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ARTICLE

RESEARCH ARTICLE

Reduction of the disease caused by *Meloidogyne chitwoodi* on tomato with nitrogen-based fertilizers

Reducción de la enfermedad causada por *Meloidogyne chitwoodi* en tomate con fertilizantes nitrogenados

Sümeyya V. Dişkaya
Çukurova University, Faculty of Agriculture, Department of Plant Protection. 01330, Sarıçam, Adana, Turkey
Corresponding author: svdiskaya@cu.edu.tr, https://orcid.org/0000-0002-3734-0135

Salim Avcıoğlu
Çukurova University, Faculty of Agriculture, Department of Plant Protection. 01330, Sarıçam, Adana, Turkey
https://orcid.org/0009-0005-6889-819X

Ece B. Kasapoğlu-Uludamar
Çukurova University, Faculty of Agriculture, Department of Plant Protection. 01330, Sarıçam, Adana, Turkey
https://orcid.org/0000-0003-0936-3759

İbrahim H. Elekcioğlu
Çukurova University, Faculty of Agriculture, Department of Plant Protection. 01330, Sarıçam, Adana, Turkey
https://orcid.org/0000-0002-1707-7392

Abstract: *Aim of study:* Tomatoes are among the most widely cultivated vegetables globally. *Meloidogyne chitwoodi* Golden, O'Bannon, Santo & Finley, 1980 is a significant yield-reducing factor in many tomato production areas. Owing to the detrimental effects of pesticides on the environment and living organisms in the management against plant parasitic nematodes, it is imperative to develop alternative methods for the management of plant parasitic nematodes. For this reason, the relationship between chemical fertilizers and plant-parasitic nematodes were investigated to determine whether these fertilizers could be utilized within the scope of an integrated pest management (IPM). *Area of study:* The study was conducted in vitro and in the growth chamber of the Nematology laboratory at the Department of Plant Protection, Faculty of Agriculture, Çukurova University. *Material and methods:* The effects of five different nitrogen fertilizers at seven dosages on the *M. chitwoodi* tomato pathosystem were studied. *Main results:* In vitro results demonstrated that all doses of urea ammonium nitrate, nitric acid, and ammonium sulphate induced 100% mortality in *M. chitwoodi* second-stage juveniles (J2) at 72 hours while, calcium nitrate fertilizer induced 80% mortality at the 1600 ppm dose. However, no mortality was observed for the urea treatment. Pot experiments showed that urea ammonium nitrate completely suppressed *M. chitwoodi* at 50 ppm and above. Ammonium sulphate and nitric acid demonstrated significant suppressive effects exceeding 80% at doses of 100-1600 ppm. Calcium nitrate had a suppressive effect of over 80% at doses of 800-1600 ppm. Petri dish experiments showed that urea fertilizer had no noticeable effect. However, pot experiments indicated that urea fertilizer exhibited a suppressive effect exceeding 80% at doses above 200 ppm. *Research highlights:* It was found that the use of some doses of these fertilizers negatively affected the development of *M. chitwoodi.*

Keywords: management; root-knot nematodes; suppressive effect; urea; urea ammonium nitrate.

Resumen: *Objetivo del estudio:* El tomate es una de las hortalizas más cultivadas en todo el mundo. *Meloidogyne chitwoodi* Golden, O'Bannon, Santo & Finley, 1980 es un importante factor de reducción del rendimiento en las zonas de producción de tomate. Teniendo en cuenta los efectos perjudiciales de los plaguicidas sobre el medio ambiente y los organismos vivos, es imperativo desarrollar métodos de control alternativos para la gestión de los nematodos parásitos de las plantas. Por esta razón, se investigó la relación entre los fertilizantes químicos y los nematodos parásitos de las plantas para determinar si estos fertilizantes pueden ser utilizados en el ámbito del manejo integrado de plagas (MIP). *Área del estudio:* El estudio se realizó in vitro y en la cámara de crecimiento del laboratorio de Nematología del Departamento de Protección Vegetal de la Facultad de Agricultura de la Universidad de Çukurova. *Material y métodos:* En este estudio se estudiaron los efectos de siete dosis de cinco fertilizantes nitrogenados diferentes sobre el patosistema *M. chitwoodi* en tomate. *Resultados principales:* Los resultados in vitro demostraron que todas las dosis de urea- nitrato amónico, ácido nítrico y sulfato amónico indujeron una mortalidad del 100% en *M. chitwoodi* juveniles de segundo estadio (J2) a las 72 horas, mientras que el fertilizante de nitrato cálcico indujo una mortalidad del 80% a la dosis de 1600 ppm. Sin embargo, no se observó mortalidad en el tratamiento con urea. Los experimentos en maceta demostraron que el nitrato de urea y amonio suprimió completamente a *M. chitwoodi* a 50 ppm y concentraciones superiores. El sulfato de amonio y el ácido nítrico mostraron un efecto supresor significativo superior al 80% en dosis de 100-1600 ppm. El nitrato de calcio tuvo un efecto supresor superior al 80% a dosis de 800-1600 ppm. Los experimentos en placas de Petri indicaron que el fertilizante de urea no tuvo un efecto apreciable. Sin embargo, los experimentos en maceta revelaron que la urea mostró un efecto supresor superior al 80% en dosis superiores a 200 ppm. *Aspectos destacados de la investigación:* El uso de algunas dosis de estos fertilizantes afectó negativamente al desarrollo de *M. chitwoodi*.

