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Evaluation of the Potential for Controlling Yam (*Dioscorea* spp.) Nematodes during the Production Phase using Wrap and Plant Technology and its Effect on Yield in Three Agro-Ecological Zones of Togo

Houngo Ame Mensah Espère*, Tchabi Atti1 and Olowotche Nicolas

Institut Supérieur des Métiers de l'Agriculture, Laboratoire des sciences agronomiques et biologie appliquée, Université de Kara, Kara, Togo

**Corresponding author*

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A B S T R A C T

Yam, a key food crop in Togo and tropical Africa, faces increasing threats from plant-parasitic nematodes such as *Scutellonema bradys*, *Pratylenchus coffeae*, and *Meloidogyne incognita*, which damage tubers and reduce yields. This study evaluates the efficacy of the "Wrap and Plant" technology, involving abamectin-impregnated banana paper, to mitigate nematode impacts on yam crops across 18 sites in three agro-ecological zones. Three treatments were tested: T1 (abamectin-treated matrices), T2 (untreated matrices), and T3 (traditional practices). Parameters assessed included sprouting rates, tuber weight, and nematode density in tubers, roots, and soil. Results showed no significant differences in sprouting rates or tuber weight across treatments and zones. However, significant differences were noted in AEZ I for nematode density in roots (P = 0.02) and tubers (P = 0.01), with T1 and T2 reducing nematode numbers in AEZ I and II. In AEZ III, traditional practices (T3) were more effective. The nematodes identified included *Pratylenchus spp.*, *Scutellonema spp.*, *Meloidogyne spp.*, and *Rotylenchus spp.* The effectiveness of the technology varied by zone, showing promise under specific conditions, while traditional methods sometimes outperformed it.

Introduction

Yam is grown mainly for its tubers, which play a crucial role in West Africa ("INTRODUCTION," n.d.). These tubers form part of the staple diet of most people in the areas where they are grown. Yam also offers numerous opportunities for development and job creation. There is considerable scope for improvement in its production, processing into cosettes, foufou, koliko and stews, and in its consumption and profitability in the yam sector (Teixeira Caixeta *et al.,* 2003). Although Togo is one of the main yam producers in the West African region and ranks fifth in terms of production volume, behind Nigeria, Ghana, Côte d'Ivoire and Benin (Adifon *et al.,* 2019), yam growing faces a number of biotic and abiotic constraints. Among the biotic constraints, attacks by pathogens and pests play a significant role in production. Plant-parasitic nematodes are known to have harmful effects on this crop (Tchabi *et al.,* 2016). Two groups of plant-parasitic nematodes are particularly damaging to the yam crop: migratory endoparasitic nematodes (*Scutellonema bradys* and *Pratylenchus coffeae*) and sedentary endoparasites (*Meloidogyne* spp., including *Meloidogyne* incognita) (Quénéhervé, 1997). By affecting the roots, root-knot nematodes slow growth and reduce yam yields in the field, while *Scutellonema bradys* and *Pratylenchus coffeae* concentrate mainly on the tubers during storage.

Studies carried out in West Africa show that *Scutellonema bradys*, the main parasite in the region, infects the majority of cultivated species and varieties, with no effective control method having been identified ("IDENTIFIER ET LUTTER CONTRE LES NÉMATODES PARASITES DE L'IGNAME," n.d.). Yield losses directly or indirectly attributable to these nematodes are estimated at between 30 and 40% (Quénéhervé, 1997).

In addition, the technique of producing yams by cuttings and the exchange of yam seedlings between growers are ways of spreading nematodes from a contaminated area to an area free of plant pathogenic nematodes.

There are several methods of controlling plant pathogenic nematodes, including chemical control using nematicides applied at harvest time or during the yam's vegetative cycle (Adesiyan, 1976), thermotherapy, which consists of eliminating the nematodes contained in the planting material using heat (Adeniji, 1977), the biotechnological method, using seedlings obtained from in vitro micro-plants or healthy material from either bulblets or in vitro cultures (Dibi *et al.,* 2016), and finally the seed coating technique known as 'Wrap and Plant'. This technology involves wrapping the tubers or seeds in a protective material before planting (Pirzada *et al.,* 2020a). The process aims to reduce the damage caused by nematodes by creating a physical or chemical barrier (when impregnated with a pesticide) between the parasites and the sensitive parts of the plant. The 'Wrap and Plant' technology, designed to control nematodes in yam (*Dioscorea* spp.) crops, has been studied in depth, notably by Dedehouanou and Affokpon (2022); Dedehouanou *et al.,* (2022). These researchers examined the overall approach to the adoption of this innovation and showed that its acceptance by producers depended heavily on socio-economic characteristics such as gender, experience in yam cultivation, membership of a cooperative, level of education, involvement in income-generating activities and type of farm. Similarly, Ochola *et al.,* (2022) highlighted the effectiveness of Wrap and Plant technology in protecting seed potatoes against the cyst nematode (*Globodera rostochiensis*). In Benin, this technology has also proved effective in managing yam nematode (*Scutellonema bradys*) populations, resulting in a significant increase in yield and a significant reduction in post-harvest losses, particularly in terms of tuber weight and cracking after 3 to 5 months' storage.

Unfortunately, none of these methods is actually used to control the spread of nematodes in Togo. The aim of this study is therefore to evaluate, under field conditions, the effectiveness of this technology in yam production in three agro-ecological zones (AEZs) in Togo. More specifically, the aim is to assess the effectiveness of the technology in controlling the main parasitic nematodes of yam, to assess the effect of the technology on the germination capacity of yam seedlings and to assess the effect of the technology on yam yield.

Materials and Methods

Experimental sites

The trial was conducted in three agro-ecological zones (AEZs) in Togo: the dense dry forests and Guinean savannahs of the central plain (Zone III), the mosaics of open, dense dry forests and mountains of the north (Zone II), and the dry savannah grasslands of the north (Zone I) (see Figure 1). In each EAZ, three villages or localities were selected, with two experimental sites per village.

