Application of hot water therapy and fertilizer additives in the management of plant-parasitic nematodes on dichotomous plantain in southeastern Nigeria Utisol

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ABSTRACT

Plant-parasitic nematodes pose a serious biotic threat among plantain cultivars in southeastern Nigeria. Field trials were conducted at the University of Uyo, Teaching and Research Farm during the 2018 and 2020 planting seasons. The objective of the study was to evaluate hot water therapy and fertilizer additives on the growth, yield, and management of parasitic nematodes on dichotomous plantain. The treatments consisted of four rates of fertilizer additives (0, 10, and 20 t ha^{-1} of poultry manure, and 400 kg ha^{-1} of NPK) applied to double and triple-bunching cultivars-*Musa* spp. AAB. Zero application without hot water therapy and additives served as control. The experiment was laid out in a randomized complete block design and replicated four times. Data collected on the growth, yield-related components of plantain, and population of plant-parasitic nematodes detected were subjected to analysis of variance at a 5% level of significance. Results showed that pared hot water sucker with fertilizer additives increased significantly ($P < 0.05$) in growth and yield-related components. Also, plant-parasitic nematode genera detected at harvest included *Meloidogyne, Pratylenchus, Helicotylenchus Radopholus,* and *Hoplolaimus* in both soil and root of plantains' first and second cropping cycles. Plant-parasitic nematode population was reduced significantly ($P < 0.05$) in treated plantain suckers in the two cropping cycles. The yield of treated plantain suckers significantly ($P < 0.05$) increased by 31.63–45.74% in the first cropping cycle (mother plant) while 57.84–69.19% was recorded in the second cropping cycle (ratoon plant). The study results imply that plant-parasitic nematodes contributed to yield losses in plantain production across southeastern Nigeria. The application of 20 t ha^{-1} poultry manure to treated plantain pared suckers is recommended for improved growth, yield, and management of nematodes. This follows that hot water therapy and adequate nutrient integration could be an eco-friendly strategy in the management of plant-parasitic nematodes to ensure sustainable yield increase of dichotomous plantain genome.

Keywords: Additives, *Musa* spp., plant-parasitic nematodes, hot water therapy, management

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INTRODUCTION

Plant-parasitic nematodes (PPN) are the major root causes of reduction in crop growth and yield efficiency in agro-ecosystem. The yield loss can rise to 75% without showing any disease symptoms on crop morphology. Perennial crops and annual crops under intensive cultivation usually experience high yield losses due to activities of plant-parasitic nematodes if crop protection management strategies are not considered. Plant-parasitic nematode feeding process damages the plant's root system and reduces the plant's ability to absorb water and nutrients. Typical nematode damage symptoms are a reduction of root mass, a distortion of root structure, and/or enlargement of the roots. Field experimental results show that plant-parasitic nematode damage accounts for yield losses of about 31–50%, with current yields of 7.8 metric tonnes per hectare (Norgrove and Hauser, 2014). However, soil nutrient depletion, plant-parasitic nematodes, and the banana weevil combine to limit the length of plantain plantation lifespan (Swennen *et al*., 1988). Nematodes destroy plantain roots undermining productivity, especially under conditions of poor soil fertility. This forces the farmers to abandon their fields in search of new crop areas, particularly following extended land fallow or at the expense of forests (Hauser, 2000; Gowen *et al*., 2005). Newly planted fields are established, for the most part, from untreated suckers in existing fields. Consequently, suckers used for newly planted fields are invariably infected with nematodes and other soil-borne pests and diseases, resulting in the contamination of new fields. Transplanting the contaminated materials facilitates the persistence and spread of nematodes and weevil problems and shortens the lifetime of plantations to only one or two cycles of production, beyond which most plants topple, become unproductive, or simply die (Wilson *et al.,* 1987a; Coyne *et al.,* 2005a; 2005b). The poor health and quality of planting materials and soil-borne pests are detrimental to the expansion of banana and plantain cultivation. The underlying biotic threat to *Musa* spp. is generally plant-parasitic nematodes that are carried from field to field through the use of infected suckers planting material (Hauser, 2000; Gowen *et al.,* 2005).

However, a number of techniques have been developed to produce large numbers of planting materials (Wilson *et al.,* 1987b; Swennen, 1990; Faturoti *et al.,* 2002; Kwa, 2003) to decontaminate infested materials (Speijer, 1999; Hauser, 2000; Ekanem and Akpheokhai, 2020), and to reduce reinfestation of fields with nematodes (Coyne *et al*., 2005a). Some nematode species considered to be most common in distribution and detrimental to plantain in the rainforest agro-ecological zone of Nigeria include *Pratylenchus coffeae, Helicotylenchus multicinctus, Meloidogyne* spp.*, Hoplolaimus pararobustus* and *Radopholous similis* (Speijer *et al.,* 2001). These nematodes severely damage the root and corm of plantain, consequently reducing nutrient and water uptake by the roots and reducing yields (Rotimi *et al.,* 2004a; 2004b). In Nigeria, plant-parasitic nematodes cause production losses of 46–54%, as noted in cv. Agbagba and damaged plant roots are easily toppled in wet windy weather (Gowen, 1995).

