Research Article

Inventory and Fertilizer-Based Control of Phytoparasitic Nematodes Associated with Onion Cultivation in the Diamaré Locality, Far North, Cameroon

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Abstract | This study, conducted in Palar-Maroua, unfolded in two distinct phases: an initial sampling phase of soils and roots from producers, followed by an experimental phase aimed at evaluating the suppressive effect of various organic fertilizers on *Meloidogyne* spp. inoculated into onion plants (*Allium cepa L.*). The experimental setup comprised 240 plastic pots, each containing one kilogram of sterilized soil, arranged in a greenhouse according to a randomized complete block design. Three types of fertilizers were tested: poultry manure (F), cattle dung (C), and chemical fertilizer (E) with a 20-10-10 + $6SO_3$ formulation. Nine treatments were applied in combinations/doses, with four replications per onion variety (Galmi Violet, Goudami, and Chagari) and per treatment. The initial inventory revealed the presence of ten nematode genera, with *Ditylenchus* spp. and *Meloidogyne* spp. predominating, representing 53.70% and 36.57% of the total phytoparasitic nematode population, respectively. Experimental results demonstrated a highly significant difference ($P < 0.01$) in parasitic density between the C94.3Me treatment on the Violet de Galmi variety and the untreated control. Treatment with poultry manure (F94.3Me) and livestock cattle manure (C94.3Me) proved particularly effective, with a 100 % reduction in the Chagari variety, followed by treatments C47.3Me and F47.3Me, resulting in a 98.46 % reduction in Violet de Galmi and Chagari varieties in soil. At the root level, a 100% reduction in parasite density was obtained with treatments C47.3Me, F47.3Me, and C94.3Me. In a broad sense, the root highest reduction rates of *Meloidogyne* spp. reached 95.25% for the C94.3Me treatment. A significant decrease ($P < 0.05$) in the number of galls was observed with this same treatment on the Chagari variety. The lowest gall severity indices were recorded with poultry manure (F47.15Me) and the combination of chemical fertilizer and manures (E0.118C5.9F5.9Me), showing no galls. The study also demonstrated a significant effect ($P < 0.05$) on the reduction of the gall index, with a 75% decrease in preventive treatment (C23.58F23.58Me) and a 50% decrease in curative treatment (F94.3Me). In conclusion, these results suggest that the use of organic amendments could constitute a promising method for the management and control of phytoparasitic nematodes, thus contributing to the improvement of onion production in the northern region of Cameroon. This ecological approach offers an interesting alternative to conventional control methods while promoting more sustainable agriculture. In general terms, the highest parasite reduction rate was 96.95% with the F47.15Me dose, while the lowest parasite reduction, 68.24%, was observed with the E0.236F23.58Me dose.

Keywords | Plant-parasitic nematode, Onion, Organic fertilizers, Diamaré, Far-North Cameroon

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INTRODUCTION

Onion (*Allium cepa* L.) is a highly prized vegetable in various culinary preparations. This energy-rich ingredient contains proteins, reducing sugars, and fats (Konate *et al*., 2017). It is a source of vitamins (B, C, provitamin A), minerals (K, Na, Zn, Fe, P, Se, Mg, Mn), essential oils, organic acids, and fiber (Ciqual, 2013). Globally, onion cultivation spans over 134 countries, covering an area of 3.35 million hectares (Sakatai *et al*., 2021). In Central Africa, particularly in Cameroon, the onion sector represents a major asset for the country, especially in its northern region. Onion remains an important cash crop, ranking after cotton and peanuts, and constitutes the country's primary market garden crop (MAAF, 2015). The most cultivated varieties are Goudami (dry season variety) and Chagari (rainy season variety). According to the Agricultural Sector Development Support Project (PADFA) in northern Cameroon, onion cultivation helps meet basic family needs, particularly in terms of nutrition and health in agricultural households (Kamga *et al*., 2016). Despite increased production, Cameroon still struggles to meet domestic onion consumption needs (Mamadou, 2012). Yields in the Sudano-Sahelian zone (North and Far North) of Cameroon can sometimes reach 38 tons/hectare with the local variety (PADFA, 2017). However, these yields remain lower than those of Niger, a major onion producer in Africa (32 to 35 tons/hectare) (CGERV, 2017), despite similar edaphoclimatic characteristics to those of the Far North. Onion production is hindered by the action of parasitic nematodes. A wide range of nematodes causes serious problems for onion cultivation, with considerable repercussions on plant production (Mbaukwu *et al*., 2016). Nematodes, elongated fusiform roundworms, can cause significant damage to cultivated plants where they are extremely widespread (Coyne *et al*., 2010). Their damage can be substantial, and their elimination is challenging due to their microscopic size, longevity in soil, and presence in seeds (Caubel and Esquibet, 1995). The manifestations of *Ditylenchus* spp. nematodes on the host plant include: bursting of the root plate or bulb, leaf deformation, and stem swelling. The leaves of affected plants turn purplish-red and exhibit stunted growth (Gowda *et al*., 2019). The genus *Meloidogyne* is considered the most detrimental obligate parasite to this crop in Africa, causing considerable losses in agricultural production, ranging between 50 and 60 % (Ogwulumba *et al*., 2022). Nematode control is complex due to their wide host range and high reproduction rate, which can reach a thousand eggs per female (Netarajan *et al*., 2016). However, the application of synthetic pesticides has contributed to a reduction in agricultural losses.