Equipment

Biological material

Three species of the Dioscorea genus were selected for the trials, one for each agro-ecological zone (AEZ). These were *D. rotundata*, a long-cycle species (commonly known as Cratchi or Kratchi) for ZAE I; *D. cayenensis*, a short-cycle species (known locally as Larboco) for ZAE II; and finally, the kpéné variety for ZAE III. These three species are among the most widely grown locally in Togo. Seeds of the three species were acquired on local markets and used as planting material.

Experimental design

In each experimental site, the trials were organised according to a completely randomised block design, comprising three (03) treatments and four (04) replications. Each block is made up of five rows of five ridges each, i.e. a total of 25 ridges per block and 300 ridges per experimental site. The treatments applied in the trial were as follows:

- T1: Yam seedlings are wrapped in banana paper matrices impregnated with abamectin before planting.
- T2: Yam seedlings are wrapped in untreated banana paper matrices (relative control) before planting.
- T3: Farmers' practices (absolute control).

Wrap and plant' technology

The 'Wrap and Plant' technique involves using matrices made from banana paper, which comes from the lignocellulosic fibres of the banana plant. These matrices are then impregnated with a pesticide (abamectin) [10]. This technology consists of coating the seedlings before they are planted, enabling a controlled, continuous and effective release of the active ingredient (abamectin) into the soil.

Effect of 'Wrap and plant' technology on agronomic parameters

The effect of the 'Wrap and Plant' technology was evaluated according to the following agronomic parameters:

- Sprouting rate: recorded three months after sowing.
- Number of tubers per mound: counted at harvest.
- Tuber weight: measured at harvest.

Visual assessment of tuber damage

A visual assessment of the symptoms (cracking, galling and dry and soft tuber rot) caused by plant pathogenic nematodes was carried out immediately after harvest. The percentage of tubers showing these symptoms was determined using the method described by Coyne *et al.,* (2006).

Determination of nematode population densities

Before planting

Nematode population densities were assessed in soil samples taken from each experimental field, at a depth of 5 to 30 cm, in four mounds chosen at random from the three middle rows. Soil samples from the same plot for each treatment were combined to form a composite sample with a volume of 250 cm³ (Coyne *et al.,* 2006).

At harvest

At harvest, the densities of nematodes belonging to the three key genera, Scutellonema, Meloidogyne and Pratylenchus, were determined in the soil, as well as in the roots and tuber skins.

Nematode extraction technique

For nematode extraction, the method of Baermann (Coyne *et al.,* 2006) was adapted as follows: 5 g of roots, yam peelings or 100 ml of soil were taken depending on the nature of the sample to be treated. These samples were placed in a sieve covered with toilet paper, which acted as a filter, and the whole was placed in a plastic dish.

The samples were carefully distributed in the sieve using tweezers. Water was then added until the samples of soil, yam peelings or roots were lightly covered, facilitating the migration of the nematodes towards the water, which constituted the extraction medium.

It is important to note that the roots and yam peelings were thoroughly cleaned in tap water, then cut with a chisel before being placed in the sieve. The prepared samples were incubated for 24 hours for the soil and 48 hours for the roots and yam peelings, at 25°C in a dark room.

After these incubation periods, the water contained in the plates was recovered in a graduated cylinder. After settling for 30 minutes, the supernatant was adjusted to a volume of 100 ml in a graduated cylinder for convenience, before observation under the microscope (Kassankogno *et al.,* 2020).

Nematode counting

10 ml of the extraction medium is pipetted into a gridded Petri dish and the nematodes observed and counted using a binocular magnifying glass. This operation was repeated three times for each extract. After calculating the average count, the number of nematodes is extrapolated to a volume of 100 ml of extract solution.

Harvesting and weighing

Harvesting was carried out when the tubers had reached maturity, i.e. at the dry leaf stage. Each tuber was weighed using an electronic balance. The yield was estimated using the following formula:

$$R = \frac{\text{Average tuber weight} \times 300 \times 10\,000}{391\ (sufarce\ of\ the\ test)}$$

Statistical analysis

The data were analysed using R software, version 4.3.3. Data relating to proportions (germination rate) were transformed using the function $x' = \arcsin\sqrt{p}$, with p=x/100, while data relating to numbers (number of nematodes) were transformed using the function log(x+1) before being subjected to statistical analysis. Analysis of variance was used to assess the effect of the treatments on each parameter measured. In the event of significant differences, the Student-Newman-Keuls (SNK) test was used to compare the means, with a significance level of 5%.

Results and Discussion

Effect of 'Wrap and plant' technology on agronomic parameters

Seed germination rate

The results of the analysis of variance show that there is no significant difference between the three treatments whatever the AEZ (P = 0.81 in AEZ I, 0.43 in AEZ II and 0.65 in AEZ III) three months after sowing.

For treatment T1, the germination rates recorded were 63% in ZAE I, 70% in ZAE II and 57% in ZAE III. In treatment T2, germination rates were 66% in ZAE I, 74% in ZAE II and 52% in ZAE III. In treatment T3, germination rates were 61% in ZAE I, 68% in ZAE II and 62% in ZAE III.

Tuber weight at harvest

Statistical analysis of tuber weight at harvest did not reveal any significant difference between the different treatments (P = 0.50 for ZAE I, 0.06 for ZAE II and 0.66 for ZAE III). However, a trend was observed: tubers from treatment T1 tended to have a slightly lower weight, while treatment T3 seemed to have a moderate effect on increasing tuber weight, compared with treatments T1 and T2.

On the other hand, the average tuber weight varied according to agro-ecological zone (see Figure 3). ZAE II, comprising the prefectures of Bassar, Sotouboua and Tchamba, had the highest average tuber weight, with a yield of 6.65 t/ha. It is followed by ZAE III with a yield of 3.79 t/ha, then ZAE I with a yield of 2.81 t/ha.

