined by a good understanding of crop water needs and irrigation schedules. The IRn for this experiment became the modified ETc under the suppositions of no leaching (LR) and no leaching (Pe) (Petkov, 2021). Losses incurred during the application of the water were not taken into account by the IRn. The formula: was used to determine the IRn.

$IR_n = ET_c - P_e$

Note, P_e = 0, therefore, $IR_n = ET_{crop-localized}$

- **Estimation of the Gross Irrigation Requirement (IR_g)**

In calculating the gross irrigation requirement, water losses that occurred during transportation and application in the field were taken into consideration. Due to the use of the drip application method, a field application efficiency (Ea) of 95% was used to calculate the gross irrigation demand. According to Coolong (2016), the application efficiency of drip irrigation typically ranges between 90% and 95%. Equation 3.8 was used to determine the gross irrigation requirement:

$$IR_g = \frac{IRn}{Ea} \quad \text{.......Equation 3.8}$$

Where:

IR_g = Gross irrigation requirement (mm)

IR_n = Net irrigation requirement (mm)

E_a = Field application efficiency (%)

3.4.1. Irrigation Scheduling

The following methods were taken to arrive at the estimations, which were then used to schedule the irrigation water.

- **Estimation of Available Water Content (AWC)**

The available water (15 bars) is the difference between the Field Capacity (0.33) and permanent wilting point (Waller and Yitayew,2016).

$$AWC = FC - PWP \quad \text{.......Equation 3.9}$$

Where:

AWC = Available water content

FC = Field capacity

PWP = Permanent wilting point

- **Estimating Total Available Water (TAW) of the Soil:** TAW was computed using equation 3.10;

$TAW = (\theta_{FC} - \theta_{WP})\ Zr$ …………………...……………………………………Equation 3.10

Zr = depth of the root zone

θFC = will be the soil water content at field capacity (%),

θWP = water content at the wilting point (%)

- **Estimation of Readily Available Water (RAW) of the Soil**

The easily accessible water for this experiment was determined by dividing the available water content by the management-permitted depletion (equation 3.11).

$RAW = AWC \times MAD$…………………………………………………………. Equation 3.11

where:

RAW = Readily available water to plant at all times,

AWC = Available water content,

MAD = Management allowable depletion that was selected concerning soil texture, crop, climate and it should not affect the yield.

For the RAW to be converted to the volume it was multiplied by crop area (intra spacing × interspacing).

RAW (liters) = RAW (mm) × Crop area (m^2) × 1000………….....………………. Equation 3.12

- **Estimation of the Maximum Irrigation Interval (days)**

$ID = \frac{RAW}{Rn}$ ………………………………………………......…………………. Equation 3.13

Where:

ID = The maximum irrigation interval or the irrigation frequency (days)

RAW = The readily available water (liters)

IR_n = The net irrigation requirement in (l/day)

All irrigation were completed in order to restore the field's capacity.

- Estimation of the Irrigation Run Time (hours)

$Ta = \frac{IRg}{Q}$

where:

Ta = Irrigation run time (hours),

IRg = The gross irrigation requirement (l),

Q = Emitter discharge (l/h),

By multiplying the data by 60, the irrigation run duration was converted from hours to minutes.

- **Estimation of Water Content for Next Irrigation**

WNI = FC – (AMC) MAD………………....…………………………………. Equation 3.14

where:

WNI = Water content for next irrigation (liters),

FC = Field capacity,

AMC = Available Moisture content,

MAD = Management Allowable Depletion (%)

3.4.2. Cultural Practices

3.4.2.1. Transplanting

The replanted seedlings were strong and healthy. Before transplanting, the nematode- inoculated pots were cleared of weeds and irrigated to Field Capacity. Tomato seedlings were transplanted using a 40 cm spacing between plants, two plants per pot, and a total of 36 plants per plot. Early in the morning, the seedlings were transplanted into holes that were 10 cm deep in the pots.

3.4.2.2. Trellising

By supporting the plants with twine ropes, the trellis system in the greenhouse was utilized to train the tomato vines for better growht.

3.4.2.3. Fertilizer Application

After transplanting, liquid NPK Grower fertilizer grade 15: 15: 15 was applied at 2 L/ha at 1 WATP. The NPK fertilizer grade 23:10: 5, 2% + MgO + 3% S + 0.3% Zn was then applied at 584 kg/ha, with the basal dose of 5 g per pot of diameter 0.33 m at 2 WATP and top dressed with 1 ml/L foliar fertilizer at 5 WATP.

3.4.3. Plant Protection Data

3.4.3.1. Chemical Control

Velum Prime is effective on RKN. For crops grown under cover such as tomato, the chemical at 0.625 L/ha and 1.25 L/ha was applied with a sprayer at 5 DATP repeated at 25 DATP.

3.4.3.2. Biological Control

Pesticidal plants could be used as an alternative to chemical pesticides for the management of bio-aggressors of vegetable crops (Bolou *et al*., 2022). Indeed, various species of botanical plants, for example, Neem can be used in the form of plant extracts (aqueous extracts, essential oils or cake) as foliar protection (Nahak and Sahu, 2015) to control pests. Neem is an amazing natural phytosanitary plant, which we call "the miracle of God".

- **Neem Leaf Extract Preparation and Application**

The materials used in the preparation of neem leaf extract include the following: Neem leaves (*Azadirachta* indica); 125g dry chilly; 125 g of garlic; 250 g rapped plain soap; ¼ L oil. Grinder (mortar and pestle), Basin for harvesting and preparation of plants pair of shears and secateurs, sieve or fine strainer, funnel for filling the water and 20 L storage cans.

- **Preparation and Treatment**

The preparation results from the fermentation of a broya in water in a controlled and spontaneous way. This includes grind or peel a basin of Neem leaves (broya), with 125 g of dry chili pepper and 125 g of garlic, as well as 250 g of grated soap. The whole product obtained was diluted in a 20 L storage container, and finally stirred. Every morning the container was opened for 5 minutes, then we close it and this was repeated for a week: that is to say seven days. Thereafter, the mixture was filtered with a fine cloth followed by the addition of ¼ L of oil and then stirred. At the time of the treatment, we realized a dilution of 1 L of the finished product; for 4 L of water. The diluted product was then ready to be sprayed on the plants, 5 DATP and every 10 days intervalles.

- **Neem Seed Extract Preparation**

Moldy seeds were sorted out and the remaining good seeds were dried in a thin layer under well ventilated shed. The dried seeds were stored in bags in a dry place for later use. A mortar and pestle were used to crush the seeds gently to remove the shell without breaking the kernel. Separate the hulls from the almonds, sorting to remove moldy almonds. The almonds were crushed gently so as not to extract the oil. A 1.5 kg of the powder obtained was mixed with 10 L of water and the mixture was allowed to stay overnight. The mixture was filtered through a fine cloth to obtain the extract. The extract was diluted to 5% by adding 1.5 L of the extract to 10 L of water. Liquid soap (ordinary soap) was then added at a rate of 100 milliliters for 10 L of solution. Considering the fact that the solution is very sensitive to the sun, spraying was done in the evening at 5 DAT and repeated at 10 days intervals.

- **Neem Cake Preparation**

The by-product of the solvent extraction process of the neem as well as the cold pressing of neem fruits and kernels is known as the biotic manure of neem cake. Because of a component that stops soil microbes from turning nitrogen molecules into nitrogen gas, neem cake appears to increase soil fertility. It is a nitrification inhibitor and extends both the short-term and long-term availability of nitrogen to crops. Because it still contains limonoid, organic manure derived from neem cake shields plant roots from worms. Neem cake could cause stunting and even plant dieback (phytotoxicity) if applied after transplanting. Nematicidal action of the cake on nematodes and on soil fertility is only apparent after some time. For these two reasons, neem cake was applied (5 DATP and every 10 days). An application of 5 t/ha of neem cake was done.

3.5. Plant Sampling

Plants were properly identified with colorful, numbered ribbons preferably attached to a hook. Growth measurement: weekly growth, chlorophyll and length of mature leaf was taken. Each week, the string at the end of the plant was marked with a felt pen. The distance between 2 marks gave us the weekly growth. Weekly growth was obtained by measuring the distance between the apex and the mark made with a felt pen on the rope during the previous week, which became our growth point to measure. The measurement at the tip of the plant stopped at the apex of the growing part of the plant, ignoring the young leaf which later pointed up. The diameter of the stem (indicator of the vigor of the plant) was taken during the growing process (mark of the previous week). When there was an obstacle such as a cluster or a leaf, the measurement was taken just below.

3.5.1. Agronomic Data

Eighteen (18) tomato plants were randomly selected from each plot and tagged. These plants were then monitored throughout the growth season, and the following data sets were gathered from the field.

- **Plant Height:** Each of the tagged plants was measured at two weeks intervals until 8 WATP. The height of the plant was measured from the base to the tip of the youngest leaf using a meter rule.

- **Number of Leaves:** At two weeks interval until 8 WATP, the leaves of the tagged plants were counted and the average were recorded.
- **Chlorophyl Content:** the chlorophyll content of tomato leaves was taken from 6 WATP from 3 leaves per plant from the tagged plants with the aid of a SPAD meter.
- **Number of Flowers per Plant:** The number of flowers per plant was determined by counting for each of the tagged plants and the averages recorded.
- **Fruit Set Rate Per Plant:** This rate was calculated as a percentage of total flowers as flowing:

$$\text{Set rate} = \frac{Total\ number\ of\ flower - \text{aborted}\ flower}{\text{Total number of flowers}} \times 100\% \ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 3.15}$$

- **Number of Fruits per Plant:** The number of fruits per plant was determined by counting for each treatment.
- **Yield (t/ha):** The weight of the fruit (kg) was multiplied by the plant population per hectare and the result divided by 1000.

3.5.2. Data Analysis

The data collected were arranged in Microsoft Excel (2019) and subjected to Analysis of Variance (ANOVA) using GenStat 12th edition statistical package. The factorial treatment combination of irrigation level, Velum Prime and neem products in General Treatment Structure (in Randomized Blocks) was used to analyze the data. The differences in treatment means were compared using the least significant difference (LSD) at the 5% probability. The relationship between, yield, and yield components was examined using correlation analysis.

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. Soil and Water Properties

4.1.1. Physical Properties of Experimental Soil

Laboratory analysis of the physical properties of the experimental soil showed that the soil texture was clay loam. The soil bulk density ranged from 1.37 to 1.43 g/cm^3 across soil depth of 0 – 40 cm with topmost layer recording the least. Field Capacity was 31.70% for the topsoil (0 to 20 cm deep) and 31.90% for the sub-surface soil (20 to 40 cm deep). On dry weight basis, the soil moisture content at the Permanent Wilting Point decreased with soil depth from 18% and 19% (Table 4.1).

Table 4.1. Soil Physical Properties of the Experimental Site.

Soil physical properties	**Soil Depth**	
	0 – 20 cm	**20 – 40 cm**
% Sand	42.00	43.60
% Clay	30.00	31.00
% Silt	28.00	25.40
Soil texture	Clay loam	Clay loam
% Gravel by Mass <2mm	43.30	53.40
Total organic matter %	2.10	1.40

Permanent wilting point %	18.80	19.20
Field capacity %	31.70	31.90
Bulk density (g/cm^{-3})	1.37	1.43
Soil Moisture content	15.20	16.10
Porosity %	36.20	52.20

(Field Experimental, 2022).

At the experimental field, the soil had Clay loam texture with 43.60% sand and 31.00% clay and 25.40% silt across the soil depths. The result is comform with the findings of Ochsner *et al.* (2001) and Ahmad and Li (2021) who reported that the soil texture in Nyankpala varied from clay to clay loam and is generally rich in clay content.

The bulk density of soil is regarded as a index parameter since it is related to soil compaction and a number of other physical, chemical, and biological characteristics. The top surface soil layer (0-20 cm) had lower bulk density value than the sub-surface layer, which might be attributed to high organic matter concentration in the top soil. The bulk density of the soil at the time of the experiment ranged from 1.37 to 1.43 g/cm^3. According Carter (1990) and Shammary*et al*. (2017), the bulk density generally within desirable range for mineral soils, ranges from 1.10 to 1.60 g/cm^3 (Lu *et al.*, 2014; Martín *et al.*, 2017). Thus, the soil used in this experiment was suitable for maximum air and water flow for crop root growth (Shammary *et al.*, 2018).

The soil organic matter was low and decreased with increasing soil depth. The results are similar with the report of Shammary *et al.* (2018) and Mokrini *et al*. (2018) who stated that organic matter decreases bulk density, as noted in this experiment. The soil organic matter might have influenced the soil moisture content at field Capacity, although there was minimal difference between the top soil (31.90%) and sub-surface soil (31.70%).

Generally, field capacity of clay-loam soils ranges from 23 to 35% (Assouline and Or, 2014: Andrenelli *et al*., 2016). Thus, the values recorded in the current investigation were within the range reported earlier. Additionally, there were variations in the moisture content at the permanent wilting point, which ranged from 18.90% to 19.20% on weight basis (Table 4.1) and these results conform with the range indicated by Busscher (2009).

Infiltration rate

The soil water infiltration rate in this experiment was 31.30 mm/hr upstream and 27.30 mm/hr downstream, with an average of 29.30 mm/hr (Figure 4.1).