Despite the attributed effectiveness of these synthetic pesticides, their continuous use promotes the development of resistance in these parasites. Excessive use of these pesticides has revealed harmful effects on human health, fauna, and the environment (Geraldin *et al*., 2020). Uncontrolled and haphazard administration of chemical fertilizers could increase the proliferation of these phytoparasites (Ogwulumba *et al*., 2022). The alternative to limit the abusive use of synthetic pesticides lies in the use of organic fertilizers. Their use has already allowed for a significant reduction in the infection rate by nematodes and their population, as well as an improvement in crop growth and yield (Ogwulumba and Mba, 2016). This control method aims to effectively reduce nematode proliferation so that a sensitive crop reinstalled on the field does not suffer excessive damage.

This study therefore proposes to inventory and contribute to limiting the proliferation of phytoparasitic nematodes of onion using organic fertilizers in the locality of Diamaré. More specifically, it aims to:

Morphologically identify the different nematode genera;
Evaluate their infestation status in the study sites;
Assess the impact of three fertilizers on the density of phytoparasitic nematodes of onion.

MATERIAL AND METHODS

Study Area

Sampling was carried out in five sites in Maroua, the capital of the Diamaré department, in the Far North of Cameroon (Gazawa, Miskine, Kongola, Goyang, and Godola). The average rainfall in the area oscillates between 350 mm and 705 mm per year on sandy-clay soil, with temperatures varying between 11°C and 46°C (Sodecoton, 2016). The department extends between the 10th and 13th degree of North latitude and the 13th and 15th degree of East longitude. The experimentation took place in Palar-Maroua in a secured greenhouse setup. The plant material used includes seeds of different varieties provided by SEMAGRI: two local varieties (Violet de Galmi and Chagari), one certified variety (Goudami), and bulbs. The animal material consists of phytoparasitic nematodes. The sampling equipment included a trowel, plastic packaging, gloves, and a cooler.

Experimental Design

Conduct of the trial and data collection: Data collection for this study was carried out through a survey and exploration of farmers' fields in five sites in the Diamaré locality. The survey was conducted in March 2021 among producers. Sampling involved 5 cultivators per chosen site, resulting in a global sampling of 25 samples, each containing 5 sub-samples. The interview was semi-structured and individual. The pre-established questionnaire included open, closed, and directed questions. Open questions allowed for gathering opinions regarding cultivation techniques, closed questions focused on knowledge of pests, methods of controlling onion nematodes, fertilizers used and application methods, and bulb losses in fields and storage. Direct observations aimed to determine the physical characteristics (nematode symptoms) of the cultivated onion varieties.

In vivo study: Onion seeds (*Allium cepa* L.) susceptible to nematodes were disinfected for 30 minutes in bleach (1%) and rinsed three times with distilled water, except for the certified Goudami variety. The seeds were then sown in sectioned 25-liter containers, filled with 60 % sand and 40% clay previously autoclaved at 120°C for 4 hours, with 3 replications. Sowing took place on May 11, 2022. After four weeks of cultivation, the seedlings were individually transplanted on June 09, 2022, into 5-micron plastic pots, 7 cm wide and 12 cm high, containing 1 kilogram of previously autoclaved soil (60% sand and 40% clay) to be disinfected of germs. Fertilizer applications were made in one phase at a single dose: in preventive testing, 120 pots received 9 treatments at different single and combined doses, and in curative testing, another series of 120 pots received the same treatments of different fertilizers:

T0: without treatment;
T1: C47.15Me (decomposed compost at 47.15g/pot with *Meloidogyne*);
T2: F47.15Me (decomposed poultry manure at 47.15g/pot with *Meloidogyne*);
T3: C94.3Me (decomposed compost at 94.3g/pot with *Meloidogyne*);
T4; F94.3Me (decomposed poultry manure at 94.3g/pot with *Meloidogyne*);
T5: E0.236Me (complex fertilizer at 0.236g/pot with *Meloidogyne*);
T6: E0.236C23.58Me (complex fertilizer at 0.236g/pot and decomposed compost at 23.58g/pot with *Meloidogyne*);
T7: E0.236F23.58Me (complex fertilizer at 0.236g/pot and decomposed poultry manure at 23.58g/pot with *Meloidogyne*);
T8: E0.118C5.9F5.9Me (complex fertilizer at 0.118g/pot + decomposed compost at 5.9g/pot + decomposed poultry manure at 5.9g/pot with *Meloidogyne*);
T9: C23.58F23.58Me (decomposed compost at 23.58g/pot + decomposed poultry manure at 23.58g/pot with *Meloidogyne*) (PRODEX, 2012).

Irrigation of plants in the greenhouse was carried out with water from an electric motor borehole according to an established schedule, three times a week for the first month and twice a week from the beginning of bulbing. Fertilization was done in a single application based on decomposed farm layer manure, decomposed livestock cattle dung, and synthetic complex mineral fertilizers with formulation (20-10-10 + 6SO3). One week after transplanting, each plant was inoculated with a egg-laying females of *Meloidogyne* spp. previously treated with streptomycin.