Palabras clave: efecto supresor; manejo; nematodos agalladores; urea-nitrato amónico; urea.

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Supplementary information ↓

1. INTRODUCTION

Tomatoes (*Solanum lycopersicum* L.) are one of the most fundamental food crops and hold significant agricultural importance due to theability to a wide range of growing conditions on a global scale. According to the Food and Agriculture Organization (FAO, 2022), the global tomato production reaches approximately 187 million tons annually, with China being the top producer, followed by India and Turkey.

Vegetable-growing regions across the globe face substantial threats from various diseases and pests. Among these, root-knot nematodes (*Meloidogyne* spp.) are particularly harmful and are widespread in tropical and subtropical regions (Ghareeb et al., 2022). These nematodes are distributed globally but are especially damaging in warm regions with intensive irrigation and fruit-vegetable cultivation (Moens et al., 2009). In countries such as Turkey, where climate and production conditions are conducive to their proliferation, root-knot nematodes have been observed to cause significant crop losses. These organisms have been shown to damage to the root system, thereby impeding the process by which nutrients and water are transported from the roots to the plant itself (Loveys & Bird, 1973; Meon et al., 1978; Melakeberhan et al., 1987). Consequently, affected plants exhibit wilting, chlorosis, and severe yield reductions (Lamberti et al., 1979). Although chemical nematicides are effective in controlling

plant-parasitic nematodes, their use raises serious environmental and economic concerns. These include increasing costs, environmental toxicity, harm to non-target organisms, and groundwater contamination (Igbedioh, 1991). Therefore, minimizing risks to human health and the environment has become a priority, prompting the exploration of alternative management strategies such as crop rotation, resistant cultivars, and cultural practices for plant-parasitic nematodes (Williamson, 1999; Castillo & Vovlas, 2007).

Fertilization, a common practice in modern agriculture, can also influence plant-parasitic nematode populations. It is noteworthy that the efficacy of organic fertilizers, such as poultry manure, has been shown to be comparable to that of chemical treatments. However, there is accompanied by lower economic returns due to higher application costs (Dyrdahl-Young et al., 2020). Although extensive research has been conducted on resistant tomato cultivars (Bailey, 1941; Barham & Winstead, 1957; Williamson, 1999), resistance is often compromised over time by the emergence of more aggressive nematode races (Roberts, 1995; Castagnone-Sereno, 2002).

Given the environmental impacts of chemical pesticides, there is a pressing need to develop and implement alternative control strategies within the framework of Integrated Pest Management (IPM). One promising approach is to investigate how different fertilization practices influence nematode populations, particularly since fertilizers are applied in large quantities annually. Plant parasitic nematodes feeding within root tissues and can interfere with plant development (Thompson et al., 2012). The effect of fertilizers on nematode dynamics depends on factors such as fertilizer type, application rate, and soil and environmental conditions. Some studies have reported that certain fertilizers may increase nematode populations by promoting root growth and providing more feeding sites (Ferraz et al., 2010), while others have found suppressive effects due to thermal or chemical properties of fertilizers (Liang et al., 2009; Khan et al., 2012; Ahmadi Mansourabad et al., 2016). When evaluating the economic feasibility of nematode management strategies, the cost of fertilizers should also be considered in comparison with chemical nematicides. Synthetic fertilizers, particularly nitrogen-based ones— are generally more affordable and widely used. However, their excessive and unbalanced application can have detrimental effects, including soil acidification, disruption of microbial communities, groundwater contamination, and even promotion of plant-parasitic nematode populations under certain conditions (Liang et al., 2009; Grabau et al., 2017). For instance, increased nitrogen inputs have been associated with higher populations of soybean cyst nematodes, likely due to enhanced root biomass, which facilitates nematode infection (Grabau et al., 2017). Thus, while fertilizers are a critical component of agricultural productivity, their use should be carefully managed within integrated pest and nutrient management programs to avoid unintended ecological consequences.

Further investigation is needed to clarify the relationship between fertilizers and nematodes and to determine the extent to which these interactions exert positive or negative effects. The present study aims to investigate the effects of nitrogen fertilizers on *Meloidogyne chitwoodi* Golden, O'Bannon, Santo & Finley, 1980 (Tylenchida; Meloidogynidae) populations *in vitro* and on their reproduction on tomato plants under laboratory and growth chamber conditions.