Number of tubers per mound at harvest

The number of tubers per ridge hardly varied from one treatment to another in ZAE II (P=0.68) and ZAE III (P=0.83). On the other hand, a significant difference (P=0.05) was observed between treatment T3 and treatments T1 and T2 in ZAE I (see Figure 4).

Treatment T3 recorded a lower number of tubers per mound than treatments T1 and T2, which are statistically equivalent in this zone. However, in AEZ II and III, treatment T3 recorded a higher average number of tubers per ridge than the other treatments.

Tuber symptoms at harvest

The results show that the three treatments statistically present an equivalent level of symptoms or damage on the tubers whatever the AEZ (Table 1). However, some notable differences were observed. In AEZ I, damage, whether from galls, termites, soft rot, cracks or dry rot, remained moderate overall, with a few peaks observed in treatments T1 and T2.

Table.1 P-value by ZAE and by damage

AEZ	Damage	P
I	Galling	1
I	Termite	0.919
I	Wet rot	0.749
I	Cracking	0.710
I	Dry rot	0.449
II	Galling	1
II	Termite	0.849
II	Wet rot	0.878
II	Cracking	0.849
II	Dry rot	0.270
III	Galling	0.519
III	Termite	0.924
III	Wet rot	0.725
III	Cracking	0.404
III	Dry rot	0.117

On the other hand, in ZAE II, the damage is more varied and frequent, particularly for cracks and termite attack, where treatments T1 and T2 seem to be more affected. ZAE III shows an even greater intensity of damage, especially as regards cracks and T.P_M, with a predominance of treatment T2 (Figure 5).

Effect of 'Wrap and plant' technology on nematode population dynamics

Soil nematodes

Nematodes in the soil before sowing

The number of nematodes in the soil before sowing yams was statistically identical (P = 0.88 in EAZ I, 0.95 in EAZ II and 0.60 in EAZ III) for each treatment, despite slight variations between treatments (Figure 6). More specifically, treatment T1 showed relatively higher numbers of nematodes in all three agro-ecological zones (AEZs) compared with the other treatments. Treatment T3 showed lower numbers of nematodes in AEZ II and III, but slightly higher numbers in AEZ I.

At harvest No significant differences (P = 0.14 for EAZ I, 0.10 for EAZ II and 0.34 for EAZ III) were observed between the mean nematode density for the three treatments in each agroecological zone (EAZ) (see Figure 7). However, specific variations are noted: in AZE I, the T1 treatment has the highest nematode density with 480.13 nematodes, compared to the T2 (305.13 nematodes) and T3 (335.69 nematodes) treatments.

Conversely, in AZE II, the T2 treatment has the highest density with 206.25 nematodes, surpassing the T1 (172.91 nematodes) and T3 (145 nematodes) treatments. Finally, in AZE III, the T3 treatment shows a higher density of nematodes than the T1 and T2 treatments (Figure 7).

Tuber nematodes

Pre-sowing tuber nematodes

The results presented in Figure 8 show that seeds in agro-ecological zones I and II are free of nematodes before planting. In agroecological zone III, on the other hand, the tubers (seeds) are already infested with nematodes before they are planted.

Nematodes in tubers at harvest

The evaluation of the density of nematodes in tubers at harvest (Figure 9) reveals a significant difference between the three treatments (P = 0.02 for AZE I, 0.36 for AZE II and 0.10 for EZ III). In agroecological zone I, treatment T1 has the highest number of nematodes with 33.19 nematodes, followed by T3 with 20 nematodes, and finally T2 with 0 nematodes. In contrast, in agroecological zone II, treatment T2 has the highest number of nematodes with 6.52, followed by T3 with 1.38 nematodes, and T1 with 0 nematodes. In agroecological zone III, the nematode densities are 6.11 for T1, 23.33 for T2, and 0.69 for T3, respectively.

Tuber root nematodes at harvest

The results presented in Figure 10 show a significant difference (P = 0.01) between T1 and T2 and T1 in AZE I, but no significant difference between T2 and T3. On the other hand, there was no significant difference in the other two areas (P = 0.36 for ZAE II and 0.22 in EZ III). Indeed, treatment T1 has the highest levels of nematodes in zones I and II, while treatment T3 shows lower levels in ZAE I but a little higher in ZAE.

Nematodes identified

The following nematodes could be identified in the roots, the peelings of the yams and the soil taken from the mounds. The most frequently encountered genera are:

- *Pratylenchus* spp.
- *Scutellonema* spp.
- *Meloidogyne* spp.
- *Rotylenchus* spp.

In all the agro-ecological zones (AEZs), a low germination rate was observed. This phenomenon could be attributed either to the quality of the seed or to the irregularity of rainfall observed after sowing in some AEZs, particularly AEZ I. According to Miège (1957), the choice of seedlings is of vital importance, as their state of health has repercussions on the emergence and vigour of the plants, thus influencing yields, which can be higher or lower. Cornet (2015) estimated this reduction at 22% for *Dioscorea alata* and 27% for *Dioscorea rotundata*. Treatment T1 shows relatively high germination rates in ZAE II, but lower in ZAE III, while treatment T2 shows the highest rates in ZAE II and the lowest in ZAE III. This suggests that these treatments may be sensitive to specific conditions or external factors. Treatment T3 shows relative stability across all ZAEs, which may indicate robustness or consistency. Although there was no significant difference between the three treatments, regardless of the AEZ, the results show that in extreme conditions, such as the absence of rain, the 'Wrap and plant' technology could have a negative effect on the germination rate of yam tubers. On the other hand, under favourable conditions, it outperforms farmers' practice (T3) in terms of sprouting rate. The work of Pirzada *et al.,* (2020b) demonstrated, under greenhouse conditions, that the use of banana leaves transformed into paper to coat maize seeds did not affect either seed germination or root development.

Statistically, our results reveal that the technology did not influence tuber weight at harvest. However, (Tchabi *et al.,* 2016) showed that using Arbuscular Mycorrhizal Mushrooms (AMM) increased yam yields compared with controls, while controlling Meloidogyne spp. nematodes.