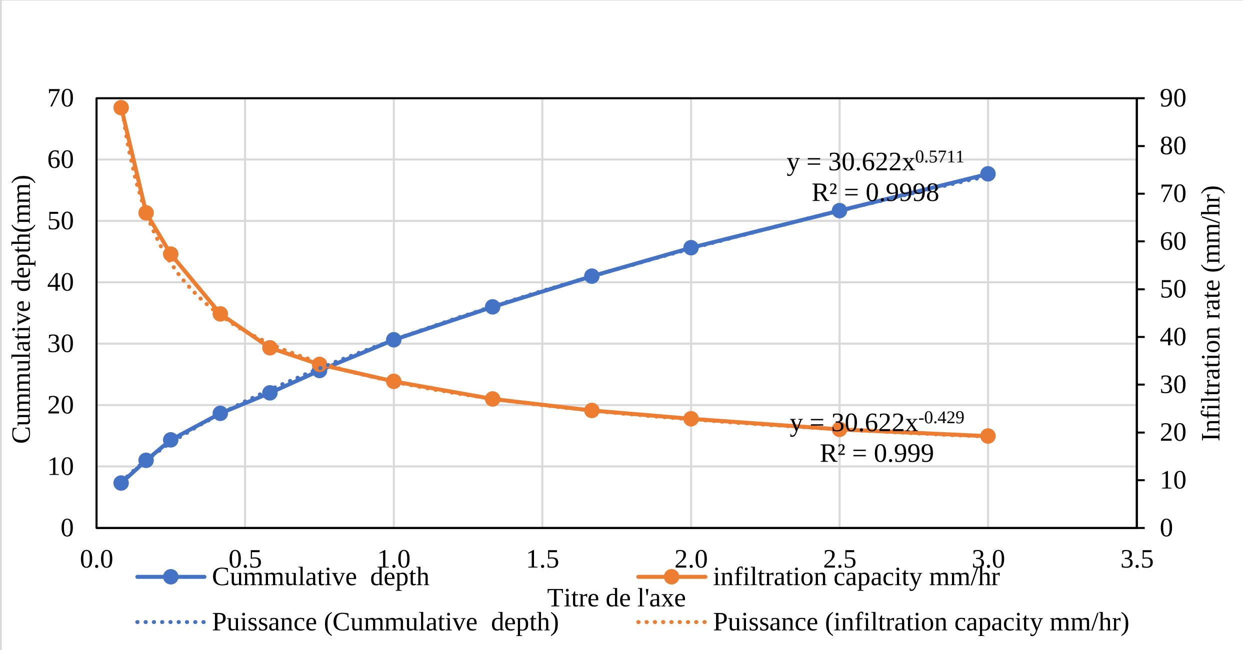

Figure 4.1. Infiltration Rate and Cumulative infiltration Depth for Upstream before the Experiment. *(Field Experimental, 2021).*

The average infiltration rate in this experiment was 29.30 mm/hr, which is comparable to findings for a vegetated Clay loam soil, which is within the 20 – 30 mm/hr range (Libutti *et al.*, 2021). This indicates that it takes an hour for water to permeate 29.30 mm of soil layer. See and Ward (1990) both defined this rate (29.30 mm/hr) as moderately invading.

4.1.2. Soil and Irrigation Water of Chemical Properties

The pH value of the soil used in this study ranged from 6.7 to 6.8 with the sub-surface giving the highest pH value (6.8). Organic carbon level was high at subsoil depth of 1.18 to 1.19%, whilst organic matter varied from 2.36 to 2.38% across to soil depth (Table 4.2). The irrigation water chemical analysis showed a pH of 7.9 which was considered normal. Table 4.2, shows the irrigation water’s electrical conductivity (EC) was 241 (µ/cm) and irrigation water’s nitrate was 34ppm.

Table 4.2. Analysis of Chemical Properties of Soil and Irrigation Water.

Soil Chemical Properties			**Soil Depth**		
	0 - 20 cm			**20 - 40 cm**	
EC (µS/dm)	28.90			28.70	
pH	6.70			6.80	
O.C (%)	1.18			1.19	
O.M (%)	2.36			2.38	
Irrigation Water	**pH**	**EC (µ/cm)**	**Salinity(µ/cm)**	**TDS (ppm)**	**$NO3^-$**
	7.90	241.00	14.40	120.30	34.00

EC = Electrical conductivity, O.C = Organic carbon, OM = Organic matter TDS = Total dissolvable solids

(Field experiment, 2022).

The findings of the soil chemistry analysis by electrometric method showed that the pH value varied between 6.70 and 6.80. The soil reaction of the study region was identified as mildly acidic by Woźnica *et al.* (2019), with a classification range of pH 6.50 - 6.90. Interestingly, pH range of 6.50 to 7.00 predisposes availability of majority of nutrients to plants (Zhang *et al.*, 2005; Woźnica *et al.*, 2019). In the experimental field, the soil had high electrical conductivity

(Table 4.2); and could be classified as saline (Zhang *et al.*, 2005) and Woźnica *et al* (2019), respectively.

The topsoil profile had the least amount of organic carbon, while the lower layer of soil contained the most. Soil organic carbon values between 0.50 and 1.50% is regarded as low, and since the soil in the study area had less than 3% OC, is an indication that the soil is poor in nutrients (Nocita *et al.*, 2013). This is consistent with similar studies that found nitrogen as the most restricting soil nutrient due to low OC content and its high volatility and ease of leaching (Plante and Parton, 2007). The results also indicates that the irrigation water with an Electrical Conductivity (salinity) of 241 µ/cm was in class one (C1), revealing sustainability for irrigation and low in salinity hazard as stated by Ohtsuka and Komatsu (2005).

4.1.3. Crop Water Requirement of Tomato

The highest net irrigation water application per experiment period was 508 mm under the 100% ETc irrigation regime, while the minimum was 254 mm under the 50% ETc highly stressed regime (Table 4.3). The 90% field application capacity method was used to compute the highest gross irrigation seasonal water need (564 mm), which was obtained from 100% ETc, while the lowest of 50% ETc, was from 282 mm.

Table 4.3. Crop Water Requirement Irrigation Regimes of Tomato.

Month	K_c	ET_0	100% ETc (mm/dec)	75% ETc (mm/dec)	50% ETc (mm/dec)
May	0.90	5.68	51.12	38.34	25.56
May	0.90	5.68	51.12	38.34	25.56

May	0.90	5.68	51.12	38.34	25.56
Jun	1.15	4.92	56.58	42.44	28.29
Jun	1.15	4.92	56.58	42.44	28.29
Jun	1.15	4.92	56.58	42.44	28.29
Jul	1.01	4.33	43.73	32.8	21.87
Jul	1.01	4.33	43.73	32.8	21.87
Jul	0.08	4.33	43.73	25.98	17.32
Aug	0.80	3.89	31.12	23.34	15.56
Aug	0.80	3.89	31.12	23.34	15.56
Total			508.00	381.00	254.00

(Field Experiment, 2022).

Water is necessary for plant growth and development. Based on the seasonal water application depth from transplanting to harvest, the seasonal crop water requirements of tomato varied depending on the treatment. The control treatment (100% ETc) produced the maximum net irrigation water application of 508 mm, whereas the minimum net irrigation water application of 254 mm (50% ETc) was produced by the stressed treatment. The 90% field application capacity method was used to compute the highest gross irrigation seasonal water need (564 mm), which was obtained from 100% ETc, while the lowest 50% ETc gave 282 mm.

Kuscu *et al.*, (2014) obtained an optimal irrigation application rate of 512 mm for tomato seasonal water requirement. As anticipated, the full irrigation regime of 100% ETc had the highest seasonal ETc, which was undoubtedly caused by the favorable soil moisture during the cultivation period. In contrast, the treatment with the highest water deficit provided the lowest seasonal crop water demand (50% ETc). The results from the study are consistent with the predicted 2011 values of seasonal ETc for tomato (512 mm for the treatment with full irrigation (Kuscu *et al.*, 2014; Zhang *et al.*, 2017; Cui *et al.*, 2019Ewaid *et al.*, 2019 and Wu *et al.*, 2021).These authors found that depending on the environment, humidity, wind, and tomato-growing season, the water requirements of tomatoes ranged from 400 to 600 mm

4.1.4. Nematode (*Meloidogynes*) count

A total of one thousand three hundred and eighty-four (1384) nematodes were collected from seventy (70) water samples at Golinga and thirty-two (32) nematodes from ten (10) samples at Bontanga irrigation scheme. After the analysis, the total quantity of water in which nematodes were found at Bontanga and Golinga was 10.5 L from which 159 ml was applied per pot to infest the experimental soil. The density of nematodes per volume of water found in the sampled soils was higher than reported earlier (Kwara *et al.*, 2014: Avdeenko *et al.*, 2021). The results of this study showed greater populations of plant parasitic nematodes in the soils of northern Region, Ghana, which calls for urgent soil management practices.

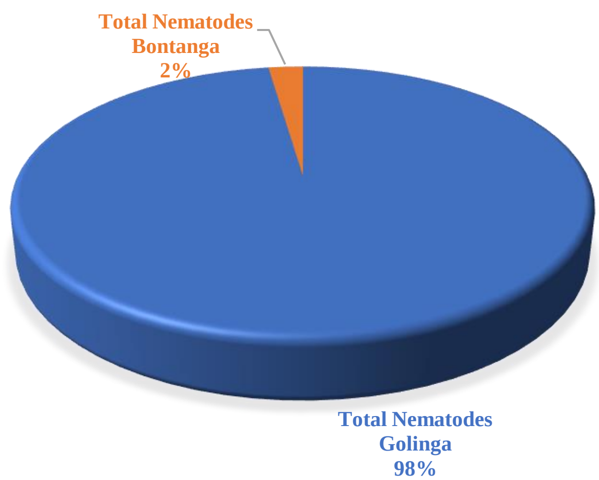

Figure 4.2. Nematode count from Bontanga and Golinga irrigation scheme waters
(Field Experiment, 2022).

4.1.5. Distribution Uniformity of the Drip Irrigation System

When employing drip irrigation systems, indicates how evenly water is spread. When the irrigation application is not constant, of the irrigated area will get varying quantities of water applied. To calculate the DU, 12 Catch cans were used in each replication. The distribution uniformity of the experimental site was found as 90.3 % in the field, with the second replication recording the highest DU at 90% and replications 1 and 3 recording the least at 88% (Table 4.4).

Table 4.4. Distribution Uniformity Test Values.

Replications	DU (%)	Qa (l/h)
Replication 1	88	44
Replication 2	95	43
Replication 3	88	44

(Field Experimental, 2022).

The DU at this experimental drip irrigation system varied from 88% to 95% (Jamrey and Nigam, 2018: Lozano *et al.*, 2020: Kah, 2021). These results are in agreement with earlier reports which indicated that the DU value of a drip irrigation system range from 85% to 100%.

4.2. Effect of Irrigation Regime, Velum Prime rate and Neem Extract on Tomato

4.2.1. Plant Height at 4, 6 and 8 WATP

At 4 WATP, both interactions and main effects were not significant ($p > 0.05$) on plant height. However, at 6 WATP, plant height was significant influenced by all interactions and main effects ($p < 0.001$)*;* except Velum Prime rate by neem extract ($p < 0.01$). Similarly, at 8 WATP, plant height was significantly influenced by all interactions and main effects at ($p < 0.001$); except Velum Prime rate by neem extract ($p < 0.01$).

At 6 and 8 WATP, the results obtained showed that plants treated with full irrigation (100% ETc), 1.25 L/ha Velum Prime and 5 t/ha neem seed extract gave the highest plant height of 80.67 cm and 90.70 cm respectively (Table 4.5). However, 50% ETc with 0.625 L/ha of Velum Prime and neem cake (5 t/ha) gave the least 47.60 and 54.00 cm respectively at 6 and 8 WATP.

Table 4.5. Effect of Irrigation Regime, Velum Prime rate and Neem Extract on Plant Height per Plant at 6 WATP and 8 WATP.

Irrigation Regime	Velum Prime	6 WATP			8 WATP		
		Neem Extract (t/ha)					
(% ETc)	(L/ha)	NC	NL	NS	NC	NL	NS
50%		47.60fg	66.70f	57.00fg	54.00f	62.67f	60.00fg
75%	0.625	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%		54.00f	54.00f	56.00fg	59.00fg	61.00f	63.00ef
75%	1.25	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).

The interaction effect of irrigation by Velum Prime rate by neem extract was significant on plant height at both 6 and 8 WATP. Plant height was highest with irrigation 100% ETc by Velum Prime (1.25 L/ha) and neem seed extract (5 t/ha). The results revealed that water, Velum Prime and neem seed extract have the potential to improve the growth of tomato plant. Plants treated with 100% water and neem seed gave the highest plant height, as compared to 50% ETc with 0.625 L/ha Velum Prime and neem cake extract (5 t/ha). These results clearly revealed the potential of water, Velum Prime and neem seed extract to improving tomato growth. This was in line with a study conducted on tomato by Aminisarteshnizi (2021) who reported that neem extract increased plant height as compared to the Velum Prime. Javed *et al.* (2007) and Sekanjako (2021) earlier found that the neem extract and Velum Prime can prevent RKN eggs from hatching and stop the development of the embryo inside the egg by killing the embryo or young adults of the first stage before the could hatch.

4.2.2. Number of Leaves ($\sqrt{(x + 0.5)}$) at 4, 6 and 8 WATP

At 4 WATP, analyses of the results indicated that the irrigation level of Velum Prime rate by neem extract, Velum Prime rate by neem extracts, irrigation level by neem extract and irrigation by Velum Prime rate and also the main effects of Velum Prime rate and Neem extract were not significant ($p > 0.05$) on number of leaves per plant. However, irrigation regime had significantly ($p < 0.001$) effect on the number of leaves per plant. According to these results, full irrigation (100% ETc) produced more leaves per plant than 50% ETc, but similar number of leaves was obtained with 75% ETc (Figure 4.3).