Data collection methods: At 110 days, the bulbs were collected in an ice-filled cooler and sent to the Applied Zoology Laboratory of the University of Ngaoundéré for nematode extraction. Parameters such as leaf height, diameter, fresh and dry bulb weight, plant weight, root length, number of leaves, and number of galls were measured on the sampled onion plants. Samples were stored in plastic bags and labeled. A properly completed information sheet for each sample allowed for collecting the following data: crop type (local or improved variety), crop development stage, soil type, plot age, applied fertilizer, and pesticide treatments. Roots and bulbs were separated from the soil to isolate the present nematode genera.

Soil Nematodes

Upon arrival at the laboratory, impurities were eliminated using a coarse-mesh sieve, and nematodes were extracted following the modified method Baermann (1917). A filter paper was placed at the bottom of a sieve, which was then positioned on a plastic tray, ensuring the sieve's base was entirely covered. Two hundred and fifty grams (250 g) of soil were weighed and deposited on the filter paper in the sieve, taking care that the soil did not overflow the filter paper. The necessary amount of water was added to the extraction trays, carefully pouring the water between the tray's edge and the sieve, rather than directly onto the filter paper or soil. The apparatus was left to rest for approximately 48 hours, adding water if needed to prevent desiccation. Nematodes traverse the paper filter to end up in the water at the bottom of the tray. The water from the tray was poured into a labeled beaker, using a wash bottle to rinse the tray. The suspension volume was reduced by decantation or by passing this suspension through a fine-mesh sieve (28 µm) to concentrate it in a beaker before nematode observation. To avoid potential errors, containers used for each sample were permanently labeled. The sieve contents were transferred to an Eppendorf tube using a jet of water from a wash bottle, then stored in darkness at +4°C after observation under a binocular microscope (x50) to confirm the presence of nematodes. Population counts were expressed as the number of nematodes per cubic decimeter of soil (N/dm^3 or N/kg).

Root grinding method: Harvested onion roots and bulbs were washed with water and cut into fragments of approximately 1 cm using scissors or a knife. Twenty grams (20 g) of roots or bulbs were weighed. Following the same extraction process as previously, the sample was placed on the filter paper in the sieve, ensuring that the fragments did not overflow the filter paper (modified Baermann method, 1917). Active nematodes pass through the tissue or paper and fall to the bottom of the container. After a period of about 72 hours, a small amount of water containing nematodes was collected and observed under a microscope (Flegg and Hooper, 1970). Nematode counting was performed using a counting plate under a binocular microscope. Population counts were expressed as the number of nematodes per gram of fresh roots (N/g roots).

Morphological identification of nematodes at the genus level: Genus identification is based on morphological characteristics observable under a binocular microscope, such as: the size and shape of the nematode, the presence and shape of the stylet and basal knobs, the position of the vulva, the intestinal overlap by esophageal glands, the shape of the tail and head, according to the morpho-biometric identification key for nematodes, MOA012 version 1. Using a pipette, the nematode suspension (1 ml) from the extraction was poured into a gridded Petri dish and observed under a binocular microscope (x50). Nematodes were collected and placed on a drop of mounting fluid on a microscope slide. A cover slip was gently placed on the drop. Nematodes were killed using a heat source by placing the slide on a heating plate. Any excess liquid was absorbed using a pipette. This operation was performed under a magnifying glass to avoid aspirating the nematodes. Phytoparasitic nematodes, characterized by the presence of a stylet, were identified according to observable morphological criteria at the genus level, under a binocular microscope (x50).

Nematode enumeration: After identifying nematodes at the genus level, enumeration was performed using a binocular microscope (50x magnification). Counts were conducted on an aliquot in a gridded open slide, following the method of Merny and Luc (1969). The suspension of each nematode extract was concentrated to a precise volume in a graduated cylinder or tube. This suspension was homogenized by agitation, then an aliquot was taken using a pipette and carefully deposited in a gridded open slide, taking care to avoid any projection. The nematodes were then counted. After counting, the aliquot was reintegrated into the initial suspension. This operation was repeated on two to three aliquots per sample, and the average per sample was calculated.

Data processing and Analysis

Microsoft Excel 2016 software was used to calculate means, frequencies, and standard deviations. Statistical analyses (ANOVA, variance test) were employed to study the correlation of densities between genera within the same sites. GraphPad software was used for graph creation and variance analysis. XLSTAT (2016) was used to calculate correlations.

RESULTS AND DISCUSSION

Phytoparasitic Nematode Genera Identified During Surveys

The study conducted across five sites allowed for the identification of ten phytoparasitic nematode genera in the soil and six in roots and bulbs. Among these, semi-endoparasites (*Helicotylenchus* spp., *Hoplolaimus* spp., *Rotylenchus* spp., *Tylenchulus* spp.), migratory endoparasites (*Ditylenchus* spp., *Hirschmanniella* spp., *Pratylenchus* spp., *Scutellonema* spp.), and sedentary endoparasites (*Meloidogyne* spp., *Globodera* spp.) were distinguished. These results corroborate those obtained by Kobchi and Essaye (2020) in the El Maarif and El Djoub stations in Algeria, where they inventoried eight genera in the soil and five in the roots.