Figure.1 Study area

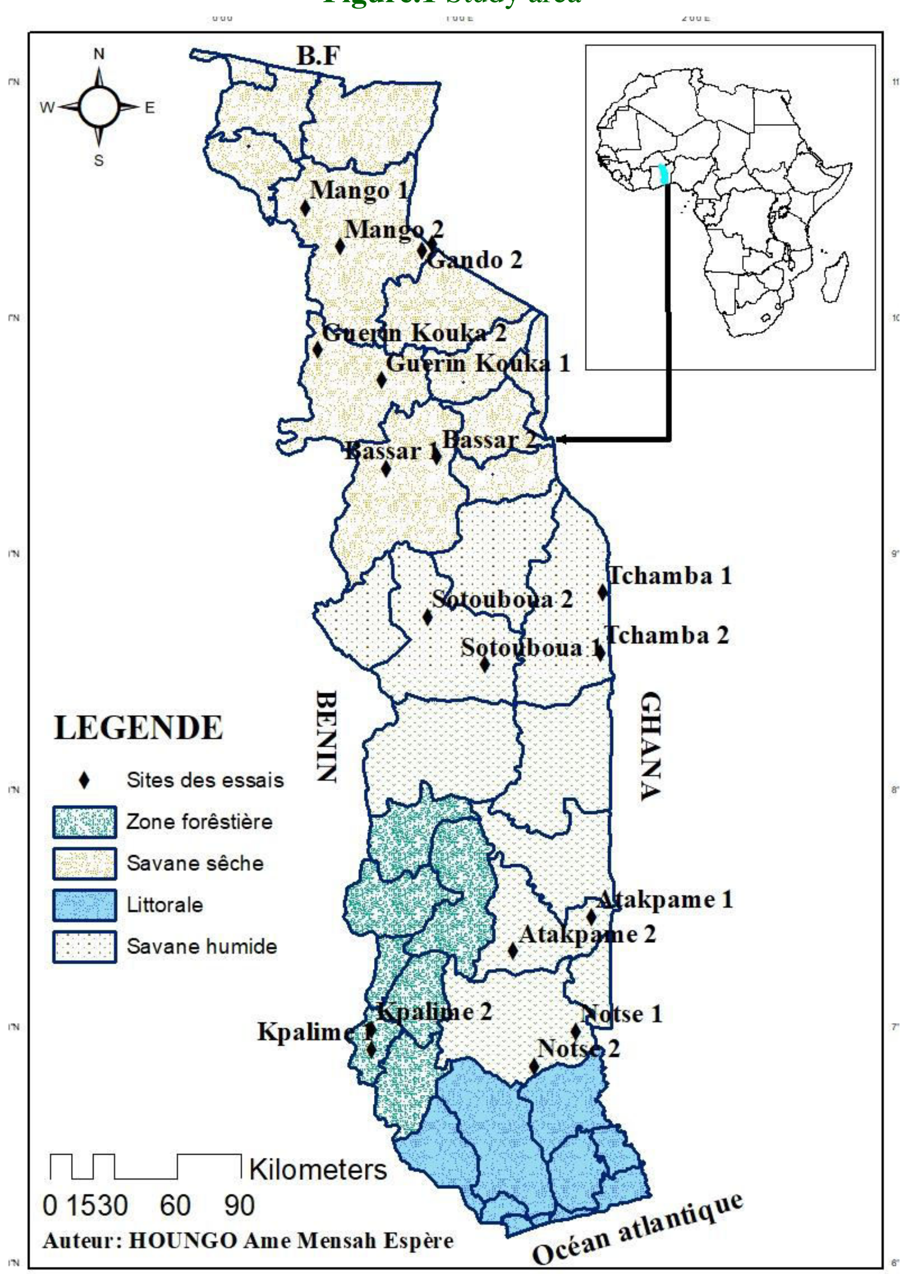


Figure.2 Yam plant emergence rates by Agroecological Zone (AEZ) three months after sowing

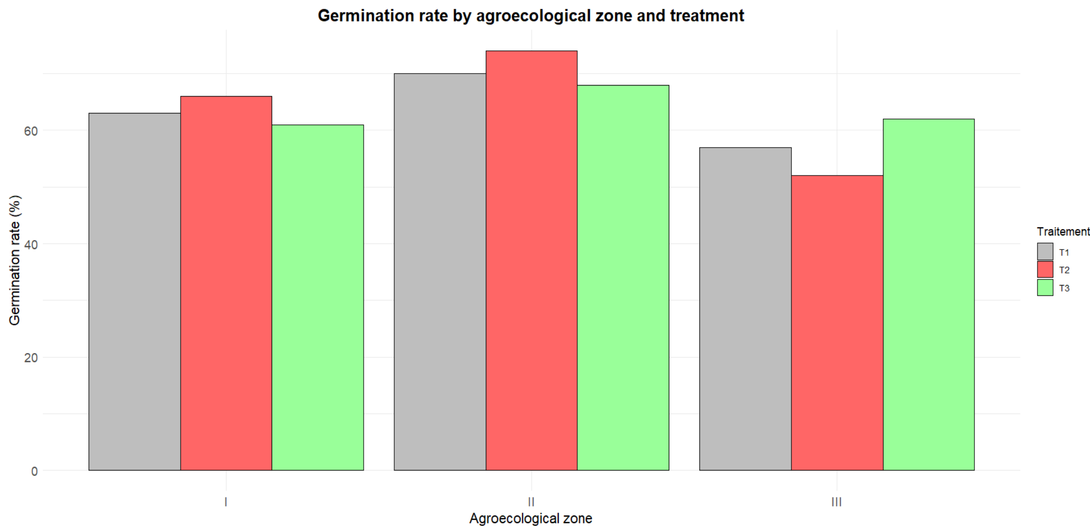


Figure.3 Weight of yam tubers at harvest by Agroecological Zone (AEZ)