At 6 and 8 WATP, the analyses of variance indicated the interaction between irrigation by Velum Prime rate by neem extract, irrigation regime by neem extract, and main effects were significant ($p < 0.001$) on number of leaves. However, irrigation regime by Velum Prime rate, Velum Prime rate by neem extract were not significant ($p > 0.05$). The full irrigation regime (100% ETc) with Velum Prime rate (1.25 L/ha) and neem seed extract (5 t/ha) gave highest number of leaves per plant (4.94 and 5.29) respectively whilst the 50% ETc with Velum Prime (0.625 L/ha) and neem cake extract (5 t/ha) had the least values (3.43 and 4.18) respectively at 6 and 8 WATP (Table 4.6).

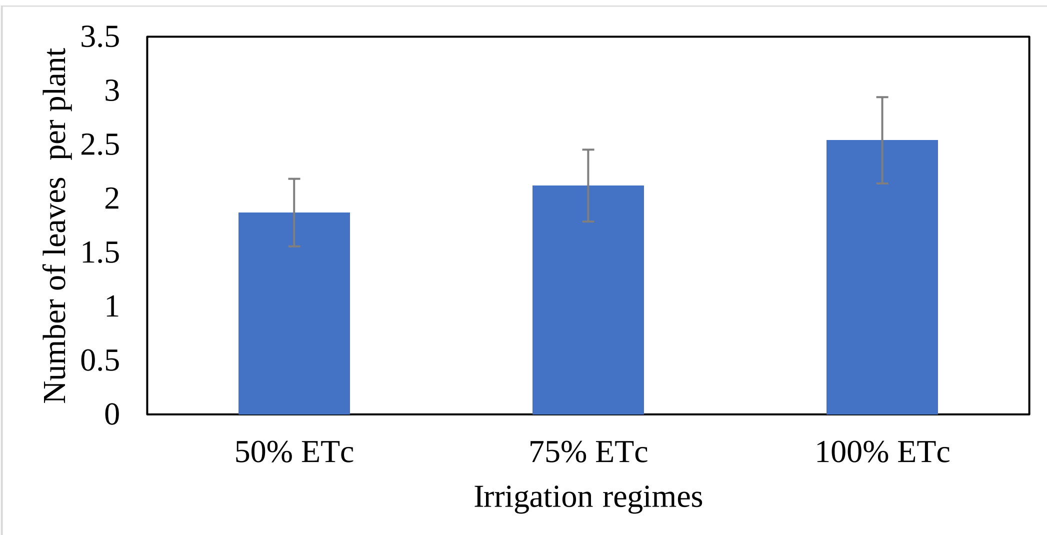

Figure 4.3. Effect of Irrigation Regime on Number of Leaves at 4 WATP. Bar = SEM *(Field Experiment,2022).*

At 4 WATP, the findings are consistent with those of (Qu *et al*., 2022), who observed that irrigation regimes between 75% ETc and 100% ETc produced more leaves than 50% ETc. The findings of the present study is also in agreement with Fernandes *et al*. (2022), who observed that tomato leaves were negatively affected by water stress at 50% ETc as compared to 100%

ETc, which was full irrigation. The additional number of leaves could be a result of the plant getting enough water for increased growth when irrigated at 75% ETc and 100% ETc.

Table 4.6. 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	Velum Prime	6 WATP			8 WATP		
		Neem Extract (5 t/ha)					
(% ETc)	(L/ha)	NC	NL	NS	NC	NL	NS
		($\sqrt{(x + 0.5)}$)					
50%		3.44g	3.80f	3.80f	4.18h	4.29fgh	4.45efg
75%	0.625	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%		3.43g	3.80f	3.80f	4.22h	5.30a	4.41efgh
75%	1.250	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).

At 6 WATP, number of leaves, which is one of the principal parameters of tomato growth which gave the highest number of leaves per plant (4.94) with 100% irrigation, Velum Prime (1.25 L/ha) and neem seed extract (5 t/ha), but water at 50% ETc with Velum Prime (0.625 L/ha) and neem cake (5 t/ha) gave the least mean leaf number (3.44). However, 100% ETc with Velum Prime (1.25 L/ha) and neem leaf extract (5t/ha) was similar to the highest.

At 8 WATP, 50% irrigation with Velum Prime (1.25 L/ha) and neem leaf extract (5 t/ha) gave maximum number of leaves per plant, whilst stress water of 50% ETc with Velum Prime (0.625 L/ha) and neem cake (5 t/ha) had least (5.29). However, the combination between 100% ETc with Velum Prime (1.25 L/ha) and neem seed extract (5 t/ha) and same level of irrigation and Velum Prime rate plus neem leaf extract and also 75% ETc with Velum Prime rte (1.25 L/ha) and neem seed extract (5t/ha) gave similar effects as the highest entry.

At 8 WATP, it was surprising that water stress at 50% ETc combined with Velum Prime (1.25 L/ha) and neem leaf extract (5 t/ha) enhanced leaf production per plant; although combinations of 100% ETc and also 75% ETc with extracts of neem seed and neem leaf increased the parameter. This could be an indication that 50% ETc in combination with Velum Prime and the neem extracts provided adequate conditions for leaf growth and production. The present results, however, is in contrast with earliers findings which showed that maximum number of leaves was attained at 100% ETc as compared to 50% ETc (Silva *et al*., 2021). Hadian *et al*. (2011) and Waisen *et al*. (2021) also reported the number of leaves obtained with neem seed extract (5 t/ha) was greater than what was observed for neem cake extract (5 t/ha), neem leave extract (5 t/ha) and Velum Prime (0.625 L/ha, 1.25 L/ha). The present results somehow agreed with these findings as the least leaf production was observed with neem cake under 50% ETc with 0.625 L/ha of Velum Prime. Probably neem cake could be releasing some allelopathic chemical to hinder the growth of tomato, which might need further research.

4.2.3. Leaf Chlorophyll Content (Spad unit) at 4, 6 and 8 WATP

The leaf chlorophyll content of the tomato plants were statistically affected by Velum Prime rate x neem extract interaction and irrigation x neem extract ($p < 0.001$) interaction at 4 WAT. All other interactions and main effects did not have any significant effect ($p > 0.05$). Similarly at 6 WATP, Velum Prime rate x neem extract interaction, irrigation x neem extract and the main effect of neem extract were significant ($p < 0.001$), but other sources of variation were not significant ($p > 0.05$). At 8 WAT, the interaction between Velum Prime rate x neem extract, irrigation regime x neem extract and the main effects of neem extract were significant ($p < 0.001$) on leaf Chlorophyll Content. However, interaction between irrigation by Velum Prime rate by neem extract, irrigation Velum Prime rate, Velum Prime rate and irrigation were not significant ($p > 0.05$) on leaf chlorophyll content.

The results showed that plants treated with full irrigation (100% ETc) with neem seed extract (5 t/ha) had the highest chlorophyll content of 52, 55 and 65 respectively at 4, 6 and 8 WAPT (Figure 4.4) and the tomato treated with 50% ETc by neem cake (5 t/ha) had the least (25, 35 and 45 values) respectively. However, at 4 and 6 WATP 100% ETc with 5 t/ha Neem leaf extract gave similar effect on the highest entry; but not at 8 WATP.

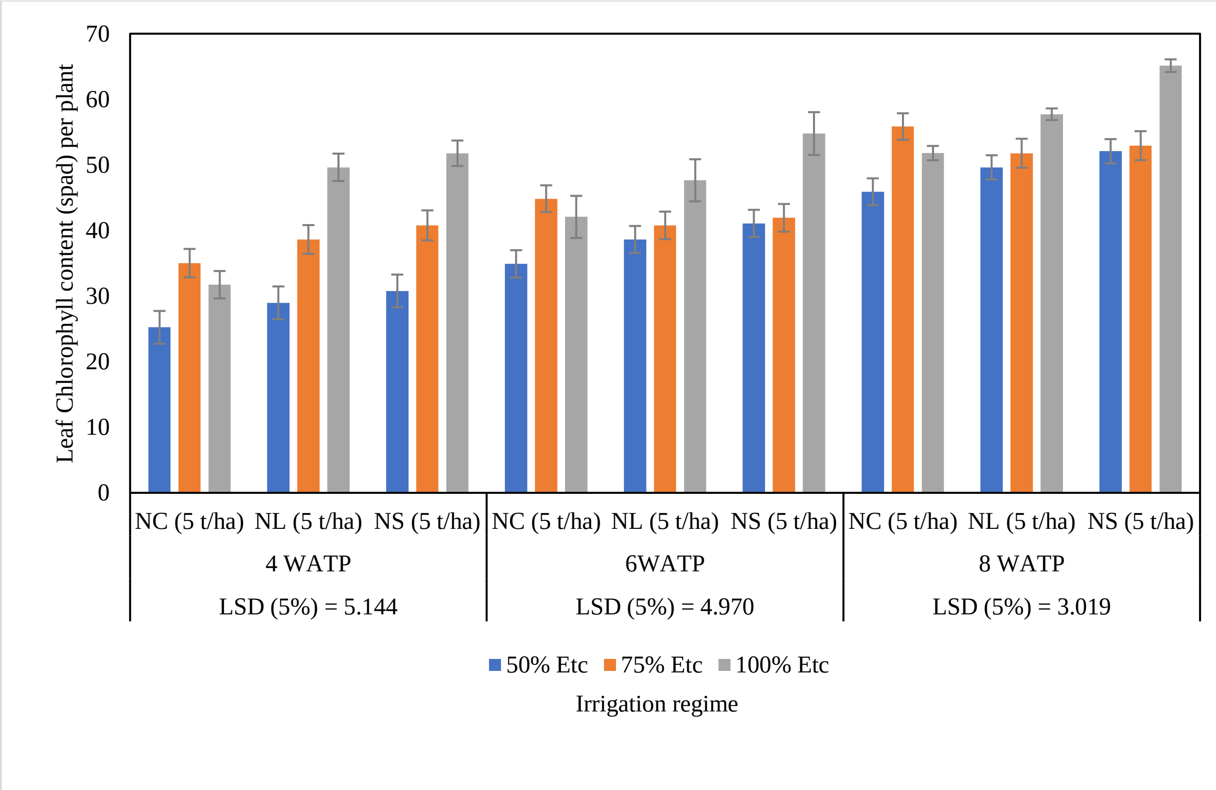

Figure 4.4. Effect of Irrigation and Neem Extract on Tomato Chlorophyll at 4, 6 and 8 WATP. Bar =SEM

(Field Experiment,2022).

Table 4.7. Effect of Velum Prime rate and Neem Extract on Tomato Chlorophyll at 4, 6 and 8 WATP.

Treatments	Velum Prime rate (L/ha)					
	0.625	1.250	0.625	1.250	0.625	1.250
	4 WATP		6 WATP		8 WATP	
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	
CV (%)	2.00		2.50		5.40	

(Field Experiment, 2022).

At 4 WAT, plants treated with Velum Prime rate (0.625 L/ha) and neem leaf extract had the highest leaf chlorophyll (37.73 Spad) as compared to Velum Prime rate (0.625 L/ha) by neem cake extract (5 t/ha) treatments. However, the interaction between Velum Prime (1.25 L/ha) with 5 t/ha neem seed extract, Velum Prime (1.25 L/ha) with neem leaf extract 5 t/ha and Velum Prime (0.625 L/ha) with 5 t/ha neem seed extract had similar effect as the treatment that gave the highest.

At 6 WAT, plants treated with Velum Prime rate (0.625 L/ha) and neem leaf extract had the highest leaf chlorophyll (47.73 Spad) as compared to Velum Prime rate (0.625 L/ha) by neem cake extract (5 t/ha) which gave the least leaf chlorophyll (36.00 Spad). However, Velum Prime (1.25 L/ha) with 5 t/ha neem seed extract, Velum Prime rate (1.25 L/ha) with neem leaf extract

5 t/ha and Velum Prime rate (1.25 L/ha) with 5 t/ha neem seed extract gave similar effect to the highest.

At 8 WAT, plants treated with Velum Prime rate (1.25 L/ha) and neem seed extract gave highest leaf chlorophyll (85.44 Spad) as compared to Velum Prime rate (0.625 L/ha) by neem cake extract (5 t/ha) which recorded the least leaf chlorophyll (71.78 Spad). However, Velum Prime (1.25 L/ha) with 5 t/ha neem leaf extract also gave similar effect.

At 4, 6 and 8 WAT, the interaction between Velum Prime (0.625 L/ha) by neem seed extract (5 t/ha) gave highest leaf chlorophyl content, showing that Velum Prime at the lower rate combined with 5 t/ha neem leaf extract adequately management the nematodes for the tomato for enhanced chlorophyll synthesis. Limited report is available on this subject; therefore, the present findings will serve as bench mark for future research on treatments promoting leaf Chlorophyll content in tomato due to nematode management.

4.2.4. Flower Count ($\sqrt{(x + 0.5)}$) Per Plant at 6 and 8 WATP

At 6 WATP, interaction of irrigation regime by Velum Prime rate by neem extract, irrigation level by neem extract, Velum Prime rate by neem extract and the main effects were significant ($p < 0.001$); whilst irrigation regime by Velum Prime did not have significant ($p > 0.05$) influence on number of flower per plant.

At 8 WATP, the interaction of irrigation regime by Velum Prime rate by neem extract and all main effect ($p < 0.001$) affected flowering.

Tomato treated with 75% ETc combined with Velum Prime (1.25 L/ha) and neem seed extract produced about 5 flowers per plant respectively at 6 and 8 WATP, whilst the least flower count of about 1-3 were produced by by the application of irrigation regime 50% ETc with Velum Prime rate (0.625 L/ha) and neem leaf extract (5 t/ha) respectively at 6 and 8 WATP (Table 4.8).

Table 4.8. Effect of Irrigation Regime, Velum Prime rate and Neem Extract on Tomato Flower Count ($\sqrt{(x + 0.5)}$) per Plant at 6 and 8 WATP.