There are several management strategies employed to clean plantain suckers from nematodes and other soil-borne pests and diseases. The simplest and least capital-intensive is the paring of corm and thermal control measures such as hot/boiling water treatment and submerging suckers in hot water (Hauser, 2000; Ekanem and Akpheokhai, 2020). The sanitation measures are non-specific and may destroy any pest or pathogen of plantain. Hot water treatment has proved to reduce the incidence and severity of other pests and diseases or cause physiological stimulation of plant growth. Pre-treatment of corm with hot water has great potential to increase plant yield (Hauser, 2007). Coyne *et al.* (2010) also reported that the boiling water technique could be a promising alternative measure in plantain sanitation. It has effectively disinfected various sizes of plantain suckers without detrimental effects on sucker's germination. In southeastern Nigeria, the productivity pattern of inflorescence dichotomous plantain and its reversion in bunches, the growth and yields of these morphotypes are sometimes hindered by soil fertility and complex pests and diseases. However, there is a paucity of information on a suitable mechanism for the management of plantain losses due to plant-parasitic nematodes and soil fertility in the Utisol of southeastern Nigeria. The study, therefore, seeks to show that inflorescence dichotomous plantain needs adequate sanitation measures for the sustainability of its production, conservation, and avoidance of extinction. The study evaluates hot water therapy and fertilizer additives on the growth and yield of dichotomous plantain cultivars as well as plant-parasitic nematodes detected and their reproduction at harvest in Utisol of southeastern Nigeria.

MATERIALS AND METHODS

Description of the Study Area

The trial was conducted at the Teaching and Research Farm of the University of Uyo, Akwa Ibom State, Nigeria located at the latitude of 5°20’ N and 5°30’ N, the longitude of 7°27’ E and 5°62’ E at 68 m above sea level. The average annual rainfall is 2,500 mm, the relative humidity ranges between 65.7 and 79.8%, and the monthly mean temperature ranges from 26.88–32°C. The soil type during the 2018–2020 cropping seasons is Ultisol (UCCDA, 2002; Agbede, 2015).

Soil and Root Samples for Plant-Parasitic Nematodes Extraction

Twenty-five core soil samples were collected randomly with a soil auger at a depth of 0–15 and 15–30 cm. The soil samples were thoroughly mixed, and a subsample of 250 cm^3 from each plot was used for initial nematode population analysis. The remaining samples bulked, air dried, crushed with mortar and pestle, and sieved using a 2 mm mesh sieve for physicochemical analyses in various methods described (Bouyoucos, 1962; McLean, 1965; Jackson, 1967; Syers *et al*., 1968; AOAC, 2016; Souza *et al*., 2016). The modified Baermann technique (Hooper, 1990) was used to extract nematodes from the soil subsamples taken from each subplot to determine the initial population of plant-parasitic nematodes (Pi). The set-up consisted of two sieves separated by a double-ply facial tissue placed on a collection tray. After thorough mixing, 250 cm^3 of soil was poured into the upper sieve, and water was added to the collection tray to fill the capacity. The extracted nematodes were collected in beakers after 48 hours and counted under the stereomicroscope (Wild M3C Leica) before planting. Plantain roots were rinsed and cut into 2 cm pieces with a knife, and 10 g sub-samples were taken for the extraction of endoparasitic nematodes following the method described by Coyne *et al*. (2007). Roots are macerated using a pulsing action on the blender for 10 seconds. Thereafter, poured through a stack of sieves (2 mm, 250, 150, and 125 µm) to trap sedentary nematodes and collect them in a becker while motile nematodes were extracted with the modified Baermann technique previously described. The extracted nematodes were observed, counted, and identified (Mai and Lyon, 1975; Coyne *et al*., 2007; Mekete, 2012).

Sources and Hot Water Treatment of Plantain Suckers

Dichotomous plantain (double and triple-bunching) suckers (a false horn cultivar - *Musa* spp. AAB genome) were collected from mother stools in the Teaching and Research Farm, University of Uyo. The suckers consisted of conventional uniform and vigorously growing sword suckers with a minimum pseudostem height and girth of 50 and 15 cm, respectively, as suggested by Nelson *et al*. (2006) and Oluwafemi (2013). The entire sword suckers were cut back to 1.5 m and separated into pared and unpared groups. In pared group, all roots and approximately 5 mm outermost layer of the corms and all discolored tissues were peeled off with a sharp knife. The pared plantain corms were dipped into boiling water at 100 °C for 30 seconds, as recommended by Hauser (2000) and Coyne *et al*. (2010), and thereafter allowed to cool for 24 hours so that treated suckers could stabilize before planting.

Field Experiment and Design

The land area used for the study was 50 m × 45 m (0.225 ha), the field was divided into plots representing an experimental unit of 10 m × 7.5 m dimension, and the distance between the plots was 0.6 m × 1 m. Pared hot water treated and untreated suckers were randomly planted in a hole of 0.3 m × 0.3 m × 0.3 m depth at 2.0 m × 3.0 m spacing between plants and within plants giving a population of 1,667 plants ha^{-1} under a monocropping system in the field (Shiyam, 2010; Akinro *et al.,* 2012). Planted suckers were treated with fertilizers from various sources for 8 weeks after planting (WAP) as follows; 0, 10, and 20 t ha^{-1} of poultry manure, NPK 15:15:15 at 400 kg ha^{-1}, and unpared suckers without hot water therapy and fertilizer (served as a control). The experiment was laid out in a randomized complete block design, and the treatments were blocks replicated four times. The experiment continued into the first ratoon generation without any modification, and similar data obtained from the parent plants were also collected to validate the data.