2. MATERIAL AND METHODS

The study was performed to determine the effect of different doses of fertilizers used in agricultural production on the root-knot nematode, *M. chitwoodi*. To achieve this, two methods were employed: the direct effects on *M. chitwoodi* second-stage juveniles (J2) were investigated on J2 suspensions in Petri dishes, while the effect on *M. chitwoodi* reproduction and root-knot nematodes disease on tomato plants were studied in pot experiments in a growth chamber.

2.1. Reproduction of *Meloidogyne chitwoodi* in laboratory

Nematode population was propagated on susceptible tomato 'Tueza F1', inoculating the soil with 1000 second-stage juveniles of *M. chitwoodi* / 500 g soil in the Nematology Laboratory of Çukurova University, Faculty of Agriculture, Department of Plant Protection.

2.2. Dose adjustment of fertilizers used in the experiment

In order to ascertain the most appropriate doses of fertilizers to be included in the experiment, it was necessary to consider not only the optimum doses applied in the field but also the extreme doses that may be toxic to the plants. These ranged from the minimum level to the maximum level. The fertilizers used in this experiment were as follows:

A. Urea ammonium nitrate (16% Urea Nitrogen, 8% Nitrate Nitrogen, 8% Ammonia Nitrogen),

B. Nitric acid (12% Nitrate Nitrogen),

C. Ammonium sulfate (21% nitrogen),

D. Calcium nitrate (26% calcium oxide, 14.2% nitrate nitrogen, 1.3% ammonia nitrogen),

E. Urea (46% nitrogen)

The fertilizer dosages were converted to ppm and applied in doses of 25 ppm (severe deficiency), 50 ppm (deficiency), 100 ppm (Low dose), 200 ppm (optimum dose) (Kalaycı et al., 1999; Torun et al., 2000), 400 ppm (high dose), 800 ppm (extremely high dose), and 1600 ppm (toxic dose).

2.3. Direct effect in Petri dish experiment

The Petri dish method was employed in laboratory experiments, as documented in the study by Yadav et al. (2021). A range of nitrogen fertilizer concentrations were employed in the *in vitro* studies. The fertilizers were converted to parts per million (ppm), and 5 cm diameter Petri dishes were utilized. The following doses were employed: 25, 50, 100, 200, 400, 800, and 1600 ppm. A mean of 100 nematodes in 50 µl of water and 950 µl of different dose solutions of nitrogen fertilizers were applied to each Petri dish. In the control group, an average of 100 nematodes/ml was administered. The experiments were set up with five replicates and were conducted twice to ensure reliability and reproducibility of the results. Subsequently, the Petri dishes were incubated at 25 °C for a period of three days in a growth chamber. The number of nematodes was counted under a stereomicroscope at 24, 48, and 72 hours (sterile water was added one hour prior to the count). After 30 minutes, the nematodes were checked with a needle to determine whether they were immobile or alive (Abbasi et al., 2008). The percent mortality was calculated using the formula (Equation 1);

$$Mortality = \frac{Total\ number\ of\ dead\ nematodes}{Total\ number\ of\ nematodes} \left(1\right)$$

2.4. Pot experiment

The pot experiments were conducted in the growth room, employing a randomized block design. The temperature of the growth room was maintained at 25 ± 1 °C throughout the experiment. The experiment utilized the 'Tueza F1' tomato. The sandy growth medium to be utilized in the pot experiment was sterilized in an autoclave at 121 °C for 15 min. In order to determine the effect on nematodes, seven doses of five different nitrogen fertilizers were used in the experiment with five replications. The doses were 25, 50, 100, 200, 400, 800, and 1,600 ppm. The fertilizers were urea, nitric acid, calcium nitrate, ammonium sulfate, and urea ammonium nitrate. The experiment utilized tubes with a length of 15 cm and a diameter of 3 cm, with a volume of approximately 25 ml. On average, 65 grams of the sterilized sandy growth medium was added to each tube, and one seed was planted in each tube. Approximately 15 days after the tomato seeds germinated, second stage juveniles (J2) of

M. chitwoodi were inoculated at 130 individuals per plant. One hour after the nematode inoculation, fertilizer was applied.

Furthermore, five controls were included in the study: the positive control, 20,000 ppm abamectin at the registered dose, and the negative control (water). The plants were irrigated at a rate that was close to the field capacity. At 70 days after sowing time, the plant's green parts were harvested and washed to remove any debris. Plant height and dry matter were measured using a meter scale and a precision balance, respectively. To determine dry matter, the plants were dried in an oven at 80 °C for 72 hours. They were then weighed using a precision balance. The plant roots were evaluated according to the 0-10 gall index (Hartman & Sasser, 1985). The reproduction factors (Rf) were estimated according to Bybd Jr et al. (1983). The relative suppression rate (%) was calculated using Abbott's formula (Abbott, 1925).