Irrigation Regime	Velum Prime	6 WATP			8 WATP		
		Neem Extract					
(% ETc)	rate (ml)	NC	NL	NS	NC	NL	NS
				($\sqrt{(x + 0.5)}$)			
50%		2.12i	1.56j	4.75a	3.39i	3.08j	4.14f
75%	0.625	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%		2.91gh	2.91gh	3.19f	3.94gh	3.94gh	4.14f
75%	1.250	2.79h	4.30b	4.75a	3.85h	5.05b	5.43a
100%		3.53cd	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).

At 6 WATP, the interaction of irrigation regime (75% ETc) by Velum Prime rate (1.25 L/ha) by neem seed extract (5 t/ha) on flower count was significant ($p < 0.001$) due to the treatments.

Similar results were obtained at 75% ETc with 0.625 L/ha plus Velum Prime and 5 t/ha neem seed extract and also 50% ETc with 0.625 L/ha Velum Prime and 5 t/ha neem seed extract at 6 WATP.

This result could possibly be due to the neem seed extract increasing plant nutrient and immobilizing nematodes in combination with Velum Prime and irrigation to support flowering. Overall, combination effect of 75% ETc, Velum Prime (1.25 L/ha) and neem seed extract (5 t/ha) gave the highest number of flower per plant (5.43 and 5.15) respectively at 6 and 8 WAT. The results of the present study clearly indicated its potential to provide integrated management of nematodes for increased flower production which could enhance fruiting in tomato. Limited report is available on this subject; therefore, the present findings will serve as basis for future research on treatments promoting flower count in tomato under root-knot nematode infested fields.

4.2.5. Tomato Fruit Set

Fruit set was calculated using equation 3.15, with irrigation regime, 1.25 L/ha and neem extract-treated plants recording fruit set (85 to 100%), while irrigation regime with 0.625 L/ha Velum Prime and neem extract supported between 60 to 87% (Table 4.9).

Table 4.9. Effect of Irrigation Regime, Velum Prime rate and Neem Extract on Percent Tomato Fruit Set.

Treatments	Velum Prime rate (L/ha)					
Irrigation	0.625			1.250		
regime	Neem extract (5t/ha)					
	NC	NL	NS	NC	NL	NS
	%					
50% ETc	60	82	87	85	86	88
75% ETc	67	87	95	98	99	100
100% ETc	78	87	88	89	89	97

(Field Experiment,2022).

Plants treated with 75% ETc with Velum Prime rate (1.25 L/ha) and 5 t/ha gave the highest fruit set whilst irrigation 50% with Velum Prime rate (0.625 L/ha), led to low fruit set rate. However, 75% ETc with 1.25 L/ha and neem leaf extract and also 75% ETc with 1.25 L/ha and neem cake extract was similar to the the treatent that gave the highest.

4.3. Fruit count at 8 and 9 WATP

AT 8 WATP, interaction of irrigation regime by Velum Prime rate by neem extract, irrigation levels by neem extract, irrigation by Velum Prime, Velum Prime rate by neem extract and main effects of Velum Prime rate and irrigation were not significant ($p > 0.05$). However, the main effect of neem extract was significant ($p < 0.05$) influence on tomato number of fruits.

At 9 WATP fruit count was not influenced ($p > 0.05$) by irrigation regime, Velum Prime rate and neem extract, irrigation regime by Velum Prime, irrigation by neem extract, Velum Prime by neem extract and main effect of Velum Prime. However, crops treated with irrigation and also neem extract determined ($p < 0.05$) fruit count.

Results obtained showed at 8 WATP plant treated with neem seed extract at 5 t/ha gave the highest fruit number per plant, whilst neem cake gave the least (Figure 4.5). At 9 WATP, results obtained indicated that plants treated with 75% ETc had the highest fruit count, whilst neem seed extract (5 t/ha) gave higher fruiting count (Figure 4.6).

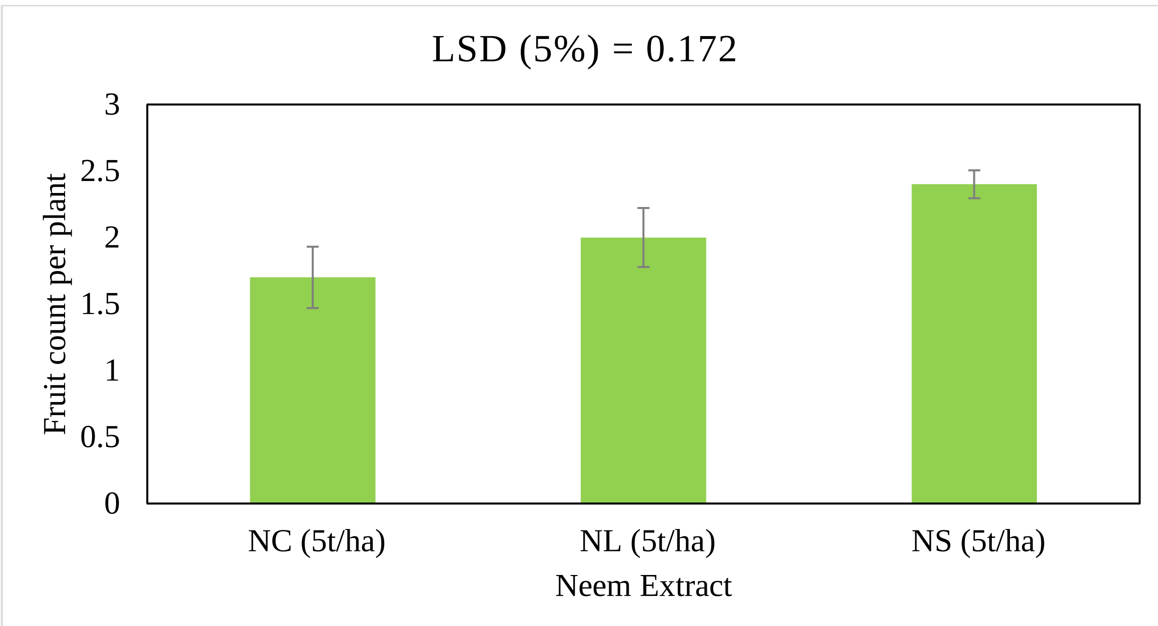

Figure 4.5. Effect of Neem Extract on Fruit count at 8 WATP. Bar = SEM

(Field Experiment,2022).

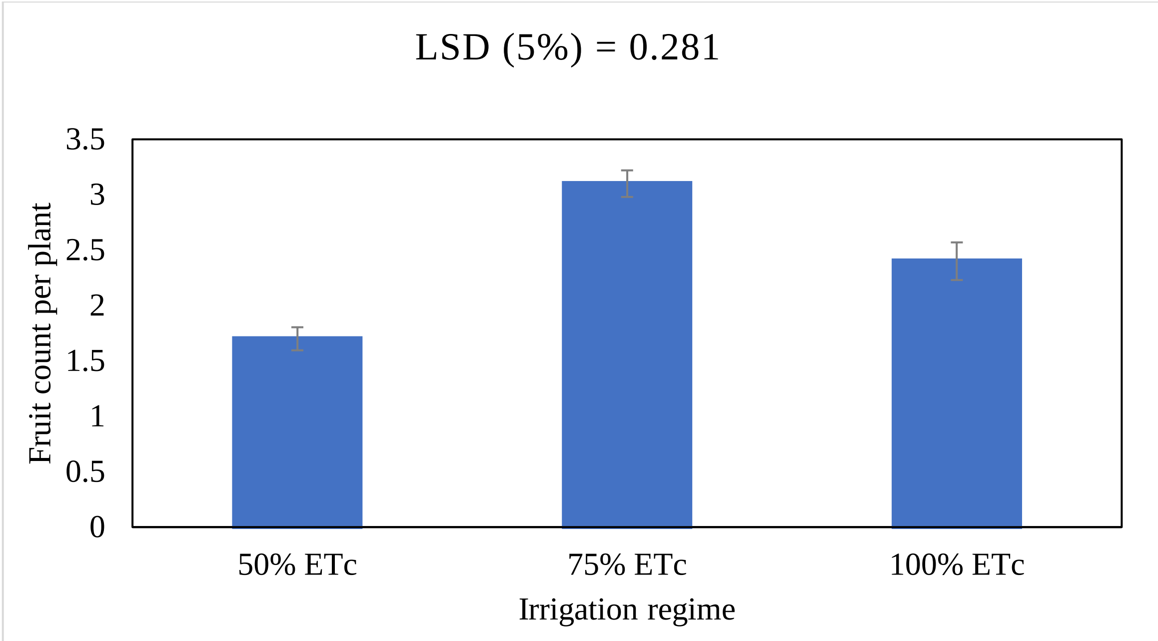

Figure 4.6. Effect of Irrigation Regime on Fruit Count at 9 WATP. Bar = SEM

(Field Experiment,2022).

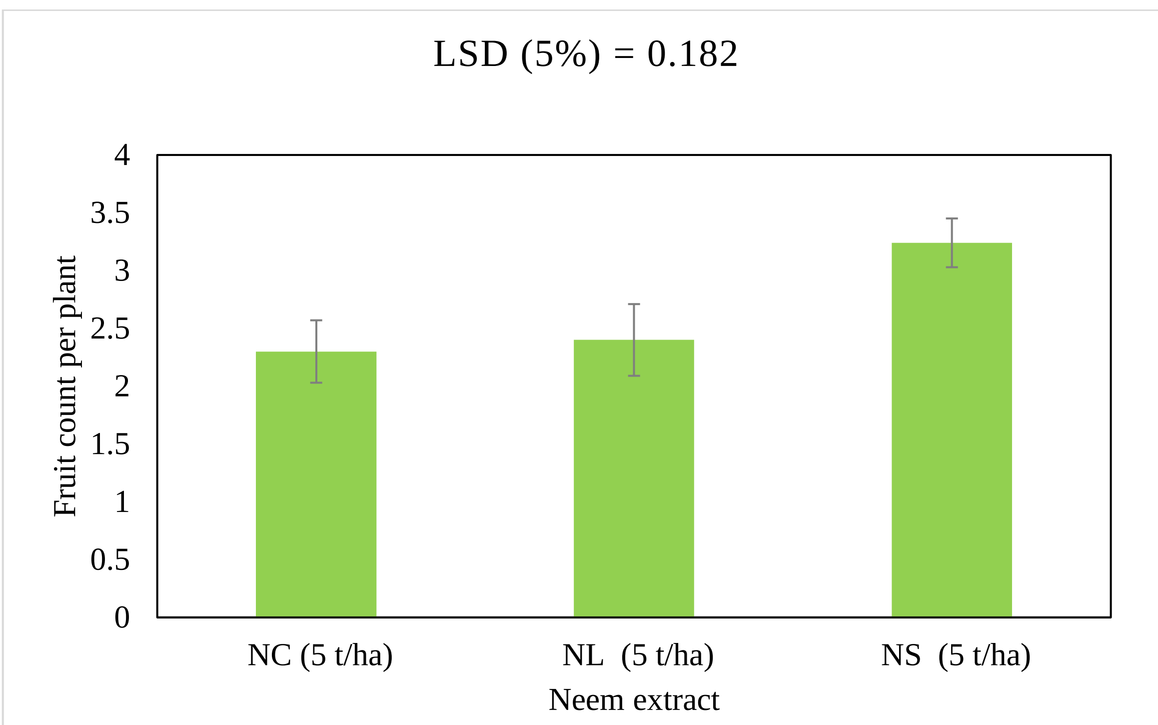

Figure 4.7. Effect of Neem Extract on Fruit Count at 9 WATP. Bar = SEM

(Field Experiment,2022).

At 8 and 9 WAT, the application of neem seed extract gave the highest number of fruits of 2 and 3 fruit count per plant respectively; whereas neem cake recorded the least. This outcome was consistent with research done by Sora and Sakata (2022), who found that neem seed extract led to more fruits per plant. In the current experiment, using neem extract might have significantly reduced the negative impact of the nematode infestation that could reduce the fruit count in tomato. Also, at 9 WATP, 75% ETc irrigation level produced more fruits, whereas a 50% ETc irrigation regime decreased fruiting. These findings were in similar with the findings of Assouma and Yacoubou (2021), who reported that neem seed extract and moderate moisture levels produced increased fruit counts when compared with other treatments in their experiment. Neem extract proved efficient for improving resistance of tomato to virulence nematodes. Findings of this research on watering effects on fruit count showing 75% ETc as optimum is in agreement with those of (Chen *et al*., 2013), who found that deficit irrigation adversely affected fruit number when compared to plants watered at 75% ETc and 100% ETc.

4.4. Tomato Fruit Yield

The analysis of variance showed that fruit yield was affected by interaction of irrigation regime by neem extract and main effect of neem extract ($p < 0.001$). However, all other interactions and main effects did not ($p > 0.05$).

Irrigation of tomato with 75% ETc with neem seed extract of 5 t/ha maximized fruit yield of 1.7 t/ha, while the lowest was 0.6 t/ha for the irrigation regime of 50% ETc with 5 t/ha neem cake extract (Figure 4.8).