Data Collection and Statistical Analysis

Data were collected on some growth parameters and yield-related components of plantain cultivars taken according to the methods described by Dadzie and Orchard (1997), Plantain Production Farmers Manual (PPFM, 2013), and National Agricultural Research and Extension Institute (NAREI, 2013). Plant height (cm) at harvest in mother and ratoon crops was determined with the aid of a graduated wooden meter pole placed from the base to the top of the plant. A measuring tape was placed onto the graduated wooden pole to validate the height from the soil level to the point where the highest petioles meet on the graduated wooden pole. Plant girth (cm) at harvest in mother and ratoon crops was determined by measuring the individual circumference of the pseudostem with a tape at the widest mid-point of 1 m from the soil surface. The number of suckers produced at harvest was counted manually, and the number of suckers per plant was recorded. Functional leaves at bunch emergence that varies between 7 and 9 months were counted manually, and the number of functional leaves per plant was recorded. Functional leaves at bunch harvest were counted manually, and the number of functional leaves per plant was recorded. The number of days to inflorescence emergence was obtained by manual counting from planting days to bunch emergence. The number of bunches per plant at harvest was counted manually. For the number of hands and fingers per bunch, the number of hands-on a bunch of dichotomous plantains was obtained by manually counting the hand on each bunch. The fingers or individual fruit was determined by manual counting of individual fruits per hand on each bunch. Fruit length (cm) was determined by measuring the outer curve of individual fruit (middle fruit of the 2nd hand) with measuring tape from the distal end to the point at the proximal end where the pulp is judged to terminate. Fruit weight (g) was determined by weighing individual fruit on a HANA scale balance (Precision HANA Scales PVT Ltd, India), and readings were recorded to 2 decimal places. Bunch weight (kg) was obtained by weighing individual bunches on a HANA scale balance (Precision HANA Scales PVT Ltd, India), and readings were recorded to 2 decimal places. Yield in tonnes per hectare (t ha^{-1}) was determined by the use of this formula:

$$\text{Yield} = \frac{\text{Bunch weight} \times 10{,}000/\text{ha}}{\text{Planting space}}$$

In addition, data on nematode multiplication in root samples were also taken. Plantain roots were obtained using a knife and hand trowel, rinsed, and cut into 2 cm pieces with a knife, and 10 g sub-samples were taken for nematode extraction. Also, soil collected from 0–15 and 15–30 cm depths with a soil auger was thoroughly mixed, and 250 cm^3 subsamples were taken for nematode extraction (Coyne *et al*., 2007). Nematodes extracted were identified from adult females and counted under a stereomicroscope (Wild M3C Leica). Morphological identification of plant-parasitic nematodes to a generic level was made with the nematode identification key of Mai and Lyon (1975) and Mekete (2012). Nematode counts from roots and soil were transformed using Log10 (X + 1) before analyses to achieve normal data distribution (Gomez and Gomez, 1984). The data collected on growth, yield, and nematode reproduction were evaluated with analysis of variance (ANOVA) to test the treatments and block effect, while Fisher's least significant difference (LSD) was used to detect differences among treatment means at a 5% level of probability using Statistical Analysis Systems (SAS) procedure outlined for the generalized linear model (SAS, 2009).

RESULTS AND DISCUSSION

The results in Table 1 show the soil pH ranged from 5.40–5.64 in 2018/2019 and 5.42–5.74 in 2019/2020, while exchangeable acidity decreased with soil depth from 2.08 to 1.98 in 2018/2019 and from 2.19 to 1.96 in 2019/2020 cropping seasons. Also, the soil textural class was sandy loam, characterized by low pH, organic matter, potassium, magnesium, and total nitrogen decreased with a high infiltration rate indicating that the soil fertility status was low (Table 1). These results are in line with those described as the soil of Southeastern Nigeria as acidic, which could be eroded easily due to high rainfall. Udoh *et al*. (2008) and Agbede (2015) reported that a high infiltration rate destroys the quality of the physicochemical parameters of soil, which suggests that the soil status becomes acidic with nutrient decrease and subsequent low soil fertility.

Table 1 Physicochemical properties of experimental soil

Physicochemical property	2018/2019			2019/2020		
	Soil depth		Poultry manure	Soil depth		Poultry manure
	0–15 cm	15–30 cm		0–15 cm	15–30 cm	
pH	5.64	5.40	-	5.74	5.42	-
Organic carbon (%)	1.45	1.39	30.63	1.47	1.22	34.26
Organic matter (%)	3.31	3.05	52.04	3.55	3.05	51.60
Sand (%)	84.13	72.08	-	76.52	71.04	-
Silt (%)	6.43	8.16	-	8.42	7.44	-
Clay (%)	11.02	15.64	-	15.39	15.63	-
Base saturation (%)	61.04	69.55	-	65.02	67.94	-
Nitrogen (g/kg)	0.05	0.04	4.54	0.06	0.05	4.77
Phosphorus (mg/kg)	38.05	25.16	43.05	43.42	33.36	50.04
Potassium (g/kg)	1.63	0.60	9.48	0.61	1.60	9.55
Calcium (cmol/kg)	2.28	2.41	3.76	2.92	2.55	3.86
Magnesium (cmol/kg)	1.24	1.65	0.37	1.62	1.80	0.36
Sodium (mg/kg)	0.13	0.05	0.46	0.16	0.07	0.44
Effective cation exchange capacity (cmol/kg)	4.30	4.08	-	4.40	4.58	-
Exchangeable acidity	2.08	1.98	-	2.19	1.96	-
Textural class	Sandy loam	Sandy loam	-	Sandy loam	Sandy loam	-