2.5. Statistical Analysis

A one-way analysis of variance (ANOVA), performed using SPSS statistical analysis, was conducted to evaluate the results of this experiment. The data were evaluated according to Tukey's test, $p < 0.05$, also it was used $\log_{10}$ transformation for required results.

3. RESULTS

3.1 Direct effect in Petri dish

After the application of a 25 ppm dose of urea ammonium nitrate and nitric acid fertilizers, 100% mortality rate on *M. chitwoodi* J2 was observed at 24 hours. In contrast, a 93% mortality rate was observed at the same dose and a 100% mortality rate was observed at doses from 50 to 1600 ppm doses of ammonium sulfate fertilizer. There was no statistical difference in calcium nitrate and urea fertilizers compared to the control at all doses used (Table 1).

The direct impact of these fertilizers on *M. chitwoodi* 72 hours after application is illustrated based on the application doses. At all tested doses of urea ammonium nitrate, nitric acid, and ammonium sulfate fertilizers, 100% mortality was observed. In the case of calcium nitrate fertilizer, mortality rates were found to be below 50% when doses were between 25 and 400 ppm. However, at doses of 800 and 1,600 ppm, mortality rates were found to be 54% and 81%, respectively. There was no statistically significant difference between the urea fertilizer doses and the control.

3.2. The pot experiment

The effects of seven doses of five nitrogen fertilizers used in the experiment on *M. chitwoodi* in tomato are shown in Table 2. The reproduction factor of *M. chitwoodi* in tomato revealed that reproduction was absent at urea ammonium nitrate fertilizer doses of 50 ppm and above. Moreover, no reproduction was observed at doses of 200-1,600 ppm ammonium sulfate, 400-1,600 ppm nitric acid fertilizers, and urea. Moreover, a pronounced reduction in reproduction was observed at 100 and 200 ppm doses of nitric acid fertilizer compared with the negative control. Similarly, the application of 100 ppm ammonium sulfate and 200 ppm urea resulted in a notable decline in reproduction. Conversely, a notable reduction was observed at 800 ppm calcium nitrate fertilizer dose, while no reproduction was evident at 1,600 ppm. On the other hand, urea ammonium nitrate fertilizer, no gall was observed at any dose except the 25 ppm dose. While there was no statistical difference between the formation of gall at 25 and 50 ppm doses of nitric acid and ammonium sulfate fertilizers and the negative control, gall formation decreased from the 100 ppm dose and no gall formation was observed from the 400 ppm dose. In urea fertilizer, no gall formation was observed at doses of 400 ppm and above. In the case of calcium nitrate fertilizer, only at the 1,600 ppm dose was no gall formation observed (Table 2).

Table 1. Direct effect of different doses of nitrogen fertilizers on *Meloidogyne chitwoodi* in Petri dish experiments

Fertilizers	Doses	Mortality Rates (%)		
		24 hours (Mean±SE)	48 hours (Mean±SE)	72 hours (Mean±SE)
urea ammonium nitrate	Control	1.5±0.2b*	4±0.7b	6.5±0.9b
	25 ppm (Sd)**	100±0a	100±0a	100±0a
	50 ppm (D)	100±0a	100±0a	100±0a
	100 ppm (Ld)	100±0a	100±0a	100±0a
	200 ppm (Od)	100±0a	100±0a	100±0a
	400 ppm (Hd)	100±0a	100±0a	100±0a
	800 ppm (Ehd)	100±0a	100±0a	100±0a
	1600 ppm (Td)	100±0a	100±0a	100±0a
nitric acid	Control	1.5±0.2b	4±0.7b	6.5±0.9b
	25 ppm (Sd)	100±0a	100±0a	100±0a
	50 ppm (D)	100±0a	100±0a	100±0a
	100 ppm (Ld)	100±0a	100±0a	100±0a
	200 ppm (Od)	100±0a	100±0a	100±0a
	400 ppm (Hd)	100±0a	100±0a	100±0a
	800 ppm (Ehd)	100±0a	100±0a	100±0a
	1600 ppm (Td)	100±0a	100±0a	100±0a
ammonium sulfate	Control	1.5±0.2c	4±0.7b	6.5±0.9b
	25 ppm (Sd)	93.75±1.1b	100±0a	100±0a
	50 ppm (D)	100±0a	100±0a	100±0a
	100 ppm (Ld)	100±0a	100±0a	100±0a
	200 ppm (Od)	100±0a	100±0a	100±0a
	400 ppm (Hd)	100±0a	100±0a	100±0a
	800 ppm (Ehd)	100±0a	100±0a	100±0a
	1600 ppm (Td)	100±0a	100±0a	100±0a
calcium nitrate	Control	1.5±0.2e	4±0.7e	6.5±0.9e
	25 ppm (Sd)	5.25±0.9de	7.5±0.8de	10.75±1.2de
	50 ppm (D)	6.75±0.6de	9.25±1cde	11.25±0.7de
	100 ppm (Ld)	8.5±2.3d	9.5±1.9cde	14.25±1.1de
	200 ppm (Od)	10.25±1.3cd	15.75±1.2cd	20±1.4d
	400 ppm (Hd)	15.25±0.8c	19.75±1.7c	37.5±3.1c
	800 ppm (Ehd)	27.25±0.8b	37.25±3.7b	54±3.3b
	1600 ppm (Td)	39±2.1a	56.75±4.5a	81±3a
urea	Control	1.5±0.2b	4±0.7a	6.5±0.9a
	25 ppm (Sd)	1.5±0.2b	2.5±0.5a	4.25±0.6a
	50 ppm (D)	10.25±1.3a	3.25±0.8a	4.5±1.1a
	100 ppm (Ld)	1.5±0.5b	2.75±0.8a	3.5±08a
	200 ppm (Od)	0.5±0.2b	3.5±0.6a	5.5±0.6a
	400 ppm (Hd)	1±0.4b	2.75±1a	4±1a
	800 ppm (Ehd)	1±0.4b	3.5±0.6a	475±0.8a
	1600 ppm (Td)	0.25±0.2b	4.75±0.6a	6.25±0.8a