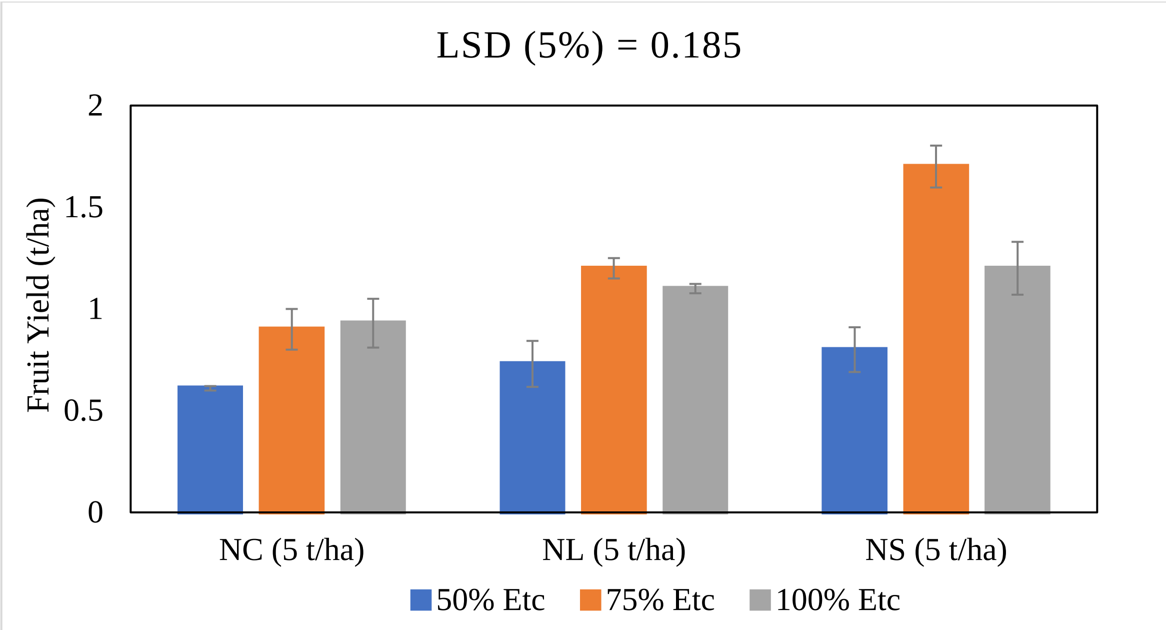

Figure 4.85. Effect of Irrigation Regime and Neem Extract on Fruit Weight. Bar = SEM *(Field Experiment,2022).*

The effects of irrigation with 75% ETc and 5 t/ha of neem seed extract increased the values recorded for most of the measured indices. The findings from the study suggested that the moderate irrigation regime combined with neem extract, could have dual effects in this experiment, by augmenting nutrient availability to plants and, more importantly checking root-knot nematodes (*Meloidogynes* spp.) infestation for effective tomato growth and fruit production. It has been reported that neem extract could promote nutrient uptake by crops (Gobezie, 2022). The findings are consistent with research by Oke *et al*. (2020), which found that applying 75% ETc with neem seed extract improved flowering and yield.

4.5. Correlation Analysis

Total fruit yield correlated high and positively with fruit count, flower count, flower abortion, chlorophyll, number of leaves and plant height; with corresponding coefficients of correlation (r) of 0.78, 0.67, 0.96, 0.85, 0.95 (Table 4.10).

Table 4.10. Correlation Analysis of Fruit Yield and Yield components

	PH	NL	CH	FL	FB	FR	FY
PH	1						
NL	0.78**	1					
CH	0.53	0.29	1				
FL	0.76**	0.67**	0.78**	1			
FB	0.31	0.51	0.53	0.48	1		
FR	0.29	0.53	0.96**	0.72**	0.57	1	
FY	0.69	0.32	0.78**	0.85**	0.53	0.95**	1

PH = Plant height, NL = Number of leaves, CH = Chlorophyll, FL= Flowers, FR = Fruit, FY = FY = Fruit Yield, ** = Highly correlated.

(Field Experimental, 2022)

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The current study evaluated the impact of integrated application of drip irrigation regime, Velum Prime rate, and neem products on root-knot nematodes control and growth and yield of tomato in the Northern Region of Ghana. The research revealed the following:

a) Interaction of 100% ETc irrigation with 1.25 L/ha Velum Prime and 5 t/ha neem seed extract and also irrigation 100% ETc with 1.25 L/ha Velum Prime and 5 t/ha neem leaf extract produced the tallest plants with heights of about 90.67 cm and 86.33 cm respectively.

b) Combination of irrigation 100% ETc with Velum Prime rate (1.25 L/ha) and neem seed extract (5 t/ha), 100% ETc with Velum Prime rate (1.25 L/ha) and neem leaf extract (5 t/ha) and also 75% ETc with Velum Prime rate (1.25 L/ha) and neem seed extract (5t/ha) increased the number of leaves per plant than the other treatments.

c) Irrigation regime at 100% ETc with 5 t/ha neem seed extract, 1.25 L/ha Velum Prime rate (1.25 L/ha) with neem leaf extract and 1.25 L/ha Velum Prime with neem seed extract (5 t/ha) increased chlorophyll content of leaves compared to the other treatments.

d) Irrigation at 75% ETc with 1.25 L/ha Velum Prime neem seed extract (5 t/ha) enhanced fruit set..

e) Tomato plants treated with irrigation at 75% ETc plus Velum Prime rate (1.25 L/ha) plus 5 t/ha neem seed extract produced more flowers.

f) Irrigation of 75% ETc and plant treated with 5 t/ha neem seed extract increased fruit number per plant.

g) Tomato plants treated with 75% ETc by 5 t/ha neem seed extract gave the highest fruit yield.

5.2. Recommendations

a) Treatment of 75% ETc irrigation plus neem seed extract could be used to enhance tomato fruit yield under root-knot nematode infested soils.

b) Future study with the treatments applied here should consider counting root-knot nematode populations in soils and plant roots to ascertain the relationship between root-knot nematode population and impact of the management method.

c) Future studies should indicate dose applications of the botanical extracts in quantity used per pot.

REFERENCES

Abad, P., Gouzy, J., Aury, J.-M., Castagnone-Sereno, P., Danchin, E. G. J., Deleury, E., Perfus-Barbeoch, L., Anthouard, V., Artiguenave, F., Blok, V. C., Caillaud, M.-C., Coutinho, P. M., Dasilva, C., De Luca, F., Deau, F., Esquibet, M., Flutre, T., Goldstone, J. V., Hamamouch, N., … Wincker, P. (2008). Genome sequence of the metazoan plant-parasitic nematode Meloidogyne incognita. *Nature Biotechnology*, *26*(8), 909-915. https://doi.org/10.1038/nbt.1482

Abrahamsson, S., Isaksson, R., & Hansson, J. (2010). Integrated management systems : Advantages, problems and possibilities. *13th Toulon-Verona Conference*, 1-12.

Adomako, J., Osei, K., Kankam, F., & Danso, Y. (2017). *Limitations to Peri-urban Vegetable Farming in Ghana : An Overview of Root Knot Nematodes Contribution*. *36*(3), 75-85.

Adongo, T. A., Abagale, F. K., & Kranjac-Berisavljevic, G. (2015). *Performance of Irrigation Water Delivery Structures in Six Schemes of Northern Ghana*. *4*(9), 10.

Affokpon, A., Dan, C. B. S., Houedjissi, M. E., Hekpazo, B. A., & Tossou, C. (2012). The efficacy of neem seed derivatives against root-knot nematodes in vegetable crops differs according to the type of derivative. *Bulletin de la Recherche Agronomique du Bénin*, *72*, 48-58.

Agbenin, N. O., Emechebe, A. M., Marley, P. S., & Akpa, A. D. (2005). Evaluation of nematicidal action of some botanicals on Meloidogyne incognita in vivo and in vitro. *Journal of Agriculture and Rural Development in the Tropics and Subtropics (JARTS)*, *106*(1), 29-39.

Ahmad, H., & Li, J. (2021). Impact of water deficit on the development and senescence of tomato roots grown under various soil textures of Shaanxi, China. *BMC Plant Biology*, *21*(1), 116.

Aichouche, S., & Amroune, L. (2020). *Comparative study between two irrigation techniques : Aspersion and drip irrigation in the m'sila region* [PhD Thesis, University Mohamed BOUDIAF-M'SILA],Morroco. https://scholar.google.com/scholar?q=Etude+des+Techniques++irrigation+(FAO)&hl=fr&as_sdt=0&as_vis=1&oi=scholart

Alheyalee, R. S., & Aljuboori, F. K. (2020). The first recording of root-knot nematodes Meloidogyne Javanica on the winter cherry Solanum pseudocapsicum and controlling it in vitro. *EurAsian Journal of BioSciences*, *14*(2).

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *Fao, Rome*, *300*(9), D05109.

Almohithef, A. H., Al-Yahya, F. A., Al-Hazmi, A. S., Dawabah, A. A., & Lafi, H. A. (2020). Prevalence of plant-parasitic nematodes associated with certain greenhouse vegetable crops in Riyadh region, Saudi Arabia. *Journal of the Saudi Society of Agricultural Sciences*, *19*(1), 22-25.

Al-Shammary, A. A. G., Kouzani, A. Z., Kaynak, A., Khoo, S. Y., Norton, M., & Gates, W. (2018). Soil bulk density estimation methods : A review. *Pedosphere*, *28*(4), 581-596.

Altaibaeva, Z., Bauer-Kenzhebolatova, M., & Zhaltyrova, O. (2016). *Development of the Flour-milling Industry in the Republic of Kazakhstan in Modern Times*. *6*, 8.

Aminisarteshnizi, M. (2021). Efficacy of neem (Azadirachta indica) formulations on suppression of root-knot nematodes (Meloidogyne javanica) and growth of eggplant

(Solanum melongena). *Research on Crops*, *22*(1), 5. https://doi.org/DOI : 10.31830/2348-7542.2021.050

Andrenelli, M. C., Maienza, A., Genesio, L., Miglietta, F., Pellegrini, S., Vaccari, F. P., & Vignozzi, N. (2016). Field application of pelletized biochar : Short term effect on the hydrological properties of a silty clay loam soil. *Agricultural Water Management*, *163*, 190-196.

Anonymous. (2011). *Improving Food Security, Agriculture and Rural Development Statistics*. 257.

Assouline, S., & Or, D. (2014). The concept of field capacity revisited : Defining intrinsic static and dynamic criteria for soil internal drainage dynamics. *Water Resources Research*, *50*(6), 4787-4802.

Assouma, S. M., & Yacoubou, A.-M. (2021). Effect of Neem Oil against Leafminer (Liriomyza spp.)(Diptera : Agromyzidae) on Field Tomato (Lycopersicon esculentum Mill.) in Northern Benin Republic. *Int. J. Progress. Sci. Technol*, *27*, 489-496.

Avdeenko, S., Stroiteleva, N., & Kondrashev, S. (2021). Plant-parasitic nematodes affecting vegetable crops in greenhouses. *Saudi Journal of Biological Sciences*, *28*(9), 5428-5433. https://doi.org/10.1016/j.sjbs.2021.05.075

Ayisah, K. D., Simiti, K., & Aziadekey, M. K. (2019). Prevalence and Occurrence of Various Wilt Pathogens Associated with Tomato (Solanum lycopersicum L.) in Togo. *Asian Journal of Agricultural and Horticultural Research*, *4*(4), 19. https://doi.org/DOI: 10.9734/AJAHR/2019/v4i430032

Baidya, B. K., & Sethy, P. (2020). *Importance of Fruits and Vegetables in Boosting our Immune System amid the COVID19*. *1*(7), 50-55.

Bélanger, A., & Musabyimana, T. (2005). Neem against insects and diseases. *Agriculture and Agri-Food Canada, Horticulture Research and Development Centre*, *430*, 13.

Benabderrazik, K. (2021). *Operationalizing resilience in the face of climate change. The case of tomato producers in Morocco and Ghana* [PhD Thesis, ETH Zurich]. https://doi.org/10.3929/ethz-b-000477538

Bénard, C. (2009). *Study of the impact of nitrogen nutrition and growing conditions on polyphenol content in tomato* [PhD Thesis, Institut National Polytechnique de Lorraine]. https://hal.univ-lorraine.fr/tel-01748724/document

Benouniche, M., Kuper, M., & Hammani, A. (2014). *Leading drip irrigation to water saving : Realistic ambition or pursuit of a chimera?* 12.

Beretta, A. N., Silbermann, A. V., Paladino, L., Torres, D., Kassahun, D., Musselli, R., & Lamohte, A. G. (2014). Soil texture analyses using a hydrometer : Modification of the Bouyoucos method. *Ciencia e investigación agraria: revista latinoamericana de ciencias de la agricultura*, *41*(2), 263-271.

Bertozzi, T. (2003). *Biology and control of the Anguinid nematode associated with flood plain staggers/by Terry Bertozzi.* [PhD Thesis, University of ADELAIDE]. https://scholar.google.com/scholar?q=Maggetti+et+Allen+1960+Meloidogyne&hl=fr&as_sdt=0%2C5&scioq=LINFORD+%28M.+B.%29+-+1942+-+The+transient+feeding+of+root-knot+nematode+larvae.+Phytopathology+32%2C+580-589.+&as_ylo=1960&as_yhi=

Blancard, D., Laterrot, H., & Marchoux, G. (2009). *Tomato diseases, identify, know and control.* (Quae). https://www.google.com/search?q=Blancard+D.%2C+Laterrot+H.%2C+Marchoux+G.+et+Candresse+T.%2C+2009.+Les+maladies+de+la+tomate%2C+identifier%2C+con naitre+et+maitriser.+Ed.+Quae.+Paris.+691p.&rlz=1C1RXGH_enSN797SN797&oq=Blancard+D.%2C+Laterrot+H.%2C+Marchoux+G.+et+Candresse+T.%2C+2009.+Les+maladies+de+la+tomate%2C+identifier%2C+connaitre+et+maitriser.+Ed.+Quae.+Paris.+691p.&aqs=chrome..69i57j69i60.1023j0j7&sourceid=chrome&ie=UTF-8

Bolou, B. B. A., Kouakou, K., Diby, L., Bel, L., Ben, Y., & Kouam, C. (2022). Biological control using essential oil of Ocimum gratissimum and four other biopesticides on Formicococcus njalensis, the most active mealybugs species in the transmission of CSSV (Cocoa swollen shoot virus). *African Journal of Agricultural Research*, *18*(4), 276-280.