In the dry season, the most abundant genera, exceeding the tolerance threshold, were *Ditylenchus* spp. (4278 N/kg), *Meloidogyne* spp. (2914 N/kg), *Tylenchus* spp. (256 N/kg), and *Pratylenchus* spp. (364 N/kg). Genera with densities below the damage threshold included *Hirschmanniella* spp. (26 N/kg), *Helicotylenchus* spp. (51 N/kg), *Hoplolaimus* spp. (33 N/kg), *Scutellonema* spp. (19 N/kg), and *Rotylenchus* spp. (28 N/kg) in the soil. In roots, the threshold was reached by *Ditylenchus* spp. (135 N/g), *Meloidogyne* spp. (47 N/g), and *Pratylenchus* spp. (11 N/g). Genera with densities below the damage threshold in roots and bulbs were *Tylenchus* spp. (7 N/g), *Hirschmanniella* spp. (4 N/g), and *Helicotylenchus* spp. (4 N/g).

Generally, the "damage threshold" or "tolerance limit" of the plant is between 100 and 1000 individuals per kilogram of soil or between 10 and 100 per gram of root (De Guiran, 1983). According to Abbad-Andaloussi and Bachikhi (1998), the economic threshold for host plants such as onion is determined from 10 nematodes per 400 cm^3 of soil. However, field trials have revealed significant losses with densities ranging from 10 to 20 nematodes per liter of soil for onion and carrot crops, respectively. These losses can be amplified by the indirect role of nematodes in synergy with fungi such as Phoma solanicola and bacteria such as *Pseudomonas* spp. and *Erwinia* spp. It should be noted that this threshold is largely exceeded for certain genera in our study.

Parasitic Density in Soil and Roots/Bulbs in Surveyed Sites (Dry Season)

The density of phytoparasites varies considerably from one site to another, both in soil and in roots and bulbs. The most infested soils with nematodes were those of Gazawa, with *Ditylenchus* spp. (10.920 N/kg) and *Meloidogyne* spp. (7.945 N/kg), followed by the Miskine site with *Ditylenchus* spp. (5.608 N/kg) and *Meloidogyne* spp. (3.548 N/kg), and the Godola site with D*itylenchus* spp. (3.095 N/kg) and *Meloidogyne* spp. (2.345 N/kg). The least infested sites with phytoparasites were the localities of Kongola, with the genus *Ditylenchus* (641 N/kg) followed by *Meloidogyne* spp. (133 N/kg), and the Goyang site with *Ditylenchus* spp. (1.124 N/kg) and *Meloidogyne* spp. (478 N/kg) (Figure 1).

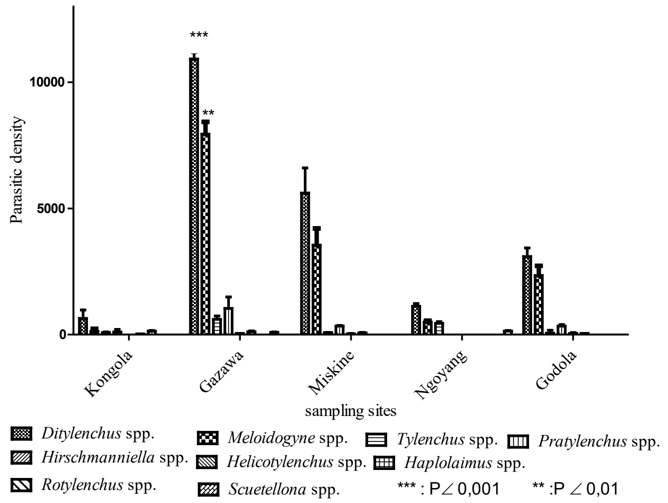

Figure 1: soil pest density by study site.

The high densities observed in Gazawa and Miskine could be explained by the more sandy texture of the soil, particularly conducive to parasite multiplication, as well as by crop rotation or mixed cropping practices. These results are in line with those obtained by Diop (1994), who reported 1,171 individuals per kilogram of soil, also exceeding the damage threshold. Similar work conducted by Konaté et al. (2019) in Burkina Faso highlighted high nematode populations in seven different sites, with densities varying between 5,240 and 32,460 N/dm^3. These results could be attributed to the age of plot exploitation, a factor likely to influence parasitic density. Indeed, according to Sawadogo *et al*. (2000), long-exploited sites generally present the highest infestation rates. These same authors had also suggested that fallow was an effective means of reducing the infestation rate of soils by phytoparasitic nematodes (Sawadogo *et al*., 2002). Statistical analysis of the data reveals a highly significant difference (P < 0.001) between the density of *Ditylenchus* spp. in Gazawa soil and that of other sites, as well as a highly significant difference (P < 0.01) between the density of *Meloidogyne* spp. in Gazawa soil and that of other inspected sites. These significant differences could be attributed to soil structure and nature (sandy, loamy, clayey, or humus-rich), which influence the movement of most nematodes, with light soils being more conducive to the development of these parasites. According to Cadet *et al*. (2005), soil characteristics affect the abundance, distribution, and structure of nematode communities that live independently of the host plant. Estioko and Reyes (1984) observed that for the same plant, nematode species present in the rhizosphere of sandy soils often differ from those in clay soils. The unequal distribution of nematodes could also be explained by interspecific competition and the heterogeneous distribution of certain physico-chemical elements in the soil (Traore *et al*., 2012). Norton and Niblack (1991) emphasize that soil temperature and moisture are the most determining factors in the seasonal dynamics of nematode populations. It should therefore be noted that the presence of a plant does not necessarily determine that of nematode species capable of parasitizing it.