* Values containing the same letter within the same column and treatment are not different from each other, $p < 0.05$ (TUKEY Test).
**Sd: Severe deficiency, D: Deficiency, Ld: Low dose, Od: Optimum dose, Hd: High dose, Ehd: Extremely high dose, Td: Toxic dose.

Table 2. Effect of different doses of nitrogen fertilizers on *Meloidogyne chitwoodi* in 'Tueza F1' tomato

Fertilizers and Doses		Reproduction Factor (Rf)	Root gall index (0-10)	Relative Suppression Rate (%)
urea ammonium nitrate	Negative Control	1.66±0.5b*	3.6±0.2c	
	25 ppm (Sd)**	1.22±0.1b	1±0b	26.88±9.3b
	50 ppm (D)	0±0a	0±0a	100±0a
	100 ppm (Ld)	0±0a	0±0a	100±0a
	200 ppm (Od)	0±0a	0±0a	100±0a
	400 ppm (Hd)	0±0a	0±0a	100±0a
	800 ppm (Ehd)	0±0a	0±0a	100±0a
	1600 ppm (Td)	0±0a	0±0a	100±0a
	Positive Control	0±0a	0±0a	100±0a
nitric acid	Negative Control	1.66±0.5b	3.6±0.2d	
	25 ppm (Sd)**	0.9±0.1ab	4.2±0.3d	45.37±6.4b
	50 ppm (D)	0.79±0.1ab	3.4±0.4cd	51.85±10.4b
	100 ppm (Ld)	0.3±0.2a	2.2±0.2bc	90.74±3.5a
	200 ppm (Od)	0.15±0.08a	2±0.4b	90.74±5a
	400 ppm (Hd)	0±0a	0±0a	100±0a
	800 ppm (Ehd)	0±0a	0±0a	100±0a
	1600 ppm (Td)	0±0a	0±0a	100±0a
	Positive Control	0±0a	0±0a	100±0a
ammonium sulfate	Negative Control	1.66±0.5b	3.6±0.2c	
	25 ppm (Sd)	1.44±0.1b	4.4±0.2d	13.33±6.2b
	50 ppm (D)	1.43±0.1b	3.2±0.2c	15.55±8.2b
	100 ppm (Ld)	0.3±0.1a	2.2±0.2b	81.48±8.4a
	200 ppm (Od)	0±0a	0±0a	100±0a
	400 ppm (Hd)	0±0a	0±0a	100±0a
	800 ppm (Ehd)	0±0a	0±0a	100±0a
	1600 ppm (Td)	0±0a	0±0a	100±0a
	Positive Control	0±0a	0±0a	100±0a
urea	Negative Control	1.66±0.5abc	3.6±0.2bc	
	25 ppm (Sd)	2.7±1,08bc	3.8±0,4c	15.55±7.4b
	50 ppm (D)	3.18±0,8c	3.4±0,2bc	9.44±6.1b
	100 ppm (Ld)	2.3±0,6abc	3±0bc	13.14±8.8b
	200 ppm (Od)	0.38±0,1ab	2.6±0,2b	77.77±7.66a
	400 ppm (Hd)	0±0a	0±0a	100±0a
	800 ppm (Ehd)	0±0a	0±0a	100±0a
	1600 ppm (Td)	0±0a	0±0a	100±0a
	Positive Control	0±0a	0±a	100±0a
calcium nitrate	Negative Control	1.66±0.5ab	3.6±0.2d	
	25 ppm (Sd)	3.98±1.1ab	3.4±0.4d	0±0b
	50 ppm (D)	3.66±1.3ab	3.2±0.2cd	5.18±5b
	100 ppm (Ld)	5.5±1.4b	3.6±0.2d	4.26±4b
	200 ppm (Od)	4.42±0.9b	2.6±0.2cd	0±b
	400 ppm (Hd)	4.82±0.7b	2.2±0.3bc	0±b
	800 ppm (Ehd)	0.12±0.1a	1.2±0.2b	92.59±7.4a
	1600 ppm (Td)	0±0a	0±0a	100±0a
	Positive Control	0±0a	0±0a	100±0a

* Values containing the same letter within the same column and treatment are not different from each other, $p < 0.05$ (TUKEY Test), **Sd: Severe deficiency, D: Deficiency, Ld: Low dose, Od: Optimum dose, Hd: High dose, Ehd: Extremely high dose, Td: Toxic dose.