In the mother plant, the height of the pseudostem of pared plantain suckers treated with hot water and fertilizer additives increased significantly ($P < 0.05$) when compared with the control and the pared hot water-treated suckers (Table 2). The tallest plant (304.83 ± 8.40 cm) was observed in hot water-treated pared suckers planted with poultry manure applied at 20 t ha^{-1}, followed by treated suckers (280.00 ± 7.10 cm) in 400 kg ha^{-1} of NPK and the least plant height (250.33 ± 7.60) was observed in control (Table 2). There was a significant ($P < 0.05$) difference in the girth of hot water-treated suckers with fertilizer sources and the control. However, suckers planted in fertilizer-treated plots had bulky girth, which ranged from 55.36 ± 1.20 to 62.44 ± 3.10 cm, while the control had the least girth sizes in mother (48.60 ± 3.20 cm) and ratoon (41.65 ± 3.30 cm). Also, the number of suckers produced, functional leaves at bunch emergence, and functional leaves at harvest increased significantly

($P < 0.05$) with hot water-treated pared suckers + fertilizer sources compared with the hot water-treated pared and unpared suckers + 0 t ha^{-1} which served as controls (Table 2). The same trends observed in the mother plant height, girth, number of suckers, and functional leaves at bunch emergence and harvest were also recorded during the second crop circle (ratoon plant). Furthermore, the high performance obtained in vegetative and reproductive parameters of pared hot-water treated suckers in the first cropping cycle (mother plant) and the second cropping cycle (ratoon) could be attributed to the integrated soil fertility management strategy utilized for its sustainability. This is supported by the work of Agbede (2015), that the integrated application of organic and inorganic fertilizers enhanced soil status. Moreso, the performance of vegetative parameters such as tallest height/biggest girth and functional leaves at bunch emergence/harvest is an indication that pre-treatment of corm suckers promotes better rooting for absorption of nutrients and water uptake in the plantain. This corroborates the report of Banful *et al.* (2008) that hot-water therapy produces sanitized planting material potentially devoid of soil-borne pests and diseases in the corm and root of plantain, thus improving nutrient and water uptake for the growth and development of plantain.

In addition, pared hot water-treated suckers in the first and second cropping cycles produced more suckers than unpared suckers without hot water treatment. This suggests that hot-water therapy is a vital technique for the disinfection of plantain suckers' for improved plant quality and subsequent regeneration of plantain suckers. This is in consonance with the report of Hauser (2000) that hot-water treatment is an effective method for disinfection of various sizes of suckers without detriment to suckers' germination.

In the mother plant, the length of time taken to first inflorescence emergence was shorter in hot-water treated suckers cultivated in various fertilizer sources and was not significantly ($P > 0.05$) different from one another but different from the control (0 t ha^{-1} + unpared sucker) that took the longest time (273.18 ± 4.50 days) to inflorescence emergence (Table 2). It took 234.95 ± 5.30 days to inflorescence for hot water-treated plantain cultivated with 400 kg ha^{-1} of NPK 15-15-15. This was followed by poultry manure applied at 20 t ha^{-1} and then at 10 t ha^{-1}, pared hot water-treated plantain suckers without fertilizer additive with the following days to first inflorescence emergence as 242.75 ± 3.70, 243.27 ± 3.70, and 249.13 ± 5.80 days in that order (Table 2). In the second cropping cycle, a similar trend was observed where it took the control 277.30 ± 8.00 days to first inflorescence emergence and was significantly different from plantain suckers treated with various fertilizers sources and hot water (Table 2).