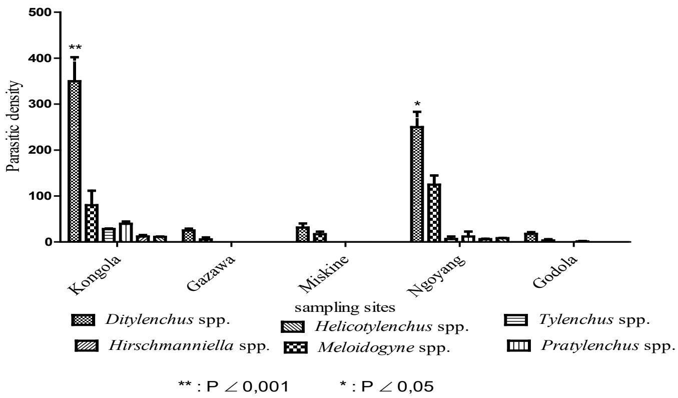

Figure 2: Parasitic density in roots and bulbs according to study sites.

In roots, infestation was particularly high in the Kongola and Goyang sites, with nematode populations reaching 350 N/kg and 250 N/kg respectively for *Ditylenchus* spp. and 80 N/kg and 125 N/kg for *Meloidogyne* spp. (Figure 2). The highest level of infestation in roots and bulbs represented 65.50 % for *Ditylenchus* spp. and 22.44 % for *Meloidogyne* spp. of the total number of nematodes identified. These average nematode densities far exceeded the economic threshold for the genus *Ditylenchus* spp. in all five sites studied, and for *Meloidogyne* spp. in the Kongola and Ngoyang sites. Statistical analysis reveals a highly significant difference (P < 0.01) between the parasitic density of nematodes in Kongola roots, and a significant difference (P < 0.05) between nematodes in Ngoyang roots. Sites presenting low root infestation were the localities of Gazawa (30 N/g of root), Miskine (49 N/g of root), and Godola (21 N/g of root). Nevertheless, the "damage threshold" or "tolerance limit" of the plant, estimated between 10 and 100 nematodes per gram of root (De Guiran, 1983), was exceeded. The damage caused to onion bulbs would be partly attributable to phytoparasites. The low density observed at the root level could be explained by the fact that most nematodes lay their eggs outside the root, and that some nematodes are ectoparasites that remain in the soil but use their long stylet to feed on nutrients from root cells (Belair, 2005). Moreover, several reproduction cycles can succeed one another in a year, and infestation can then reach 100,000 to 200,000 larvae per kilogram of soil, at a depth that can exceed 30 cm (De Guiran, 1983). Korenko and Schmidt (2006) observed that the greatest diversity of nematofauna is found in minimally tilled soils, while Neher (1999) demonstrated that the absence of living roots for several years reduces the nematode population, particularly plant parasites. These observations could explain the low diversity in genera observed in the three sites of Gazawa, Miskine, and Godola, where soils are intensively worked.

Among the genera identified, *Ditylenchus* spp. and *Meloidogyne* spp. represented more than 53.70 % and 36.57 % respectively of the total number of phytoparasites in the soil. These results corroborate those of Khan *et al.* (2007), who demonstrated that the genus *Ditylenchus,* of which the sole species *Ditylenchus dipsaci* is recognized as a major parasite, is prevalent in all onion-producing regions. Other similar studies have revealed that *Meloidogyne hapla* and *Meloidogyne incognita* are also likely to cause serious damage to onion crops, and that excessive and disorderly use of chemical fertilizers could increase the nematode population (Pang *et al*., 2009). Thoden *et al.* (2011) demonstrated that prolonged use of organic fertilizers allows for the reconstitution of soil biodiversity. Yavuzaslanoglu (2015) reinforces this by asserting that fertilizers based on organic materials constitute a relevant alternative to chemical products in pest control, thus ensuring the sustainability of the ecosystem while maintaining satisfactory yield.