The study resulted in a 100% suppression rate in all doses of urea ammonium nitrate fertilizer, with the exception of the 25 ppm dose in the pot experiment. The application of nitric acid fertilizer resulted in approximately 50% suppression rate at 25 and 50 ppm doses, while 100% suppression rate was observed at doses from 100 to 1,600 ppm. In the case of ammonium sulfate fertilization, there was no observed suppression compared to the negative control at 25 and 50 ppm doses. However, approximately 80% suppression rate was observed at the 100 ppm dose, and 100% suppression rate was observed between 200 and 1,600 ppm doses. Among the application doses of urea fertilizer, 77% suppression rate was observed at the 200 ppm dose, while 100% suppression rate was observed at doses from 400 to 1,600 ppm. In the case of calcium nitrate fertilizer, no activity was observed in *M. chitwoodi* at doses from 25 to 400 ppm. Nevertheless, a high efficacy of 92% was observed at 800 ppm, and 100% suppression rate was observed at 1,600 ppm (Fig. 1).

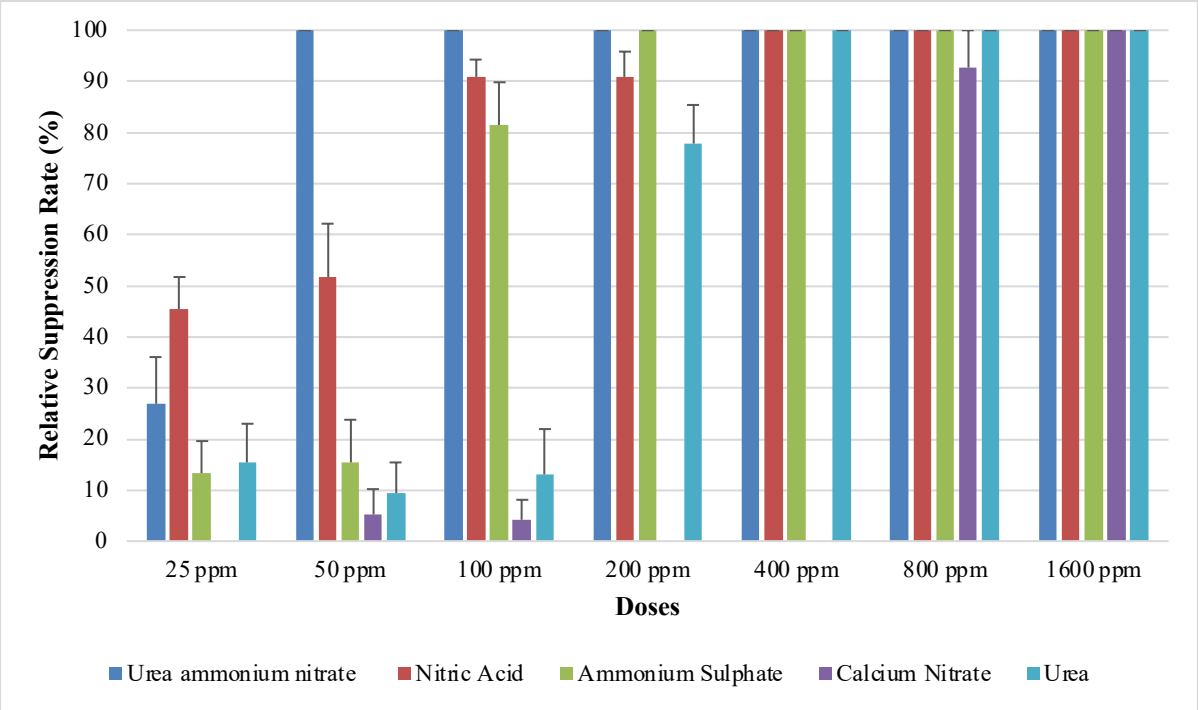

Figure 1. The relative suppression rate (%) of different doses of nitrogen fertilizers on *Meloidogyne chitwoodi* in 'Tueza F1' tomato.