Bosques Martínez, M. (2020). *Jeffrey P. Mitchel* [PhD Thesis, The Ohio State University]. https://etd.ohiolink.edu/apexprod/rws_olink/r/1501/10?clear=10&p10_accession_num=osu1577534641175364

Bozbuga, R. (2020). Effect of Submerging Solanum lycopersicum Roots in Salicylic Acid (SA) Solution for Different Durations on Nematode Infection and Expressions of SlPR5 Gene. *Horticultural Studies*, *37*(2), 144-149. https://doi.org/10.16882/hortis.833488

Broglie, L. A. de, Guéroult, D., & Buchard, S. (2005). Tomatoes of yesterday and today. *Paris, Hoëbeke.*, 143.

Brouwer, C., Prins, K., Kay, M., & Heibloem, M. (1990). Methods of irrigation. *FAO, Italy*, *5*, 74.

Busscher, W. J. (2009). *Field estimation of soil water content : A review*. https://doi.org/10.2489/jswc

Cabibel, B. (2020). Orientation de recherches en matière d'irrigation goutte à goutte. *Orientation de recherches en matière d'irrigation goutte à goutte (1973)*, *73*, 16.

Carter, M. R. (1990). Relative measures of soil bulk density to characterize compaction in tillage studies on fine sandy loams. *Canadian Journal of Soil Science*, *70*(3), 425-433.

Castillo, P., & Vovlas, N. (2007). *Pratylenchus (Nematoda : Pratylenchidae): diagnosis, biology, pathogenicity and management* (Vol. 6). Brill Academic Publishers. https://books.google.com.gh/books?hl=fr&lr=&id=WgiwCQAAQBAJ&oi=fnd&pg=PR13&dq=Castillo,+P.,+%26+N.+Vovlas.+(2007).+Pratylenchus+(Nematoda:+Pratylenchidae):+Diagnosis,+biology,+pathogenicity+and+management.+Leiden:+Brill+Academic+Publishers.&ots=3oJQsCFeo7&sig=aCqGHx9L3fu_Uc5lr2-qRUTSucU&redir_esc=y#v=onepage&q=Castillo%2C%20P.%2C%20%26%20N.%20Vovlas.%20(2007).%20Pratylenchus%20(Nematoda%3A%20Pratylenchidae)%3A%20Diagnosis%2C%20biology%2C%20pathogenicity%20and%20management.%20Leiden%3A%20Brill%20Academic%20Publishers.&f=false

Chaux, C. L., & Foury, C. L. (1994). Vegetable and market garden crops. *Tome III: légumineuses potagères, légumes fruit. Tec et Doc Lavoisier, Paris*, *3*, 563.

Chen, J., Kang, S., Du, T., Qiu, R., Guo, P., & Chen, R. (2013). Quantitative response of greenhouse tomato yield and quality to water deficit at different growth stages. *Agricultural water management*, *129*, 152-162.

Clerk, G. C. (1974). Crops and their diseases in Ghana. *Ghana Publishing Corp.*

Coleguwor, D. M. (2018). *Assessing the current status of greenhouse industry in selected regions in Ghana* [PhD Thesis]. University of Ghana.

Coolong, T. (2016). Evaluation of shallow subsurface drip irrigation for the production of acorn squash. *HortTechnology*, *26*(4), 436-443. https://doi.org/10.21273/HORTTECH.26.4.436

Cui, J., Shao, G., Lu, J., Keabetswe, L., & Hoogenboom, G. (2019). Yield, quality and drought sensitivity of tomato to water deficit during different growth stages. *Scientia agrícola*, *77*.

Darimani, H. S., Kpoda, N., Suleman, S. M., & Luut, A. (2021). Field Performance Evaluation of a Small-Scale Drip Irrigation System Installed in the Upper West Region of Ghana. *Computational Water, Energy, and Environmental Engineering*, *10*(2), 82-94.

De Lannoy, G. (2001). Vegetables : Crop production in Tropical Africa. *Directorate General for Intl. Cooperation, Brussels, Belgium*, 403-511.

Denny, R. (2019). Contributions to Global Climate Change : A Cross-national Analysis of Greenhouse Gas Emissions from Meat Production. *Global Meat: Social and Environmental Consequences of the Expanding Meat Industry*, 145.

Deravel, J., Krier, F., & Jacques, P. (2013). Biopesticides, complements and alternatives to chemical phytosanitary products (bibliographic synthesis). *Biotechnologie, agronomie, société et environnement*, *18*(2), 13.

Devindrappa, M., Kamra, A., Grover, M., & Gawade, B. (2022). Nematicidal rhizobacteria with plant growth-promoting traits associated with tomato in root-knot infested polyhouses. *Egyptian Journal of Biological Pest Control*, *32*(1), 1-11.

Domingues, J. P. T., Sampaio, P., & Arezes, P. M. (2015). Analysis of integrated management systems from various perspectives. *Total Quality Management & Business Excellence*, *26*(11-12), 1311-1334. https://doi.org/10.1080/14783363.2014.931064

Ecker, O. (2018). Agricultural transformation and food and nutrition security in Ghana : Does farm production diversity (still) matter for household dietary diversity? *Food policy, 79*, 271-282.

Edwards, E. E. (1953). The root-knot eelworm on weeds and cultivated plants in the Gold Coast. *Journal of Helminthology*, *27*(3-4), 181-184.

Evans, R. G., & Sadler, E. J. (2008). Methods and technologies to improve efficiency of water use. *Water resources research*, *44*(7), 1-15. https://doi.org/10.1029/2007WR006200

Ewaid, S. H., Abed, S. A., & Al-Ansari, N. (2019). Crop water requirements and irrigation schedules for some major crops in Southern Iraq. *Water, 11*(4), 756.

Fall, A. (2018). *Efficacy of the nematicide Football 50 (Fosthiawate at 50g/L) on parasitic nematodes of tomato (Solanum lycopersicum L.)* [University Cheikh Anta diop]. http://bibnum.ucad.sn/greenstone/cgi-bin/library.cgi?a=q&r=1&hs=1&e=p-00000-00---off-0theses-articles%2Cthm%2Cthd%2Cmmoires%2Cths%2Cofficiel%2Cthl%2Crares%2Ctheses-01-2----0-10-0---0---0direct-10---4-------0-1l--10-fr-50---20-about---00-3-1-00-0--4--0--0-0-01-10-0utfZz-8-00&fqf=DC&q=Asta+fall

FAO. (1993). *Food and Agriculture Organization of the United Nations), 1993, Let's value the diversity of nature, traditional knowledge and biodiversity*. http://www.fao.org/DOCREP/004/V1430F/V1430F03.htm#ch2

FAO (Éd.). (2017a). *The future of food and agriculture : Trends and challenges*. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/i6583e/i6583e.pdf

FAO. (2017b). *Water for Sustainable Food and Agriculture. A report produced for the G20 Presidency of Germany* (p. 33). www.fao.org/publications

FAO, L. (2018). *Non-timber forest products from land restoration to income generation*. www.fao.org/docrep/t0122f/t0122f06.htm

Fernandes, Â., Chaski, C., Pereira, C., Kostić, M., Rouphael, Y., Soković, M., Barros, L., & Petropoulos, S. A. (2022). Water Stress Alleviation Effects of Biostimulants on Greenhouse-Grown Tomato Fruit. *Horticulturae*, *8*(7), 645. https://doi.org/10.3390/horticulturae8070645

Gahukar, R. T. (2012). Evaluation of plant-derived products against pests and diseases of medicinal plants : A review. *Crop Protection*, *42*, 202-209.

Gahukar, R. T. (2014). Factors affecting content and bioefficacy of neem (Azadirachta indica A. Juss.) phytochemicals used in agricultural pest control : A review. *Crop Protection*, *62*, 93-99.

Giordano, M., de Fraiture, C., Weight, E., & van der Bliek, J. (2012). *Water for wealth and food security : Supporting farmer-driven investments in agricultural water management. Synthesis report of the AgWater Solutions Project*. IWMI.

Gobezie, E. (2022). Effect of Neem (Azadirachta indica) leaf powder on the growth performance and carcass quality of Broiler Chicken-A Review. *Journal of Livestock Science (ISSN online 2277-6214)*, *13*, 152-158. https://doi.org/10.33259/JLivestSci.2022.152-158

Griffith, A. (2000). Integrated management systems : A single management system solution for project control? *Engineering, Construction and Architectural Management*.

Hadian, S., Rahnama, K., Jamali, S., & Eskandari, A. (2011). Comparing neem extract with chemical control on Fusarium oxysporum and Meloidogyne incognita complex of tomato. *Advances in Environmental Biology*, *5*(8), 2052-2057.

Hajihassani, A., Lawrence, K. S., & Jagdale, G. B. (2018). Plant Parasitic Nematodes in Georgia and Alabama. In S. A. Subbotin & J. J. Chitambar (Éds.), *Plant Parasitic Nematodes in Sustainable Agriculture of North America : Vol.2—Northeastern, Midwestern and*

Southern USA (p. 357-391). Springer International Publishing. https://doi.org/10.1007/978-3-319-99588-5_14

Idrenmouche, S. (2011). *Biology and ecology of the tomato leafminer Tuta absoluta (Meyrick, 1917) (Lepidoptera : Gelechiidae) in the Boumerdes region* [PhD Thesis, Ecole National Superieur Agronomique El Harrach Alger]. http://dspace.ensa.dz:8080/jspui/bitstream/123456789/926/1/idrenmouche_s.pdf

Jägermeyr, J., Gerten, D., Schaphoff, S., Heinke, J., Lucht, W., & Rockström, J. (2016). Integrated crop water management might sustainably halve the global food gap. *Environmental Research Letters*, *11*(14), 025002. https://doi.org/10.1088

Jamrey, P. K., & Nigam, G. K. (2018). Performance evaluation of drip irrigation systems. *The Pharma Innovation Journal*, *7*(1), 346-348.

Javed, N., Gowen, S. R., Inam-ul-Haq, M., Abdullah, K., & Shahina, F. (2007). Systemic and persistent effect of neem (Azadirachta indica) formulations against root-knot nematodes, Meloidogyne javanica and their storage life. *Crop Protection*, *26*(7), 911-916.

Jean, B. (2009). *Pharmacognosy, phytochemistry, medicinal plants* (4th éd.). Lavoisier. https://scholar.google.com/scholar?hl=fr&as_sdt=0%2C5&q=Bruneton+J.%2C+1993 %2C+Pharmacognosie%2C+phytochimie+et+plantes+m%C3%A9dicinales&btnG=

Kah, K. N.-S. (2021). *Effects of deficit drip irrigation and rice straw mulch on flowering, fruiting and yield of two tomato (lycopersicon esculentum mill.) varieties* [PhD Thesis, department of agricultural engineering, school of engineering, university …]. https://wacwisa.uds.edu.gh/wp-content/uploads/2022/05/Kah-Ngiah-Sah-Kyria-2021.pdf

Kamran, M., Javed, N., Khan, S. A., Jaskani, M. J., & Ullah, I. (2014). Efficacy of Pasteuria penetrans on Meloidogyne incognita reproduction and growth of tomato. *Pakistan Journal of Zoology*, *46*(6).

Kane, M. (2018). *Comparative study of the effects of different types of organic amendments on root-knot nematode dynamics and growth in tomato* [Memory]. University Cheikh Anta Diop.

Kankam, F., & Adomako, J. (2013). *Asian Online Journals (www.ajouronline.com) 171 Influence of Inoculum Levels of Root Knot Nematodes (Meloidogyne spp.) on Tomato (Solanum lycopersicum L.)*.

Kankam, F., & Adomako, J. (2014). *Asian Online Journals (www.ajouronline.com) 171 Influence of Inoculum Levels of Root Knot Nematodes (Meloidogyne spp.) on Tomato (Solanum lycopersicum L.)*. http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=4EF44D9E0F4D05F33429B0D0AB1933BF?doi=10.1.1.931.1620&rep=rep1&type=pdf

Kiewnick, S., & Sikora, R. A. (2006). Biological control of the root-knot nematode Meloidogyne incognita by Paecilomyces lilacinus strain 251. *Biological control*, *38*(2), 179-187.

Kumar, S., Kumar, S., & Arzoo, K. (2019). Fungal Biopesticides : A Novel Tool for Management of Plant Parasitic Nematodes. In *Biofertilizers and Biopesticides in Sustainable Agriculture* (1st Edition, p. 337-358). Apple Academic Press. https://www.taylorfrancis.com/chapters/edit/10.1201/9780429059384-17/fungal-biopesticides-novel-tool-management-plant-parasitic-nematodes-erayya-sanjeev-kumar-santosh-kumar-kahakashan-arzoo

Kurniawan, D. (2008). DAFTAR PUSTAKA. Agrios, GN Plant pathology 5th Ed. Elsevier Academic Press. Burlington. *Burlington: Elsevier Academic Press.*, 922.

Kuşçu, H., Turhan, A., & Demir, A. O. (2014). The response of processing tomato to deficit irrigation at various phenological stages in a sub-humid environment. *Agricultural Water Management*, *133*, 92-103.

Kuscu, H., Turhan, A., Ozmen, N., Aydinol, P., & Demir, A. O. (2014). Optimizing levels of water and nitrogen applied through drip irrigation for yield, quality, and water productivity of processing tomato (Lycopersicon esculentum Mill.). *Horticulture, Environment, and Biotechnology*, *55*(2), 103-114.

Kwara, B. K., Kwoseh, C. K., & Starr, J. L. (2014). Effectiveness of root-knot nematode (meloidogynespecies) resistant tomato (*solanum lycopersicum* l.) and pepper (capsicumspecies) cultivars in ghana. *nematropica*, *44*(2), 130-136.