In the first cropping cycle (mother plant), the number of bunches $plant^{-1}$ was not significantly ($P > 0.05$) different in hot water-treated plants grown with various sources of fertilizers and the control (Table 3). However, in the second cropping cycle (ratoon), the hot water-treated plantain cultivated with poultry manure at 20 t ha^{1} significantly produced more bunches (2.33 ± 0.20 bunch $plant^{-1}$) than other fertilizer sources and the control (0.83 ± 0.20 bunch $plant^{-1}$). This was followed by hot water-treated pared suckers grown with NPK 15-15-15 applied at the rate of 400 kg ha^{-1} and poultry manure applied at 10 t $ha^{-1,}$ which produced 1.67 ± 0.30 and 1.17 ± 0.20 bunch $plant^{-1}$, respectively (Table 3). In the first cropping cycle (mother plant), the number of fingers produced per bunch in hot water-treated suckers and grown with different fertilizer sources increased significantly ($P < 0.05$) when compared with the control (Table 3). Hot water-treated suckers grown with NPK 15-15-15 applied at the rate of 400 kg ha^{-1} had the highest number of fingers $bunch^{-1}$ (50.62 ± 3.00 fingers $bunch^{-1}$) than poultry manure applied at the rate of 10 and 20 t ha^{-1} with 42.48 ± 1.60 and 48.52 ± 1.80 fingers $bunch^{-1}$, respectively. In the ratoon crop, similar trends were observed in the number of fingers produced per bunch. The highest number of fingers $bunch^{-1}$ was observed when applied NPK 15-15-15 at the rate of 400 kg ha^{-1} (57.37 ± 2.60 fingers $bunch^{-1}$), followed by poultry manure applied at 20 t ha^{-1}, 10 t ha^{-1}, and the least was the control with the values of 51.98 ± 2.00, 44.40 ± 3.20, and 17.73 ± 3.60 in that order (Table 3). The number of hands bunch^{-1} produced by pared plantain suckers treated with hot water and cultivated with various fertilizer sources was significantly ($P < 0.05$) higher than the control. The suckers grown with poultry manure applied at the rate of 20 t ha^{-1} had the highest number of hands per bunch (10.52 ± 0.20) followed by NPK 15-15-15 applied at 400 kg ha^{-1} and the least number of hands per bunch was 7.07 ± 0.80 in the control (Table 3). In the second cropping cycle (ratoon), similar trends were observed (Table 3). The fruit length, fruit weight, and bunch weight of pared hot water-treated suckers grown with various poultry manure produced significantly ($P < 0.05$) more than the control (Table 3). Furthermore, the yield t ha^{-1} of bunches recovered from hot water-treated dichotomous plantain suckers grown with various fertilizer sources produced significantly more bunches per hectare when compared with the control (Table 3). Poultry manure applied at 20 t ha^{-1} produced 24.22 ± 1.00 t ha^{-1} of fruit, NPK 15-15-15 applied at 400 kg ha^{-1} produced 21.50 ± 0.80 t ha^{-1} of fruits, 10 t ha^{-1} of poultry manure gave a yield of 20.51 ± 0.90 t ha^{-1} while the control produced 13.14 ± 1.90 t ha^{-1} of fruits in the first cropping cycle (Table 3). In the second cropping cycle (ratoon plants), hot-water treated dichotomous plantain suckers and fertilizer additives produced significantly ($P < 0.05$) superior yield t ha^{-1} than the control in this order: 20 t ha^{-1} of poultry manure (26.78 ± 1.00), NPK 15-15-15 applied at 400 kg ha^{-1} (23.75 ± 0.70), 10 t ha^{-1} of poultry manure (22.27 ± 0.90) and the untreated control (8.25 ± 1.60). However, pared hot-water treated plantain suckers without fertilizer produced 19.57 ± 0.70 t ha^{-1} of plantain bunches which was not significantly ($P > 0.05$) different from yield (bunch weight) t ha^{-1} in fertilizer applied at 10 t ha^{-1}, but significantly ($P < 0.05$) better than the control (Table 3).

The performance noted in days to flowering/harvest in the first cropping cycle and second cropping cycle of pared hot-water treated plant is attributed to adequate nutrient management, healthy root system, and absence of pests and diseases. This agrees with the report of Banful *et al*. (2008) that a healthy corm and better rooting system in *Musa* promote the absorption of nutrients and gives the higher performance of plantain and bananas.

The non-significance in the number of bunches in the first cropping cycle evaluated in pared hot-water and unpared treated plants could be due to inherent characteristics of reversion among the cultivars and the exhibition of incomplete penetrance by dichotomous plantain cultivars. This observation agrees with Ekanem and Brisibe (2018) that inflorescence developmental polymorphism occurs in dichotomous plantain (*Musa* spp. AAB). The higher number of fingers, hands, longest fruit length, number of fruit/bunch weight, and superior yield were noted with pared hot-water treated plants than the control in the mother plant and ratoon crops.

Worthy of note is that PPS + HW + PM at 20 t ha^{-1} (pared) had superior yield t ha^{-1} with 24.22 ± 1.00 and 26.78 ± 1.00 in the first and second cropping cycles. This suggests a better rate and proper mineralization of organic sources applied. It simply reaffirmed the report of Kannaiyan (1999) that the nutrient supply system of the soil, native or applied sources, governs the yield and uptake of nutrients. This also supports Ndukwe *et al.* (2011) that proper mineralization of organic sources enhanced superior yield.

Table 2 Effect of pared sucker and hot water therapy on the vegetative growth of dichotomous plantain in various fertilizer sources in Utisol, southeastern Nigeria