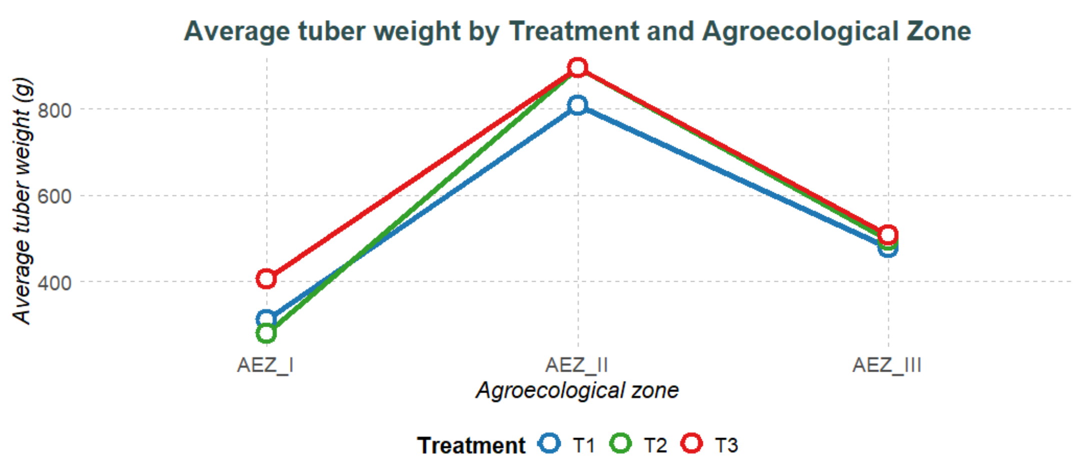


Figure.4 Number of yam tubers per bute (NT/B) at harvest by Agroecological Zone (AEZ)

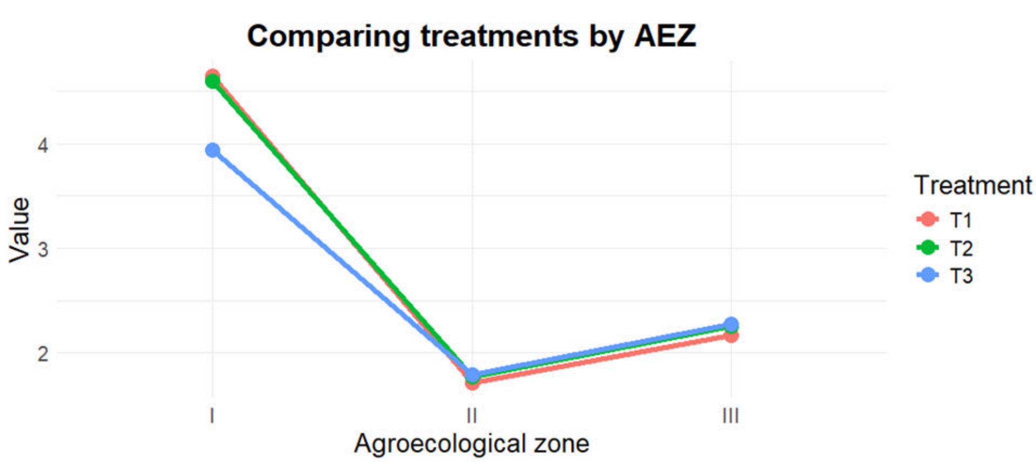


Figure.5 Number of tubers showing symptoms per treatment and per EAZ

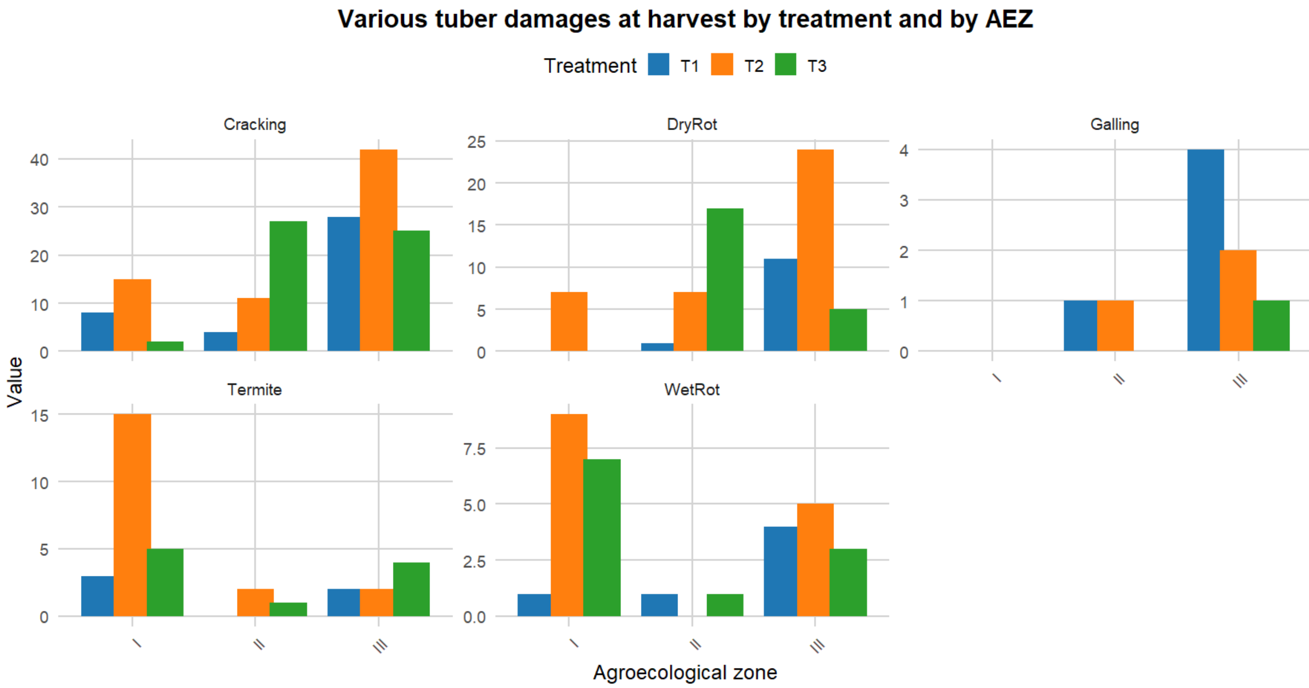


Figure.6 Number of nematodes in the soil before sowing by Agroecological Zone (AEZ) Soil nematodes