Variation of Parasitic Density in Soil According to Treatments

In the context of a preventive test, the application of organic fertilizers (poultry droppings added with chips and decomposed cow dung) and synthetic fertilizer at different combinations doses (9 treatments) allowed for a considerable reduction in nematode density in the greenhouse. In the soil, a highly significant difference (P < 0.01) is observed between the parasitic density with cow dung manure C94.3Me in pots containing the Violet de Galmi variety in preventive testing, while no significant difference is observed for parasitic density in roots and bulbs. These results could be explained by the richness of organic fertilizers in nitrogenous elements and their effectiveness in promoting the development of organisms antagonistic to parasites. Other exogenous inputs of organic fertilizers can stimulate the proliferation of antagonistic organisms or nematode predators (Forge et al., 2009). Ogwulumba and Mba (2016) reported that poultry manure provides essential nutrients to onion plants and serves as a source of organic matter for the soil, thus improving its properties and water retention capacity. The different treatments demonstrated their effectiveness in reducing parasitic density both in soil and in roots and bulbs.

Thus, at the soil level in preventive testing, treatment based on poultry droppings (F94.3Me) and livestock cow manure (C94.3Me) proved particularly effective, with a 100 % reduction for the Chagari variety, followed by treatments C47.3Me and F47.3Me, resulting in a 98.46% reduction for the Violet de Galmi and Chagari varieties (Figure 3).

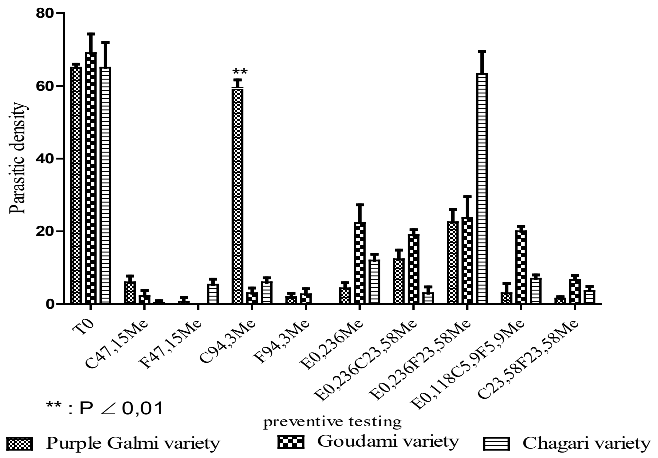

Figure 3: Variation of parasitic density in soil according to treatments in preventive testing.

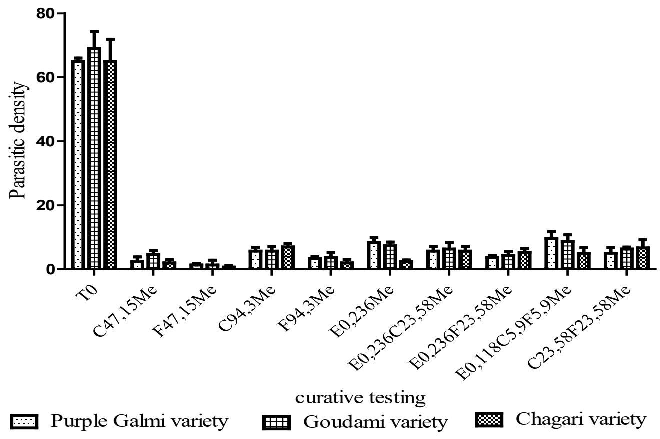

Figure 4: Variation of parasitic density in soil according to treatments in curative testing.

In curative testing, all treatments based on organic fertilizers had a positive effect on nematode reduction, with the most effective being poultry droppings F47.3Me and F94.3Me, with a reduction of 98.46 % each (Figure 4). These results corroborate those of Oka and Yermiyahu (2002), who highlighted a positive correlation between nitrogen content and effectiveness in nematode suppression. These high reduction rates obtained with farm chicken manure and farm cow dung could also be explained by their richness in nitrogen and nematode-predatory microorganisms. Various studies have also demonstrated that the application of organic manure alone on soil heavily infested with root-knot nematodes allows for a considerable reduction in their population density, both in roots and in cultivated soil (Farouk *et al*., 2002). Similarly, Al Rehiayami and Hafez (1998) conducted a greenhouse experiment on the incorporation of oil radish, buckwheat, rapeseed, castor bean, and corn residues, as well as *Meloidogyne chiwoodi*, into sterile soil. These studies show that all treatments significantly reduced the *Meloidogyne* level by 94 % compared to the untreated control.

At the root level, a 100 % reduction rate in parasitic density was obtained with treatments C47.3Me, F47.3Me, and C94.3Me, both in preventive and curative testing. The lowest reduction rate was observed with treatment F94.3Me, at 34.14 %. Synthetic fertilizers did not have the expected positive effect on nematode reduction. This reduction at the root level could be explained by the fact that most phytoparasites had already been eliminated at the soil level. These rates testify to the effectiveness of these two manure doses: C47.3Me, F47.3Me, and C94.3Me. These results corroborate those of Nico *et al*. (2004), who reported that composted agro-industrial wastes reduced *Meloidogyne* spp. populations by 24.4 % to 87.9 %. Similar results were validated by Yavuzaslanoğlu (2015), with an average reduction of nematodes in onion bulb and stem ranging between 42 and 60 nematodes per tube with humic acid and green manure, compared to 465 nematodes per tube for the negative control.