Lawson, I. Y. D., Issahaku, A., Acheampong, S. K., Adams, B., & Tuffour, V. (2013). Time of planting and weed suppression abilities of some legumes intercropped with maize in the Guinea savanna zone of Ghana. *Agric. Biol. J. North Am*, *4*, 358-363.

Libutti, A., Francavilla, M., & Monteleone, M. (2021). Hydrological Properties of a Clay Loam Soil as Affected by Biochar Application in a Pot Experiment. *Agronomy*, *11*(3), 489.

Ling, X., Zhao, Y., Gong, L., Liu, C., & Wang, T. (2019). Dual-arm cooperation and implementing for robotic harvesting tomato using binocular vision. *Robotics and Autonomous Systems*, *114*, 134-143.

Loeillet, D. (2019). *Africa and the global commodity commodity markets* (p. 09) [Cyclope]. Policy Center for the New South. https://agritrop.cirad.fr/592436/1/ID592436.pdf

Lozano, D., Ruiz, N., Baeza, R., Contreras, J. I., & Gavilán, P. (2020). Effect of pulse drip irrigation duration on water distribution uniformity. *Water*, *12*(8), 2276.

Lu, Y., Lu, S., Horton, R., & Ren, T. (2014). An empirical model for estimating soil thermal conductivity from texture, water content, and bulk density. *Soil Science Society of America Journal*, *78*(6), 1859-1868.

Luc, M., Bridge, J., & Sikora, R. A. (2005). Reflections on nematology in subtropical and tropical agriculture. *Plant Parasitic Nematodes in Subtropical and Tropical Agriculture, Ed. 2*, 1-10.

Lutuf, H. (2015). *Identification Of Nematodes And Morphological Characterization Of Meloidogyne Incognita Associated With Solanum Lycopersicum L. In The Ashanti, Brong Ahafo And Upper East Regions of Ghana* [Thesis, University Of Ghana]. http://ugspace.ug.edu.gh/handle/123456789/22752

Martín, M. Á., Reyes, M., & Taguas, F. J. (2017). Estimating soil bulk density with information metrics of soil texture. *Geoderma*, *287*, 66-70.

Medel, M., Zipper, J., Dabancens, A., & Thomas, M. (1976). Contraceptive efficacy of two different metals using a modified seven vector. *International Journal of Gynaecology and Obstetrics: The Official Organ of the International Federation of Gynaecology and Obstetrics*, *14*(6), 494-498. https://doi.org/10.1002/j.1879-3479.1976.tb00092.x

Mehdizadeh, M., Darbandi, E. I., Naseri-Rad, H., & Tobeh, A. (2013). Growth and yield of tomato (Lycopersicon esculentum Mill.) as influenced by different organic fertilizers. *2013*, 734-738.

Mekonnen, D., Choufani, J., Bryan, E., Abizari, A.-R., Ringler, C., & Amikuzuno, J. (2019). *Irrigation-nutrition linkages : Evidence from northern Ghana. IFPRI Discussion Paper, 1887, Rome, Italy. IFPRI.* 36.

Mokrini, F., Janati, S., Houari, A., Essarioui, A., Bouharroud, R., & Mimouni, A. (2018). Management of plant parasitic nematodes by means of organic amendment. *Rev Mar Sci Agron Vét*, *6*(3), 337-344.

Nahak, G., & Sahu, R. K. (2015). Biopesticidal effect of leaf extract of neem (Azadirachta indica A. Juss) on growth parameters and diseases of tomato. *Journal of Applied and Natural Science*, *7*(1), 482-488.

Naika, S., Lidth de Jeude, J. van, Goffau, M. de, Hilmi, M., & Dam, B. van. (2005). *Tomato cultivation : Production, processing and marketing* (05 éd., Vol. 5). Wageningen. https://cgspace.cgiar.org/bitstream/handle/10568/64598/AD17fr.pdf?sequence=1&isAllowed=y

Namara, R. E., Horowitz, L., Kolavalli, S., Kranjac-Berisavljevic, G., Dawuni, B. N., Barry, B., & Giordano, M. (2011). *Typology of irrigation systems in Ghana* (International Water Management Institute (IWMI), Vol. 142). IWMI. https://www.iwmi.cgiar.org/Publications/Working_Papers/working/WOR142.pdf

Nikolaou, G., Neocleous, D., Christou, A., Kitta, E., & Katsoulas, N. (2020). Implementing sustainable irrigation in water-scarce regions under the impact of climate change. *Agronomy*, *10*(8), 1120.

Nocita, M., Stevens, A., Noon, C., & van Wesemael, B. (2013). Prediction of soil organic carbon for different levels of soil moisture using Vis-NIR spectroscopy. *Geoderma*, *199*, 37-42.

Noling, J. W. (2014). *Nematode management in tomatoes, peppers, and eggplant* (N° 03200; p. 16). https://edis.ifas.ufl.edu/publication/NG032

Norton, D. C., & DC, N. (1976). *Relationship of hoplolamus galeatus and pratylenchus hexincisus to reduction of corn yields in sandy soils in iowa*. *60*(3), 197-200.

Ochsner, T. E., Horton, R., & Ren, T. (2001). A new perspective on soil thermal properties. *Soil science society of America Journal*, *65*(6), 1641-1647.

Ohtsuka, T., & Komatsu, T. (2005). Enhancement of electric conductivity of the rust layer by adsorption of water. *Corrosion science*, *47*(10), 2571-2577.

Oka, Y., Shapira, N., & Fine, P. (2007). Control of root-knot nematodes in organic farming systems by organic amendments and soil solarization. *Crop Protection*, *26*(10), 1556-1565. https://doi.org/10.1016

Oke, A. M., Osilaechuu, A. P., Aremu, T. E., & Ojediran, J. O. (2020). Effect of drip irrigation regime on plant height and stem girth of tomato (Lycopersicon esculentum Mill). *IOP Conference Series: Earth and Environmental Science*, *445*(1), 012016.

Owusu, S. B., Kwoseh, C. K., Starr, J. L., & Davies, F. T. (2016). Grafting for management of root-knot nematodes, Meloidogyne incognita, in tomato (Solanum lycopersicum L.). *Nematropica*, *46*(1), 14-21.

Panpatte, D. G., Jhala, Y. K., Shelat, H. N., & Vyas, R. V. (2016). Pseudomonas fluorescens : A promising biocontrol agent and PGPR for sustainable agriculture. In *Microbial inoculants in sustainable agricultural productivity* (p. 257-270). Springer.

Petkov, P. (2021). Using the double-ring infiltrometer to evaluate key unsaturated and saturated hydrological. *Water Resources Research*, *14*(4), 601-604.

Philouze, J. (1993). Greenhouse tomatoes in the Mediterranean region. *5. Rencontres INRA-ENSAM*, *7*(6), 4.

Plante, A. F., & Parton, W. J. (2007). The dynamics of soil organic matter and nutrient cycling. In *Soil microbiology, ecology and biochemistry* (p. 433-467). Elsevier. https://scholar.google.com/scholar?hl=fr&as_sdt=0%2C5&q=organic+carbon%2C+organic+matter+and+nutrient+&btnG=

Postel, S. L. (2000). Entering an era of water scarcity : The challenges ahead. *Ecological applications*, *10*(4), 941-948.

Qu, Z., Chen, Q., Feng, H., Hao, M., Niu, G., Liu, Y., & Li, C. (2022). Interactive effect of irrigation and blend ratio of controlled release potassium chloride and potassium chloride on greenhouse tomato production in the Yellow River Basin of China. *Agricultural Water Management*, *261*, 107346.

Reddy, P. P. (2017). *Agro-ecological approaches to pest management for sustainable agriculture*. Springer.

Saydee, V. J. (2015). *An Evaluation of the nematicidal potential of five botanicals in the management of meloidogyne Spp on tomato (Solanum Lycopersicum)* [Thesis, University of Cape Coast]. http://ir.ucc.edu.gh/jspui/handle/123456789/2605

See, B., & Ward, R. (1990). *infiltration and the use of the double ring infiltrometer. - Recherche Google*. https://www.google.com/search?hl=fr&q=See+Bouwer+(1986),+ILRI+(1974),+Ward+%26+Robinson+(1990)+for+further+information+concerning+soil+water,+infiltration+and+the+use+of+the+double+ring+infiltrometer.

Seid, A., Fininsa, C., Mekete, T., Decraemer, W., & Wesemael, W. M. L. (2015). Tomato (Solanum lycopersicum) and root-knot nematodes (Meloidogyne spp.) – a century-old battle. *Nematology*, *17*(9), 995-1009. https://doi.org/10.1163/15685411-00002935

Sekanjako, I. (2021). *Evaluation of application regimes and rates of biological control agents for the management of root knot nematodes and bacterial wilt of tomato* [PhD Thesis]. Makerere University.

Seshweni, M. D. (2016). *Integrated system for the management of Meloidogyne javanica in tomato production* [PhD Thesis]. http://ulspace.ul.ac.za/handle/10386/2003

Sikandar, A., Zhang, M., Wang, Y., Zhu, X., Liu, X., Fan, H., Xuan, Y., Chen, L., & Duan, Y. (2020). In vitro evaluation of Penicillium chrysogenum Snef1216 against Meloidogyne incognita (root-knot nematode). *Scientific Reports, 10*(1), 1-9.

Sikora et Fernandez, R. et E. (2005). *Plant parasitic nematodes in subtropical and tropical agriculture*. 319-392.

Silva, C. J. da, Frizzone, J. A., da Silva, L. F., Santos, Y. A. de O., Golynski, A., & Pontes, N. de C. (2021). Flower abortion and yield of processing tomato according to irrigation depths. *Revista Brasileira de Engenharia Agrícola e Ambiental*, *25*, 415-421.

Singh, A. U., & D, P. (2017). Management of Plant-parasitic Nematodes by the Use of Botanicals. *Journal of Plant Physiology & Pathology*, *2*(1), 12. https://doi.org/10.4172/2329-955X.1000116

Singh, S. P. (2001). Broadening the genetic base of common bean cultivars : A review. *Crop science*, *41*(6), 1659-1675.

Sora, S. A., & Sakata, W. M. (2022). *Management of Some Common Insect Pests and Diseases of Tomato (Solanum lycopersicon L.)*. *8*(2), 10. https://doi.org/10.11648/j.ijsd.20220802.12

Tileubayeva, Z., Avdeenko, A., Avdeenko, S., Stroiteleva, N., & Kondrashev, S. (2021). Plant-parasitic nematodes affecting vegetable crops in greenhouses. *Saudi Journal of Biological Sciences*, *28*(9), 5428-5433. https://doi.org/10.1016/j.sjbs.2021.05.075

Topalović, O., Hussain, M., & Heuer, H. (2020). Plants and Associated Soil Microbiota Cooperatively Suppress Plant-Parasitic Nematodes. *Frontiers in Microbiology*, *11*(313), 14. https://doi.org/10.3389/fmicb.2020.00313

Treonis, A. M., Unangst, S. K., Kepler, R. M., Buyer, J. S., Cavigelli, M. A., Mirsky, S. B., & Maul, J. E. (2018). Characterization of soil nematode communities in three cropping systems through morphological and DNA metabarcoding approaches. *Scientific reports*, *8*(1), 1-12. https://doi.org/10.1038/s41598-018-20366-5

Trivedi, P. C., & Barker, K. R. (1986). Nematological reviews : Management of nematodes by cultural practices. *Nematropica*, 213-236.

Umar, I. and Aji, M.B. (2013). Effect of Botanicals in the Control of Meloidogyne incognita (Kofoid and White)Chitwood on Soybean [Glycine max (L) Merr. *IOSR Journal of Agriculture and Veterinary Science*, *4*(2), 43-45. https://doi.org/10.9790/2380-0424345

Vigbedor, H. D., Nyaku, S. T., & Cornelius, E. W. (2022). Effect of Meloidogyne incognita and Fusarium oxysporum f. Sp. Lycopersici on tomato varietal growth under Ghanaian field conditions. *African Crop Science Journal*, *30*(2), 155-166.

Wabere, G. N. (2016). *Evaluation of root-knot nematode management strategies based on nematode distribution in tomato (Solanum lycopersicum) fields in Mwea, Kirinyaga County, Kenya* [PhD Thesis, Thesis Master of Science, School of Pure and Applied Sciences, Kenyatta …]. https://ir-library.ku.ac.ke/bitstream/handle/123456789/15000/Evaluation%20of%20root%20knot%20nematode%20management.pdf?sequence=1

Waisen, P., Wang, K.-H., Uyeda, J., & Myers, R. Y. (2021). Effects of fluopyram and azadirachtin integration with sunn hemp on nematode communities in zucchini, tomato and sweet potato in Hawaii. *Journal of Nematology*, *53*(1), 1-15.

Wazed, S. M., Hughes, B. R., O'Connor, D., & Calautit, J. K. (2018). A review of sustainable solar irrigation systems for Sub-Saharan Africa. *Renewable and Sustainable Energy Reviews*, *81*, 1206-1225. https://doi.org/10.1016

Wen, L., Lee-Marzano, S., Ortiz-Ribbing, L. M., Gruver, J., Hartman, G. L., & Eastburn, D. M. (2017). Suppression of soilborne diseases of soybean with cover crops. *Plant disease*, *101*(11), 1918-1928. https://doi.org/Plant Dis. 10:1918-1928.

Windham, G. L., & Edwards, D. I. (1999). Diseases caused by nematodes. *Compendium of corn diseases:*, 56-62.

Wood, T. N. W. (2013). *Agricultural Development in the Northern Savannah of Ghana*. 73.

World bank. (2020a). *World Bank Group—International Development, Poverty, and Sustainability* [Text/HTML]. World Bank. https://www.worldbank.org/en/home.

World bank. (2020b). https://www.worldbank.org/en/topic/agriculture.