Treatment	Plant height (cm)	Plant girth (cm)	Number of suckers	Functional leaves at bunch emergence	Functional leaves at harvest	Number of days to first inflorescence emergence
First cropping cycle (mother plant), 2019						
PPS + HW + PM at 10 t ha^{-1}	276.83 ± 6.10^b	58.55 ± 1.20^a	7.50 ± 0.20^b	15.45 ± 0.20^a	3.82 ± 0.20^b	243.27 ± 3.70^b
PPS + HW + PM at 20 t ha^{-1}	304.83 ± 8.40^a	62.44 ± 3.10^a	9.83 ± 0.70^a	15.82 ± 0.20^a	4.45 ± 0.20^a	242.75 ± 3.70^b
PPS + HW + NPK 400 kg ha^{-1}	280.00 ± 7.10^b	58.01 ± 0.80^a	7.67 ± 0.60^b	15.75 ±.0.20^a	4.31 ± 0.30^{ab}	234.95 ± 5.30^b
PPS + HW + PM at 0 t ha^{-1}	256.33 ± 6.20^c	55.36 ± 1.20^{ab}	5.67 ± 0.90^c	14.66 ± 0.40^b	3.24 ± 0.50^c	249.13 ± 5.80^b
0 t ha^{-1} + unpared (control)	250.33 ± 7.60^c	48.60 ± 3.20^b	3.50 ± 0.20^d	13.66 ± 0.30^b	2.31 ± 0.20^a	273.18 ± 4.50^a
LSD ($P < 0.05$)	21.54	6.39	1.64	0.80	0.83	22.10
F-test	S	S	S	S	S	S
Second cropping cycle (ratoon plant), 2020						
PPS + HW + PM at 10 t ha^{-1}	286.33 ± 4.80^a	59.98 ± 1.20^a	8.17 ± 0.40^b	15.57 ± 0.20^a	4.17 ± 0.20^{ab}	237.33 ± 7.50^a
PPS + HW + PM at 20 t ha^{-1}	308.00 ± 7.00^a	65.60 ± 1.50^a	10.33 ± 0.30^a	15.93 ± 0.20^a	5.00 ± 0.10^a	242.20 ± 7.10^a
PPS + HW + NPK 400 kg ha^{-1}	287.00 ± 7.70^a	58.83 ± 1.00^a	7.83 ± 0.20^b	15.75 ± 0.10^a	4.50 ± 0.20^a	251.20 ± 7.30^{ab}
PPS + HW + PM at 0 t ha^{-1}	266.00 ± 6.20^a	56.08 ± 1.10^a	5.50 ± 0.20^c	14.82 ± 0.20^a	3.50 ± 0.30^b	261.60 ± 7.00^{bc}
0 t ha^{-1} + unpared (control)	217.83 ± 3.90^b	41.65 ± 3.30^b	3.00 ± 0.60^d	10.94 ± 2.20^b	2.33 ± 0.50^c	277.30 ± 8.00^c
LSD ($P < 0.05$)	59.43	11.52	1.16	2.95	0.90	27.51
F-test	S	S	S	S	S	S

Note: Values are mean ± standard error. ^{a,b,c} Values with the same alphabet in each column at a specific cropping cycle are not significantly different according to Fisher's least significant difference (FLSD). S = significant at 5% probability, PPS = pared plantain sucker, HW = hot water, PM = poultry manure.

Table 3 Effect of pared sucker and hot water therapy on yield components of dichotomous plantain in various fertilizer sources in Utisol, southeastern Nigeria

Treatment	Number of bunches plant^{-1}	Number of fingers bunch^{-1}	Number of hands bunch^{-1}	Fruit length (cm)	Fruit weight (g)	Bunch weight (kg)	Yield t ha^{-1}
First cropping cycle (mother plant), 2019							
PPS + HW + PM at 10 t ha^{-1}	1.50 ± 0.30	42.48 ± 1.60^{ab}	9.55 ± 0.40^{a}	20.73 ± 0.70^{bc}	316.13 ± 18.00^{a}	12.50 ± 0.50^{b}	20.51 ± 0.90^{b}
PPS + HW + PM at 20 t ha^{-1}	1.50 ± 0.20	48.52 ± 1.80^{ab}	10.52 ± 0.20^{a}	24.17 ± 1.80^{a}	336.25 ± 8.50^{a}	14.83 ± 0.60^{a}	24.22 ± 1.00^{a}
PPS + HW + NPK 400 kg ha^{-1}	1.50 ± 0.30	50.62 ± 3.00^{a}	9.93 ± 0.50^{a}	22.05 ± 0.70^{ab}	328.15 ± 10.70^{a}	13.12 ± 0.50^{ab}	21.50 ± 0.80^{b}
PPS + HW + PM at 0 t ha^{-1}	1.00 ± 0.00	38.42 ± 3.10^{b}	9.12 ± 0.30^{a}	20.17 ± 0.60^{bc}	316.12 ± 16.50^{a}	11.55 ± 0.40^{b}	19.22 ± 1.70^{b}
0 t ha^{-1} + unpared (control)	1.00 ± 0.00	27.28 ± 3.80^{c}	7.07 ± 0.80^{b}	17.68 ± 1.30^{c}	159.32 ± 33.00^{b}	8.01 ± 1.10^{c}	13.14 ± 1.90^{c}
LSD ($P < 0.05$)	0.72	8.53	1.44	3.32	58.68	2.09	3.48
F-test	NS	S	S	S	S	S	S
Second cropping cycle (ratoon plant), 2020							
PPS + HW + PM at 10 t ha^{-1}	1.17 ± 0.20^{bc}	44.40 ± 3.20^{bc}	9.65 ± 0.40^{ab}	21.23 ± 0.80^{ab}	328.93 ± 1.60^{a}	13.50 ± 0.50^{ab}	22.27 ± 0.90^{ab}
PPS + HW + PM at 20 t ha^{-1}	2.33 ± 0.20^{a}	51.98 ± 2.00^{ab}	10.74 ± 0.30^{a}	24.42 ± 1.90^{a}	343.60 ± 11.20^{a}	15.17 ± 0.60^{a}	26.78 ± 1.00^{a}
PPS + HW + NPK 400 kg ha^{-1}	1.67 ± 0.30^{b}	57.37 ± 2.60^{a}	10.50 ± 0.30^{a}	22.62 ± 0.80^{ab}	345.03 ± 8.00^{a}	13.87 ± 0.40^{ab}	23.75 ± 0.70^{a}
PPS + HW + PM at 0 t ha^{-1}	1.50 ± 0.20^{b}	39.73 ± 3.50^{c}	9.28 ± 0.40^{b}	18.44 ± 0.40^{b}	306.02 ± 14.00^{a}	12.18 ± 0.50^{b}	19.57 ± 0.70^{b}
0 t ha^{-1} + unpared (control)	0.83 ± 0.20^{c}	17.73 ± 3.60^{d}	4.35 ± 0.90^{c}	12.65 ± 2.60^{c}	106.28 ± 21.20^{b}	4.83 ± 0.90^{c}	8.25 ± 1.60^{c}
LSD ($P < 0.05$)	0.63	9.18	1.52	4.65	41.34	1.70	2.88
F-test	S	S	S	S	S	S	S