Certain plants, despite high nematode populations, developed without apparent stress. It appears that compost contains enzymatic substances responsible for nematode suppression. Indeed, a study conducted by El-Masry *et al*. (2002) revealed the presence of several enzymes in compost extracts, such as protease, lipase, and chitinase, involved in nematode inhibition. Cayrol *et al*. (1992) demonstrated that some nematocidal plants secrete toxins acting differentially on nematodes, either by inhibiting larval development or by hindering the egg hatching process. NPK fertilization did not significantly affected soil nematode populations. This could be explained by the absence of microorganisms antagonistic to nematodes. According to Noling et al. (2019), there are potential mechanisms of pathogen suppression by composts: direct inhibition of the pathogen or reduction of organism levels in the plant host, and an increase in the population of beneficial organisms in the soil. Tabarant (2011) reported that plants grown in fertile, nutrient-rich soils better tolerate nematode attacks due to compensation for damage inflicted on the plant. These organic fertilizers prove useful for the long-term construction of soil biodiversity (Thoden *et al*. 2011). Ogwulumba *et al*. (2022) demonstrated that the use of poultry manure mixed with Jatropha leaf powder resulted in a significant reduction of nematodes in onion crop infection. This mixture of poultry waste and Jatropha leaves acts as a nematic pesticide by reducing infection incidences (Yavuzaslanoğlu, 2015). This amply demonstrates that basic organic fertilizers constitute an excellent alternative for long-term maintenance of soil constituents, surpassing synthetic chemical fertilizers. Thus, Yavuzaslanoğlu (2015) recommends, for good onion bulb yield, the application of 10t/ha mixed with 15t/ha of Jatropha leaves, ensuring significant gall suppression and optimal plant growth. Mcsorley *et al*. (2014) emphasized that, despite the prevalence of poultry manure in almost all localities, its nematocidal properties remain unknown to farmers. The gall index and severity of nematode attacks on roots were estimated according to the Bridge and Page (1980) scale. This evaluation revealed that the number of galls was reduced in both preventive and curative tests compared to the control, with different treatments. A significant difference ($P < 0.05$) at the 5 % threshold was observed between the C94.3Me treatment and the number of galls in the preventive test for the Chagari variety (14 ± 0.70), with a parasite.

Notwithstanding the prevailing constraints, the utilization of manure persists as a viable option for populations in specific regions of northern Cameroon, attributable to its cost-effectiveness, enhanced soil fertility, and optimal yield. Moreover, Dinissia *et al*. (2021) underscore the financial limitations faced by most farmers, which preclude their access to synthetic chemical fertilizers or premium poultry manure in sufficient quantities, owing to the occasionally exorbitant costs associated with these inputs. As a result, a mere 29% of producers opt for organic amendments to fertilize their onion fields, whereas 69% rely on synthetic chemical fertilizers, and a paltry 2% employ biofertilizers. The advocacy for organic fertilizers in tropical regions with limited financial resources remains a salient concern, transcending regional boundaries. The impediments to this endeavor are multifaceted, encompassing the escalating cost of fertilizers and the frequently inadequate subsidies for procuring equipment for handling and transporting manure, which are occasionally provided by project-based initiatives (CIRAD-GRET, 2002), a range of constraints impede the effective utilization of manure, including land tenure insecurity, a lack of expertise in manure production techniques, and the unavailability of animals and their excreta (Adoum *et al*., 2008). Moreover, farmers frequently encounter difficulties in accessing water for manure irrigation, acquiring production equipment and handling tools, and affording the high costs associated with transportation equipment and labor required for manure production, transportation of water and straw to the stable, and application. As a result, the valorization of animal waste remains constrained and often insufficient (Landais, 1990). According to Hesse (1996), certain livestock producers are averse to manure removal from their cattle enclosures, citing the benefits of retained heat for their animals during cold periods, which thereby limits access to and availability of manure, occasionally due to limited financial resources and logistical challenges. Nonetheless, Abdou (2014) fervently

Table 1: Root gall index in reponse to treatments.

	Prophylactic test			Curative test			Meloidogyne-free test		
Treatment/ Varieties	Galmi violet	Goudami	Chagari	Galmi violet	Goudami	Chagari	Galmi violet	Goudami	Chagari
0Me	3 ± 1,52	4 ± 0,70	4 ± 1,52	3 ± 1,52	4 ± 0,70	4 ± 1,52	3 ± 2	00 ± 00	00 ± 00
C47,15Me	8 ± 2,64	2 ± 1,41	2 ± 0,70	7 ± 1,41	5 ± 1	6 ± 3	00 ± 00	2 ± 1,41	2 ± 1
F47,15Me	3 ± 0,81	4 ± 1,41	4 ± 1,25	3 ± 1	5 ± 2	00 ± 00	00 ± 00	00 ± 00	00 ± 00
C94,3Me	4 ± 0,70	6 ± 0,70	14 ± 0,70*	6 ± 1,41	7 ± 1,41	8 ± 0,70	00 ± 00	3 ± 0,70	1 ± 1
F94,3Me	2 ± 0,57	3 ± 1,41	4 ± 2,51	4 ± 0,57	5 ± 1,52	3 ± 0,57	2 ± 0,70	3 ± 0,70	2 ± 00
E0,236Me	4 ± 1,15	4 ± 1,41	3 ± 1	3 ± 1	2 ± 00	2 ± 2	00 ± 00	3 ± 0,70	1 ± 1
E0,236C23,58Me	5 ± 1,41	19 ± 1,41	3 ± 1,73	3 ± 1,52	4 ± 1,41	7 ± 2,08	00 ± 00	00 ± 00	00 ± 00
E0,236F23,58Me	4 ± 2,51	3 ± 2,08	2 ± 1,73	3 ± 1,73	2 ± 1	4 ± 2,30	00 ± 00	4 ± 2	00 ± 00
E0,118C5,9F5,9Me	5 ± 2,21	6 ± 2,23	6 ± 1,73	2 ± 1	00 ± 00	3 ± 1	3 ± 0,47	2 ± 0,70	2 ± 0;70
C23,58F23,58Me	2 ± 1,25	8 ± 2,82	5 ± 2,12	5 ± 2	2 ± 00	5 ± 3,7	2 ± 0,70	2,5 ± 1	2 ± 0;70