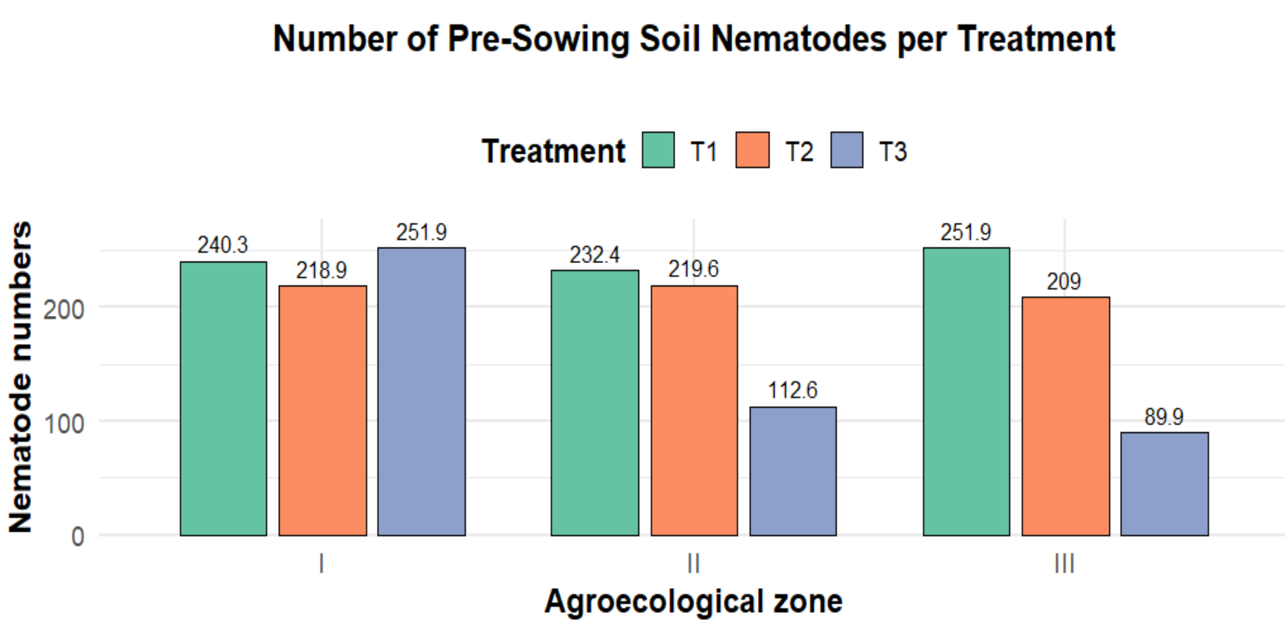


Figure.7 Number of nematodes in soil at harvest by Agroecological Zone (AEZ)

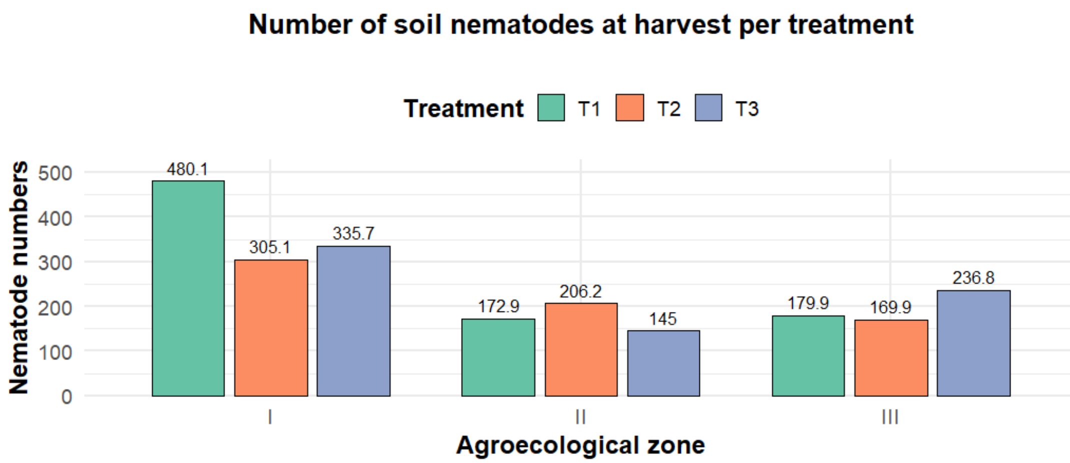


Figure.8 Number of Nematodes in Pre-Seeded Tubers by Agro-Ecological Zone

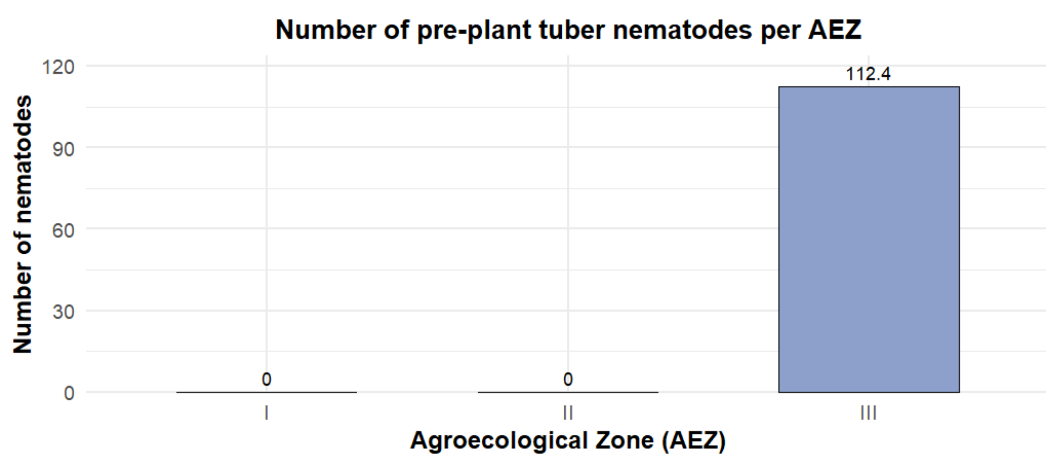


Figure.9 Number of nematodes in tubers at harvest by Agro-Ecological Zone (EAZ)