Note: Values are mean ± standard error. ^{a,b,c} Values with the same alphabet in each column at a specific cropping cycle are not significantly different according to Fisher's least significant difference (FLSD). NS = not significant, S = significant at 5% probability, PPS = pared plantain sucker, HW = hot water, PM = poultry manure.

Interestingly, pared hot-water treated plants with zero fertilization (PPS + HW + PM at 0 t ha^{-1}) perform lower than pared hot-water treated plants with additives (PPS + HW + PM at 10 t ha^{-1}, PPS + HW + PM at 20 t ha^{-1} and PPS + HW + NPK 15:15:15 at 400 kg t ha^{-1}) but perform better than the control. This is a clear indication that pared hot water-treated suckers had good growth and development as initial nematode infection had been eliminated from suckers, but without appropriate integrated nutrient management, the crop may not be able to attain its full genetic yield production potential. This is in line with the independent reports of Roy *et al.* (2006) and Agbede (2015) that integrated management approaches could enhance crop production. The low performance recorded in growth and yield-related components in control (0 t ha^{-1} + unpared without hot water treatment) on the mother plant and ratoon could be attributed to factors such as low soil fertility, the presence of pathogens, particularly plant-parasitic nematodes with their attendant poor yields and consequent economic losses. It is worthy of note that yields increased by 31.63–45.74% in the first cropping cycle (mother plant) and further increased by 57.84–65.26% in the second cropping cycle (ratoon) tonnes per hectare. Perhaps, the combined integrated management options of crop nutrition and nematodes could have encouraged superior yield in the treated plants. This corroborates with the findings of Banful *et al.* (2008), who reported that the bunch weight and yield of untreated plantain suckers without hot-water treatment were lower than those treated with boiled water for 30 seconds before planting. This is also similar to the report of Gold *et al.* (1999) that associated low soil fertility and nematode infestation with a decline in plantain could subsequently cause tremendous yield loss if not managed. It also supports the report of Aravind *et al*. (2010) that infestation by nematodes can reduce the development of banana bunches and fruit yield. Coyne *et al.* (2013), in a series of pathogenicity trials, reported that yield reduction of plantain (*Musa* spp., AAB genome) cv. Agbagba by 33.30–50.80% in the first cropping cycle and consistent reduction throughout subsequent cropping cycles tend to support the present findings.

Plant-parasitic nematodes in four genera detected and identified: *Meloidogyne, Pratylenchus, Helicotylenchus,* and *Radopholus* were in the soil before planting in the 2019 season. The quantities of these nematode genera recovered from 250 cm^3 of soil varied across the plots before treated suckers were planted, but these were not significantly different from one another (Table 4). The population of nematodes recovered from soil ranged as follows: *Meloidogyne* (45.00 ± 5.00 to 65.00 ± 7.90); *Pratylenchus* (35.83 ± 5.20 to 56.25 ± 9.30); *Helicotylenchus* (37.50 ± 5.70 to 52.50 ± 23.90); *Radopholus* (5.83 ± 1.50 to 20.00 ± 7.90); *Hoplolaimus* was not present in the nematodes recovered from soil (Table 4). The final plant-parasitic nematodes population recovered from 10 g of plantain root and 250 cm^3 of soil in the first crop cycle (mother plant) reduced significantly ($P < 0.05$) in pared hot water-treated plantain sucker cultivated in various fertilizer sources when compared with the control. The population of nematode in treated plants ranged from 2,738.30 ± 175.70 to 3,966.70 ± 354.60 for *Meloidogyne,* 1,741.70 ± 220.10 to 2,167.50 ± 207.00 for *Pratylenchus,* 1,319.20 ± 104.30 to 1,653.30 ± 187.60 for *Helicotylenchus*, and 310.00 ± 101.30 to 1,126.70 ± 202.60 for *Radopholus* compared with their various controls of the identified nematodes 7,155.00 ± 479.70, 5,293.30 ± 993.80, 3,866.70 ± 679.80, and 1,387.50 ± 317.70 in that order for 2019 cropping season (Table 4).