***:** $P < 0,05$.

recommends the utilization of manure to prolong bulb storage duration and mitigate losses during storage. According to Sawadogo *et al*. (2020), biological fertilizers offer a viable solution to the challenges of sustainable agriculture, and a minimum application rate of 0.5 t/ha is recommended to optimize bulb onion yields. Farmers in the Senegal River valley attest that manure application not only accelerates vegetative growth but also enhances yield potential, while concomitantly improving soil physical and chemical fertility. Furthermore, organic matter provides a multitude of essential nutrients to plants, improves soil structure and stability, enhances water retention capacity, and fosters plant biological activity (Lhoste, 2004). Enda Pronat's research (2017, 2018). demonstrates that compost application to onions results in increased yields and improved bulb storage capacity over prolonged periods. Mbaye et al. (2022) findings also suggest that onions produced using organic manure exhibit extended shelf life produced using conventional methods. reduction rate of 90.77 %. The low gall severity rate was observed between 21 and 30 %. The lowest gall severity estimates were recorded for treatments F47.15Me, E0.118C5.9F5.9Me with 0 % galls for Goudami and Chagari varieties, followed by C47.15Me, E0.236Me, E0.236F23.58Me, C23.58F23.58Me with a gall severity estimate between 11 and 20 % (Table 1). Ogwulumba *et al*. (2022) also noted that with a dose of 10 t/ha of poultry manure mixed with 15 t/ha of Jatropha leaf powder, they obtained a highly significant reduction in the number of galls in onion roots and soil. Iqbal (2019) obtained a reduction in onion galls during the second year of their field study of 60.80 % /ha with poultry droppings and 56.04 % /ha with tricho-compost 1 and 2. In the third year, he obtained the greatest reduction in gall severity at 64.16 % with poultry waste, followed by Furadan 5G, Tricho-compost-2, Tricho-compost-1, and mustard cakes, respectively 63.29%, 63.29%, 63.01%, and 59.54%. Overall, the highest reduction rate in roots is 95.25 % with the C94.3Me soil treatment, while the lowest reduction rate was obtained with the F94.3Me soil treatment, at 78.14%.

CONCLUSIONS AND RECOMMENDATIONS

Onion represents a vegetable crop with high economic potential for the population of the North and Far North regions of Cameroon. However, its large-scale production faces numerous constraints, particularly phytoparasitic diseases. Infestation from the fields reduces the chances of good long-term conservation, leading to considerable losses due to phytoparasitic nematodes. During trials, 10 genera of PPNs were inventoried in the soil against 6 in the roots, including *Helicotylenchus* spp., *Haplolaimus* spp., *Rotylenchus* spp., *Tylenchulus* spp., *Ditylenchus* spp., *Hirschmaniella* spp., *Pratylenchus* spp., *Scutellonema* spp., *Meloidogyne* spp., and *Globodera* spp. The haphazard application of fertilizers makes onion plants vulnerable, hence the need to find an adequate formulation (dose) that can limit PPN proliferation. Thus, treatment with poultry manure (F94.3Me) and livestock cattle manure (C94.3Me) proved particularly effective, with a 100 % reduction in the Chagari variety, followed by treatments C47.3Me and F47.3Me, resulting in a 98.46 % reduction in Violet de Galmi and Chagari varieties. At the root level, a 100% reduction in parasite density was obtained with treatments C47.3Me, F47.3Me, and C94.3Me. The number of galls was markedly improved compared to negative and positive controls. Overall, the highest parasite reduction rate was 96.95% with the F47.15Me dose, while the lowest parasite reduction, 68.24%, was observed with the E0.236F23.58Me dose.

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NOVELTY STATEMENTS

This pioneering study sheds light on the diverse genera of nematodes in the Diamaré region and their impact on crop yields, especially onions, which local farmers attribute to 'soil fatigue.' Moreover, our findings demonstrate the efficacy of targeted organic matter applications (94.3 g/pot of poultry manure and 94.3 g/pot of cow dung compost) in controlling phytoparasitic nematodes while ensuring environmental and human safety.

AUTHOR'S CONTRIBUTIONS

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Conflict of Interest

The authors have declared no conflict of interest.

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