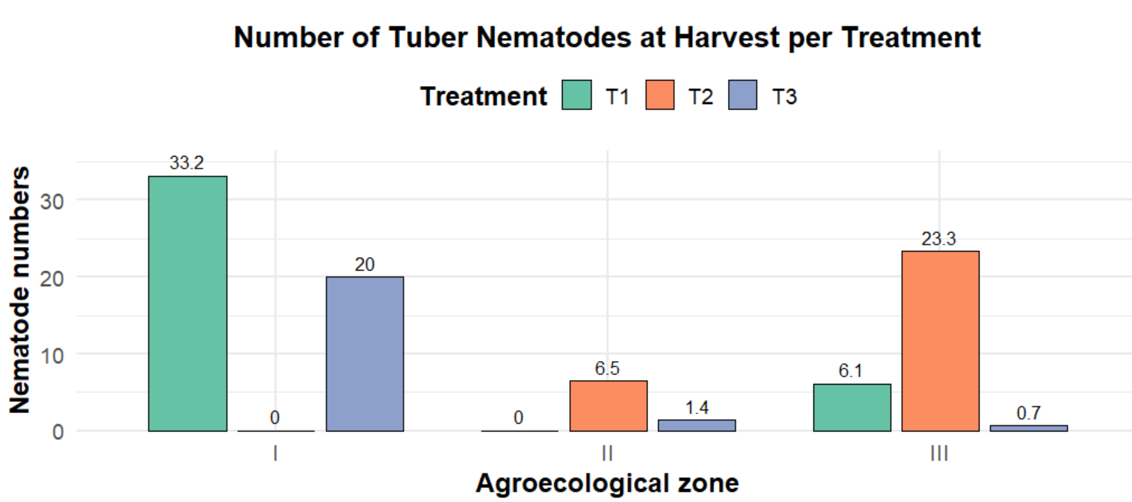
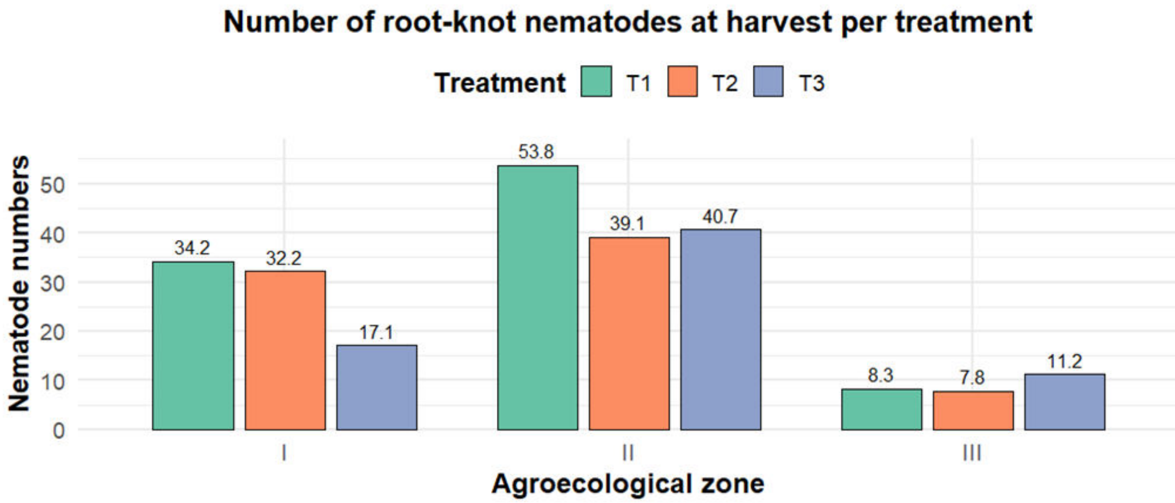


Figure.10 Number of nematodes in roots at harvest by Agro-Ecological Zone (EAZ) and by treatment



AMM thus acted not only as a biofertiliser, but also as a biopesticide. Similarly, Brandford *et al.,* (2019) achieved a 40-41% increase in yields using neem leaf powder against yam pests, particularly nematodes. However, treatment T3 performed slightly better in all EAZs, producing the heaviest tubers, while treatment T2 came second, tending to produce tubers slightly lighter than T3, but heavier than T1. Treatment T1 performed least well in terms of tuber weight in all zones. The specific conditions of each AEZ seem to influence the performance of the treatments. Tubers become heavier when moving from EAZ I to EAZ III, probably due to factors such as soil quality, humidity or temperature, which favour tuber growth more in the higher zones.

The difference in yield, weight and number of tubers between EAZs could also be attributed to the variety of yam grown, which differs in the three EAZs. Djinet *et al.,* (2015) showed in a comparative study of ten sweet potato varieties that the number of tubers per mound varies between varieties. The Laborco variety would therefore appear to be better suited to optimal yam tuber production. Furthermore, it can be concluded that ZAE II is the most suitable for yam cultivation in Togo, followed by ZAE III. These results corroborate those of Toukam *et al.,* (2015), who also demonstrated that yam yield per hectare is highly dependent on geographical area.