The impact of the fertilizer doses utilized in the experiment on plant growth in tomato was also investigated. The growth of plants treated with urea ammonium nitrate at doses of 25 and 50 parts per million (ppm) was similar to the control. However, toxic effects were observed at doses of 100 ppm and above. In contrast, the growth of plants treated with urea, nitric acid, and ammonium sulfate fertilizers at a dose of 25-200 ppm was similar to that of the control plants. However, the growth of plants treated with high, exceedingly high, and toxic doses of these fertilizers (400, 800, and 1,600 ppm) was adversely affected. Nevertheless, the commonly utilized doses of calcium nitrate fertilizer demonstrated similar growth with control plants, and toxicity was observed only at the 1,600 ppm dose (Table 3).

Table 3. The effect of nitrogen-based fertilizers on dry matter and plant height in tomato plants after 70 days' inoculation with *Meloidogyne chitwoodi*

Fertilizers and Doses		Dry matter (g) (Mean±SE)	Plant height (cm) (Mean±SE)
urea ammonium nitrate	Negative Control	0.8±0.02b*	34.4±0.03b
	25 ppm (Sd)***	0.4±0b	37±0.05b
	50 ppm (D)	0.4±0.01b	39±0.03b
	100 ppm (Ld)	ne**	ne**
	200 ppm (Od)	ne	ne
	400 ppm (Hd)	ne	ne
	800 ppm (Ehd)	ne	ne
	1600 ppm (Td)	ne	ne
	Positive Control	1.9±0.06a	64±0.05a
nitric acid	Negative Control	0.8±0.02a	34.4±0.03a
	25 ppm (Sd)	1.2±0.08ab	45.8±0.09a
	50 ppm (D)	2.3±0.1ab	57.4±0.16a
	100 ppm (Ld)	0.9±0.07ab	44.6±0.08a
	200 ppm (Od)	2.2±0.13a	51±0.13a
	400 ppm (Hd)	ne	ne
	800 ppm (Ehd)	ne	ne
	1600 ppm (Td)	ne	ne
	Positive Control	1.9±0.06a	64±0.05a
ammonium sulfate	Negative Control	0.8±0.02b	34.4±0.03a
	25 ppm (Sd)	1.1±0.09ab	49.6±0.07a
	50 ppm (D)	0.9±0.01ab	52.2±0.08a
	100 ppm (Ld)	3.3±0.13a	62.6±0.1a
	200 ppm (Od)	0.6±0.04b	51.8±0.05a
	400 ppm (Hd)	ne	ne
	800 ppm (Ehd)	ne	ne
	1600 ppm (Td)	ne	ne
	Positive Control	1.9±0.06ab	64±0.05a
urea	Negative Control	0.8±0.02a	34.4±0.03a
	25 ppm (Sd)	1.5±0.1a	74.4±0.07a
	50 ppm (D)	2.1±0.16a	65.4±0.08a
	100 ppm (Ld)	0.9±0.08a	52.2±0.1a
	200 ppm (Od)	0.6±0.06a	31±0.05a
	400 ppm (Hd)	ne	ne
	800 ppm (Ehd)	ne	ne
	1600 ppm (Td)	ne	ne
	Positive Control	1.9±0.06ab	64±0.05a
calcium nitrate	Negative Control	0.8±0.02ab	34.4±0.03a
	25 ppm (Sd)	1±0.05ab	52±0.06a
	50 ppm (D)	2.4±0.08a	59.6±0.08a
	100 ppm (Ld)	1.2±0.07ab	45.2±0.05a
	200 ppm (Od)	1.1±0.1ab	42±0.1a
	400 ppm (Hd)	0.5±0.05b	41±0.09a
	800 ppm (Ehd)	2.5±0.09a	61±0.1a
	1600 ppm (Td)	ne	ne
	Positive Control	1.9±0.06ab	64±0.05a

*Values containing the same letter within the same column and treatment are not different from each other, $p < 0.05$ (TUKEY Test (Log10)).

**ne: not evaluated due to plant death.

***Sd: Severe deficiency, D: Deficiency, Ld: Low dose, Od: Optimum dose, Hd: High dose, Ehd: Extremely high dose, Td: Toxic dose.

4. DISCUSSION

It is well established that fertilizers can exert both beneficial and detrimental effects on nematode populations, depending on the type of fertilizer, application rate, and environmental conditions (Liang et al., 2009; Ahmadi Mansourabad et al., 2016; Zhang et al., 2016; Herren et al., 2020). In the present study, varying concentrations of nitrogen-based fertilizers demonstrated a suppressive effect on the plant-parasitic nematode *M. chitwoodi*. These findings are consistent with previous reports, where certain nitrogen fertilizers inhibited nematode populations (Irshad et al., 2006; Khan et al., 2012; Viaene et al., 2013; Shakeel et al., 2022). Interestingly, Herren et al. (2020) observed a decline in fungivorous and predatory nematodes following nitrogen application, while plant-parasitic nematodes responded positively, highlighting the complex and species-specific effects of nitrogen inputs on nematode communities.