Worqlul, A. W., Dile, Y. T., Jeong, J., Adimassu, Z., Lefore, N., Gerik, T., Srinivasan, R., & Clarke, N. (2019). Effect of climate change on land suitability for surface irrigation and irrigation potential of the shallow groundwater in Ghana. *Computers and electronics in agriculture*, *157*, 110-125.

Wossen, T., & Berger, T. (2015). Climate variability, food security and poverty : Agent-based assessment of policy options for farm households in Northern Ghana. *Environmental Science & Policy*, *47*, 95-107.

Woźnica, K., Józefowska, A., Soko\lowska, J., Mazurek, R., & Zaleski, T. (2019). Classification of brown earths based on field and laboratory properties : Problematic issues and proposition of their solution. *Polish Journal of Soil Science*, *52*(2), 225. https://doi.org/10.17951/pjss/2019.52.2.225

Wu, Y., Yan, S., Fan, J., Zhang, F., Xiang, Y., Zheng, J., & Guo, J. (2021). Responses of growth, fruit yield, quality and water productivity of greenhouse tomato to deficit drip irrigation. *Scientia Horticulturae*, *275*, 109710.

Zafari, J. K., & Mohammadi, N. K. (2019). A review on drip fertigation on field crops. *International Journal of Engineering Science and Technology*, *8*(11), 722-729.

Zhang, H., Schroder, J. L., Pittman, J. J., Wang, J. J., & Payton, M. E. (2005). Soil salinity using saturated paste and 1 : 1 soil to water extracts. *Soil Science Society of America Journal*, *69*(4), 1146-1151.

Zhang, H., Xiong, Y., Huang, G., Xu, X., & Huang, Q. (2017). Effects of water stress on processing tomatoes yield, quality and water use efficiency with plastic mulched drip irrigation in sandy soil of the Hetao Irrigation District. *Agricultural Water Management*, *179*, 205-214.

APPENDICES

Appendix 1. Crop Water Requirement

Month	Decade	Stage	K_c	ET_0	100 % ETc (mm/dec)	75 % ETc (mm/dec)	50 % ETc (mm/dec)
May	1	Ini	0.90	5.68	51.12	38.34	25.56
May	2	Ini	0.90	5.68	51.12	38.34	25.56
May	3	Ini	0.90	5.68	51.12	38.34	25.56
Jun	1	Dev	1.15	4.92	56.58	42.44	28.29

Jun	2	Dev	1.15	4.92	56.58	42.44	28.29
Jun	3	Dev	1.15	4.92	56.58	42.44	28.29
Jul	1	Mid	1.01	4.33	43.73	32.8	21.87
Jul	2	Mid	1.01	4.33	43.73	32.8	21.87
Jul	3	Mid	0.08	4.33	43.73	25.98	17.32
Aug	1	Late	0.80	3.89	31.12	23.34	15.56
Aug	2	Late	0.80	3.89	31.12	23.34	15.56
Total					508	381	254

Kc = crop coefficient, ETo = evapotranspiration of reference crop, ETc = crop evapotranspiration, (mm/dec) = millimeter per decade, Ini = Initial Stage, Dev = development stage.

Appendix 2. Nematodes Count

Bontanga	1	2	3	4	5	6	7	8	Total
Samples	10	3	0	1	5	3	0	10	32

Golinga			
Samples	Nematodes (1st count)	Nematodes (2nd count)	Total

1	3	5	8
2	0	0	0
3	7	6	13
4	10	1	11
5	1	0	1
6	28	8	36
7	13	13	26
8	3	3	6
9	8	8	16
10	0	0	0
11	1	0	1
12	13	13	26
13	10	10	20
14	0	0	0
15	4	4	8
16	26	26	52
17	10	10	20
18	12	12	24
19	2	2	4
20	37	37	74
21	8	8	16
22	10	10	20
23	2	2	4

24	12	12	24
25	12	12	24
26	9	9	18
27	8	8	16
28	16	16	32
29	13	13	26
30	5	5	10
31	27	27	54
32	0	0	0
33	13	15	28
34	19	19	38
35	28	28	56
36	17	17	34
37	2	2	4
38	14	14	28
39	9	9	18
40	11	11	22
41	30	30	60
42	2	2	4
43	3	3	6
44	8	0	8
45	13	13	26
46	0	0	0

47	16	16	32
48	10	10	20
49	4	4	8
50	26	26	52
51	8	8	16
52	2	2	4
53	0	0	0
54	12	12	24
55	10	10	20
56	5	5	10
57	14	14	28
58	24	24	48
59	13	13	26
60	19	0	19
61	12	12	24
62	16	5	21
63	5	5	10
64	9	7	16
65	10	1	11
66	3	3	6
67	1	1	2
68	3	2	5
69	5	5	10

70	10	8	18
Total Nematode count, Golinga			1352
Total Nematode count, Bontanga			32
Total			1384
Water quantity/mL			10.5
infected pot			66
Each pot (L)			0.159091

Appendix 3. Distribution Uniformity test values

Replications	DU (%)	Qa (l/h)
Replication 1	0.88	0.44
Replication 2	0.95	0.43
Replication 2	0.88	0.44

Appendix 4. Plant Height at 4WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation	2	502.8	251.4	1.74	0.191
Velum Prime	1	294.0	294.0	2.03	0.163
Neem extract	2	40.4	20.2	0.14	0.870
Irrigation.Velum Prime	2	60.8	30.4	0.21	0.812
Irrigation. Neem extract	4	503.4	125.9	0.87	0.492
Irrigation.Velum Prime. Neem extract	4	419.4	104.9	0.73	0.581
Residual	34	4917.2	144.6		
Total	53	8333.3			

Appendix 5. Plant Height at 6 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation	2	2902.93	1451.46	140.48	<0.001
Velum Prime	1	362.96	362.96	35.13	<0.001
Neem extract	2	815.81	407.91	39.48	<0.001
Irrigation.Velum Prime	2	233.37	116.69	11.29	<0.001
Irrigation. Neem extract	4	354.85	88.71	8.59	<0.001
Velum. Neem extract	2	140.04	70.02	6.78	0.006

Irrigation.Velum Prime. Neem extract	4	389.96	97.49	9.44	<0.001
Residual	34	351.30	10.33		
Total		53	5605.26		

Appendix 6. Plant Height at 8 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation	2	2902.93	1451.46	140.48	<0.001
Velum Prime	1	362.96	362.96	35.13	<0.001
Neem extract	2	815.81	407.91	39.48	<0.001
Irrigation.Velum Prime	2	233.37	116.69	11.29	<0.001
Irrigation. Neem extract	4	354.85	88.71	8.59	<0.001
Velum Prime. Neem extract	2	140.04	70.02	6.78	0.005
Irrigation.Velum Prime. Neem extract	4	389.96	97.49	9.44	<0.001
Residual	34	351.30	10.33		
Total		53	5605.26		

Appendix 7. Number of Leaves at 4 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation	2	396.93	198.46	16.38	<0.001
Velum Prime	1	31.13	31.13	2.57	0.118
Neem extract	2	23.59	11.80	0.97	0.388
Irrigation.Velum Prime	2	1.59	0.80	0.07	0.936
Irrigation. Neem extract	4	28.52	7.13	0.59	0.673
Irrigation.Velum Prime.Neem extract	4	20.07	5.02	0.41	0.797
Residual	34	411.85	12.11		
Total	53	1101.87			

Appendix 8. Number of Leaves at 6 WATP

Source of variation	d.f	s.s.	m.s.	v.r.	F pr.
Irrigation	2	478.259	239.130	133.12	<0.001
Velum Prime	1	31.130	31.130	17.33	<0.001
Neem extract	2	104.148	52.074	28.99	<0.001
Irrigation.Velum Prime	2	49.593	24.796	13.80	0.006
Irrigation. Neem extract	4	9.630	2.407	1.34	<0.001
Velum. Neem extract	2	9.926	4.963	2.76	0.007

Irrigation.VelumPrime .Neemextract	4	129.185	32.296	17.98	<0.001
Residual	34	61.074	1.796		
Total		53	879.204		

Appendix 9. Number of Leaves at 8 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation	2	335.259	167.630	39.62	<0.001
Velum Prime	1	24.000	24.000	5.67	<0.001
Neem extract	2	82.926	41.463	9.80	<0.001
Irrigation.Velum Prime	2	32.444	16.222	3.83	0.006
Irrigation.Neem extract	4	22.741	5.685	1.34	<0.001
Velum Prime.Neem extract	2	24.778	12.389	2.93	0.067

Irrigation.Velum Prime. Neem extract	4	97.111	24.278	5.74	<0.001
Residual	34	143.852	4.231		
Total		53	799.259		

Appendix 10. Chlorophyll content at 4 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation	2	735.156	367.578	38.24	<.001
Velum Prime	1	2.756	2.756	0.29	0.596
Neem extract	2	233.896	116.948	12.17	<0.001
Irrigation.Velum Prime	2	39.591	19.796	2.06	0.143
Irrigation. Neem extract	4	365.067	91.267	9.50	<0.001
Velum. Neem extract	2	890.863	445.431	46.34	<0.001

Irrigation.Velum Prime. Neem extract	4	31.870	7.967	0.83	0.516
Residual	34	326.792	9.612		
Total		53	2649.699		

Appendix 11. Chlorophyll content at 6 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation	2	898.303	449.151	50.07	<0.001
Velum Prime	1	2.802	2.802	0.31	0.580
Neem extract	2	265.489	132.745	14.80	<0.001
Irrigation.Velum Prime	2	42.188	21.094	2.35	0.111
Irrigation. Neem extract	4	391.136	97.784	10.90	<0.001
Velum Prime. Neem extract	2	899.710	449.855	50.15	<0.001

Irrigation.Velum Prime. Neem extract	4	29.996	7.499	0.84	0.512
Residual	34	305.006	8.971		
Total	53	2860.663			

Appendix 12. Chlorophyll content at 8 WATP

Source of variation	d.f	s.s.	m.s.	v.r.	F pr.
Irrigation	2	731.23	365.61	33.37	<0.001
Velum Prime	1	6.13	6.13	0.56	0.459
Neem extract	2	285.40	142.70	13.03	<0.001
Irrigation.Velum Prime	2	57.70	28.85	2.63	0.861
Irrigation. Neem extract	4	419.27	104.82	9.57	<0.001
Velum Prime.Neem extract	2	844.80	422.40	38.56	<0.001
Irrigation.VelumPrime.Neem extrat	4	18.27	4.57	0.42	0.795
Residual	34	372.47	10.95		
Total	53	2738.63			

Appendix 13. Flower count at 6 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation	2	525.444	262.722	628.07	<0.001
Velum Prime	1	88.166	88.1667	210.77	<0.001
Neem extract	2	320.444	160.222	383.03	<0.001
Irrigation.Velum Prime	2	1.444	0.7222	1.73	<0.001

Irrigation. Neem extract	4	241.777	60.4444	144.50	<0.001
Velum Prime. Neem extract	2	23.111	11.5556	27.63	<0.001
Irrigation.Velum Prime. Neem extract	4	59.111	14.7778	35.33	<0.001
Residual	34	14.222	0.4183		
Total	53	1276.833			

Appendix 14. Flower count at 8 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation	2	6.960202	3.480101	602.85	<0.001
Velum Prime	1	1.300577	1.300577	225.29	<0.001
Neem extract	2	4.198160	2.099080	363.62	<0.001
Irrigation.Velum Prime	2	0.105110	0.052555	9.10	<0.001
Irrigation. Neem extract	4	2.989771	0.747443	129.48	<0.001
Velum Prime. Neem extract	2	0.408718	0.204359	35.40	<0.001

Irrigation.VelumPrime. Neem extract	4	59.1111	14.7778	30.69	<0.001
Residual	34	0.196274	0.005773		
Total	53		17.091545		

Appendix 15. Fruit count at 8 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation	2	80.70	40.35	3.02	0.061
Velum Prime	1	37.50	37.50	2.80	0.103
Neem extract	2	206.93	103.46	7.74	0.002
Irrigation.Velum Prime	2	4.11	2.06	0.15	0.858
Irrigation. Neem extract	4	33.41	8.35	0.62	0.648
Velum Prime. Neem extract	2	24.11	12.06	0.90	0.415

Irrigation.Velum Prime. Neem extract	4	93.78	23.44	1.75	0.160
Residual	36	481.33	13.37		
Total		53	961.87		

Appendix 16. Fruit count at 9 WATP

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation	2	157.00	78.50	4.06	0.016
Velum Prime	1	71.19	71.19	3.68	0.064
Neem extract	2	310.11	155.06	8.01	0.001
Irrigation.Velum Prime	2	23.81	11.91	0.62	0.546
Irrigation. Neem extract	4	58.22	14.56	0.75	0.564

Velum Prime. Neem extract	2	31.59	15.80	0.82	0.451
Irrigation.Velum Prime. Neem extract	4	163.41	163.41	40.85	2.11
Residual	34	657.89	19.35		
Total	53	1511.33			

Appendix 17. Fruit Yield

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Irrigation	2	2272	2136	18.17	0.31
Velum Prime	1	1830	2787	1.43	0.486
Neem extract	2	25150	12575	19.68	<.001
Irrigation.Velum Prime	2	3600	1830	2.87	0.086
Irrigation.Neem extract	4	35702	26575	21.65	<.001
Velum Prime.Neem extract	2	2600	986	0.97	0.652

Irrigation.Velum Prime.Neem extract	4	1150	575	0.27	0.852
Residual	34	1304	38		
Total	53	91608			

Appendix 18. Field Picture with Tomato 2 WATP (left) and Neem Extract Preparation (right)

Appendix 19. Field Picture with Treatment At 3WATP

Appendix 20. Field Picture with Data Collection (left) and Tomato at the Fruiting Stage (right)

Appendix 21. Tomato Field at 12 WATP