We can also conclude that the number of tubers per hillock influences the average weight of the tubers. ZAE I had the highest number of tubers per mound, but also the lowest average weight per tuber, unlike ZAE II. The results of this study do not show any significant difference in the symptoms observed on the tubers, whatever the treatment, although many tubers show cracks. Treatments T1 and T2 appear to be more vulnerable to termite attack or soft rot than treatment T3 (farmers' practice). Although the banana leaves used to coat the seeds (in treatments T1 and T2) are biodegradable, they could attract termites or carry bacteria or fungi responsible for soft rot in yams.

Contrary to our results, Pirzada *et al.,* (2023, 2020b) obtained the opposite results, reporting that the Wrap and plant technology effectively reduces nematodes (*Scutellonema bradys*) while considerably increasing tuber yield and reducing tuber cracking symptoms. She perm (Brandford *et al.,* 2019) found a reduction in these symptoms on tubers using neem leaf powder. This technology has also been used in Benin to effectively control populations of yam nematodes (*Scutellonema bradys*) while considerably increasing yield and substantially reducing weight loss and post-harvest tuber cracking after 3 and 5 months' storage (Pirzada *et al.,* 2023).

Nematodes in the soil varied according to the EAZ, although the results were not statistically significant. Each treatment showed different performance depending on the ZAE, which may be due to environmental factors or characteristics specific to each zone. Only in ZAE III was the 'Wrap and plant' technology more effective than farming practice. The results obtained in ZAE III confirm the observations of Brandford *et al.,* (2019). However, those for ZAE I and II diverge from these conclusions. Indeed, Brandford *et al.,* (2019), using neem leaf powder, observed a significant reduction in the number of nematodes in the soil of treated plots. Nevertheless, a decrease in nematode numbers was observed after harvest, except in ZAE I, where a slight increase was recorded. Mudiope *et al.,* (2007) showed a decrease in nematode numbers after yam harvest in a study of nematode distribution and damage to yams in central and eastern Uganda.

These variations are thought to be linked to the humidity in each zone, which, according to ("Thompson: Nematodes in stored yams - Google Scholar," n.d.) Thomson *et al.,* (1973), influences the reproduction of nematodes (*Scutellonema*, *Pratylenchus*) in tubers. These results could also be linked to varietal diversity, with varieties differing from one AEZ to another. Mudiope *et al.,* (2007) reported that the variation in nematode damage and density in tubers is largely explained by varietal diversity. It should also be noted that the averages are generally low in ZAE II, moderate in ZAE III and high in ZAE I, this difference being due to varietal sensitivity.

The nematodes identified, notably *Pratylenchus* spp, *Scutellonema* spp, *Meloidogyne* spp, and *Rotylenchus* spp, are known to cause significant damage to yam roots and tubers, affecting plant growth and yield. Their frequent presence indicates high parasitic pressure on crops, requiring adapted control strategies to preserve yam productivity and quality. These results corroborate those of Mudiope *et al.,* (2003, 1988), who also identified the genera *Pratylenchus* spp. and *Meloidogyne* spp. in the roots, tubers and surrounding soil of yams. Similarly, the work of Itolou *et al.,* (2020) revealed the presence of these two genera in the soil around tubers and in yam roots and peelings in the central region of Togo.

It is therefore difficult to comment on the effectiveness of the 'Wrap and plant' technology on the agronomic parameters of field-grown yam, whatever the EAZ. This technology does not have a negative impact on yam cultivation, but neither does it significantly reduce the density of nematodes in the soil around the tubers, in the roots and in the peelings. Dedehouanou *et al.,* (2022) came to similar conclusions regarding the adoption of this technique in Benin, where farmers felt that their traditional practices resulted in better yields compared with the 'Wrap and plant' technology. In East Africa, and more specifically in Kenya, the wrapping of potato seeds using 'Wrap and plant' technology considerably reduced the inoculum of *Globodera rostochiensis* and increased yields fivefold, whether or not the seeds were impregnated with doses of abamectin (Ochola *et al.,* 2022). The nematicidal effect of the abamectin used in the T1 treatment could not be proven in this study, although other studies (d'ERRICO *et al.,* 2017; Mam *et al.,* 2019; Massoud *et al.,* 2023) gave contrary results. In fact, abamectin is not officially recognised as a nematicide. According to the ACTA Plant Health Index 2021 (www.unitheque.com, 2021), it acts mainly by ingestion, and to a lesser extent by contact, on mobile forms of mites and certain biting insects such as thrips, leafminers and psyllids. Due to its translaminarity, it has a persistence of action of 3 to 6 weeks. However, the yam growth cycle extends over a period of 7 to 9 months (Cornet, 2015), whereas nematodes have variable reproductive cycles, ranging from 3 weeks for *Meloidogyne javanica* to more than a year for *Xiphinema diversicaudatum* ("Info-Bioagresseurs - Biologie," n.d.). The rapid multiplication of nematodes, favoured by certain environmental conditions specific to each agro-ecological zone (AEZ), could therefore explain why abamectin did not have a significant nematicidal effect in this study.

In conclusion, the results of this study highlight the complexity of the interactions between applied treatments, agro-ecological conditions and environmental factors in yam cultivation. Although the Wrap and Plant technology did not demonstrate a significant effect on nematode reduction or tuber weight improvement, neither did it have a major negative impact. Treatment performance differed between agro-ecological zones, suggesting that the effectiveness of this technology is largely dependent on local conditions, such as soil moisture and quality.

The results corroborate previous studies, while highlighting the importance of varietal and environmental factors in treatment performance. It also appears that traditional farming practices, embodied by the T3 treatment, are relatively effective, and even superior under certain conditions, particularly in terms of resistance to termites and soft rot. The adaptation of new technologies such as Wrap and Plant should therefore be studied further, taking into account the specific conditions of the different agro-ecological zones, and ensuring that they provide advantages comparable to or superior to local practices.

Author Contributions

Houngo Ame Mensah Espère: Conceived the original idea and designed the model, wrote the manuscript, and analysed the data.; Atti Tchabi: Review & Editing, Visualization, Supervision, Project Administration, and Funding Acquisition.; Olowotche Nicolas: Data Curation

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

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