In this study, both *in vitro* and pot experiments revealed similar trends for some fertilizers. For instance, all doses of urea ammonium nitrate and calcium nitrate produced consistent suppressive effects on *M. chitwoodi* in both experimental setups. Similarly, ammonium sulfate and nitric acid showed significant nematicidal activity at doses of 100 ppm and above across both experiments. However, urea displayed divergent results: it was ineffective in the *in vitro* assay, yet highly suppressive in the pot experiment, with up to 77% suppression at 200 ppm and 100% at 400, 800, and 1,600 ppm. This difference may be attributed to the rapid conversion of urea to ammonia in soil through microbial urease activity, which could generate toxic levels of ammonia for nematodes under soil conditions. Supporting this observation, Irshad et al. (2006) reported that urea, along with fish meal and NPK, significantly inhibited *Meloidogyne javanica* (Treub, 1885) Chitwood, 1949 (Nematoda: Meloidogynidae), suggesting that nitrogen-rich organic and inorganic fertilizers can contribute to nematode suppression under appropriate conditions. In the current study, urea exhibited a clear dose-dependent suppressive effect against *M. chitwoodi*, with particularly strong activity at higher doses. Among the tested fertilizers, urea ammonium nitrate demonstrated the most pronounced nematicidal effect. Suppression rates approached 100% at doses as low as 50 ppm under soil conditions, indicating a strong direct toxic effect on *M. chitwoodi*. Nitric acid also exhibited high efficacy, achieving over 90% suppression at doses of 100 ppm and higher. Importantly, nitric acid is commonly used in drip irrigation systems to prevent clogging, suggesting that its integration into fertigation practices may offer dual benefits —maintaining irrigation infrastructure while contributing to nematode control when timed appropriately during nematode management periods.

Despite the promising suppressive effects of these fertilizers, caution must be exercised due to the potential phytotoxicity observed at higher concentrations. Urea, nitric acid, and ammonium sulfate showed toxic effects on tomato plants at 800 and 1,600 ppm, while calcium nitrate induced toxicity only at the highest concentration tested (1,600 ppm). Notably, urea ammonium nitrate exhibited toxicity at lower doses relative to the other fertilizers. This heightened sensitivity may be linked to its high salinity content and the confined root environment created by narrow plastic tubes used in the experiment, which may have intensified direct plant-fertilizer contact.

Overall, these findings underscore the importance of balancing nematode management efficacy with plant safety when applying nitrogen-based fertilizers. While certain fertilizers, especially urea ammonium nitrate and nitric acid, hold strong potential for integrated nematode management, their phytotoxic thresholds must be clearly established to ensure safe application in agricultural systems.

5. CONCLUSIONS

The findings of this study demonstrate that the application of nitrogen-based fertilizers in agricultural systems can exert a significant suppressive effect on plant-parasitic nematodes, with overall efficacy reaching up to 100% in some cases. Notably, the application of urea ammonium nitrate at 50 ppm and ammonium sulfate and nitric acid at 100 ppm or higher proved highly effective in reducing nematode populations. Likewise, urea showed strong nematicidal activity at doses of 200 ppm and above. These results highlight the potential of certain nitrogen fertilizers not only for promoting plant growth but also

as practical tools for managing nematode infestations in crop production. In particular, the consistent suppressive effect of nitric acid (commonly used to prevent clogging in drip irrigation systems) suggests a dual-purpose role in agricultural management. Given this, it is worth investigating whether similar suppressive effects can be achieved against other economically important nematode species such as *Tylenchulus semipenetrans* Cobb, 1913 (Tylenchida; Tylenchulidae) in citrus orchards, *Meloidogyne* spp. (Tylenchida; Meloidogynidae) in greenhouse vegetable systems, and *Helicotylenchus* spp. (Tylenchida; Hoplolaimidae) and *Rotylenchulus reniformis* Linford & Oliveira, 1940 (Tylenchida; Hoplolaimidae) in banana plantations. Further studies should focus on evaluating the interactions between various fertilizer types —including chemical fertilizers, biofertilizers, biochar, and vermicompost— and a broader range of plant-parasitic nematodes. Additionally, understanding the impact of fertilizer application timing and dosage on nematode dynamics is essential. Integrating such insights into broader pest management frameworks will be critical for developing effective, environmentally sustainable, and economically viable nematode control strategies.

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Supplementary material

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Data availability

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Authorship contribution statement

Sümeyya V. Dişkaya: Conceptualization, Data curation, Investigation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing.

Salim Avcıoğlu: Conceptualization, Data curation, Investigation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing.

Ece B. Kasapoğlu-Uludamar: Writing – review & editing.

Ibrahim H. Elekcioğlu: Conceptualization, Data curation, Investigation, Formal analysis, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. All authors read and approved the final manuscript.

Competing interests

The authors have declared that no competing interests exist.

Statement on the use of Artificial Intelligence

The author(s) employed ChatGPT (OpenAI) in order to translate the title, abstract and keywords from English to Spanish while preparing this work. Following their use, the author(s) assumed full responsibility for the publication's content and reviewed and edited it as necessary.

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