Table 4 Evaluation of pared sucker, hot water therapy, and fertilizer sources on nematode reproduction in soil and root of pared dichotomous plantain cultivars in Ultisol, southeastern Nigeria

Treatment	*Meloidogyne*	*Pratylenchus*	*Helicotylenchus*	*Radopholus*	*Hoplolaimus*
Initial nematode populations in 250 cm^3 soil, before planting, 2019					
PPS + HW + PM at 10 t ha^{-1}	65.00 ± 7.90	41.67 ± 4.80	45.83 ± 13.80	5.83 ± 1.50	-
PPS + HW + PM at 20 t ha^{-1}	51.70 ± 10.30	56.25 ± 9.30	44.17 ± 6.10	20.00 ± 7.90	-
PPS + HW + NPK 400 kg ha^{-1}	45.00 ± 5.00	45.00 ± 5.20	37.50 ± 5.70	15.00 ± 2.60	-
PPS + HW + PM at 0 t ha^{-1}	58.30 ± 13.70	40.00 ± 7.70	40.00 ± 13.90	10.00 ± 1.80	-
0 t ha^{-1} + unpared (control)	60.00 ± 12.60	35.83 ± 5.20	52.50 ± 23.90	11.67 ± 6.00	-
LSD ($P < 0.05$)	349.22	18.62	41.36	13.15	
F-test	NS	NS	NS	NS	
Nematode population from 10 g root and 250 cm^3 soil, first cropping cycle (mother plant) at harvest, 2019					
PPS + HW + PM at 10 t ha^{-1}	2,803.30 ± 285.60^b	1,880.00 ± 230.00^b	1,345.00 ± 164.10^b	310.00 ± 101.30^c	-
PPS + HW + PM at 20 t ha^{-1}	2,738.30 ± 175.70^b	1,741.70 ± 220.10^b	1,319.20 ± 104.30^b	341.70 ± 84.90^c	-
PPS + HW + NPK 400 kg ha^{-1}	3,060.80 ± 198.60^b	2,167.50 ± 207.00^b	1,644.20 ± 107.00^b	759.20 ± 116.90^{bc}	-
PPS + HW + PM at 0 t ha^{-1}	3,966.70 ± 354.60^b	2,090.00 ± 304.30^b	1,653.30 ± 187.60^b	1,126.70 ± 202.60^b	-
0 t ha^{-1} + unpared (control)	7,155.00 ± 479.70^a	5,293.30 ± 993.80^a	3,866.70 ± 679.80^a	1,387.50 ± 317.70^a	-
LSD ($P < 0.05$)	1,396.90	1,406.50	904.54	561.17	
F-test	S	S	S	S	

Table 4 Cont.

Treatment	***Meloidogyne***	***Pratylenchus***	***Helicotylenchus***	***Radopholus***	***Hoplolaimus***
Nematode population in 10 g root and 250 cm^3 soil, second cropping cycle (ratoon plant) at vegetative stage, 2019					
PPS + HW + PM at 10 t ha^{-1}	1,555.00 ± 96.70^b	1,356.70 ± 137.30^b	2,270.80 ± 325.30^b	313.30 ± 74.60^d	90.80 ± 12.70
PPS + HW + PM at 20 t ha^{-1}	1,518.30 ± 74.00^b	1,278.30 ± 82.40^b	2,349.60 ± 240.50^b	363.30 ± 71.00^{cd}	137.90 ± 27.10
PPS + HW + NPK 400 kg ha^{-1}	1,817.50 ± 119.90^b	1,294.20 ± 77.50^b	3,055.80 ± 276.60^b	790.80 ± 104.90^{bc}	116.70 ± 20.50
PPS + HW + PM at 0 t ha^{-1}	2,208.30 ± 192.10^b	1,155.00 ± 54.10^b	3,180.00 ± 382.90^b	1,093.30 ± 149.70^{ab}	123.30 ± 19.10
0 t ha^{-1} + unpared (control)	3,700.00 ± 472.30^a	1,746.70 ± 184.40^a	7,733.30 ± 1,317.40^a	1,285.80 ± 255.60^a	122.50 ± 11.20
LSD ($P < 0.05$)	720.48	348.79	1,807.10	434.96	57.83
F-test	S	S	S	S	NS
Nematode population in 10 g root and 250 cm^3 soil, second cropping cycle (ratoon plant) at harvest, 2020					
PPS + HW + PM at 10 t ha^{-1}	3,555.00 ± 186.30^b	2457.70 ± 175.10^b	3183.10 ± 222.00^c	444.10 ± 70.20^{bc}	128.00 ± 12.70
PPS + HW + PM at 20 t ha^{-1}	3,518.30 ± 181.20^b	2267.30 ± 185.20^b	3229.80 ± 205.10^c	240.30 ± 60.20^c	162.50 ± 17.10
PPS + HW + NPK 400 kg ha^{-1}	3,817.50 ± 170.00^b	2404.20 ± 187.30^b	3985.80 ± 217.90^c	691.50 ± 94.20^b	144.50 ± 10.50
PPS + HW + PM at 0 t ha^{-1}	3,208.30 ± 202.20^b	3265.00 ± 169.70^b	5460.50 ± 412.30^{bc}	1,143.30 ± 116.30^a	135.50 ± 8.10
0 t ha^{-1} + unpared (control)	15,700.00 ± 542.10^a	4,746.70 ± 191.50^a	12,733.30 ± 527.40^a	1,480.80 ± 148.20^a	181.50 ± 8.20
LSD ($P < 0.05$)	933.70	748.10	2,152.00	428.77	62.83
F-test	S	S	S	S	NS

Note: Values are mean ± standard error. ^{a,b,c} Values with the same alphabet in each column at a specific cropping cycle are not significantly different according to Fisher's least significant difference (FLSD). Analysis of nematode data undertaken on log10 (X + 1) transformed. Back-transformed means presented. NS = not significant, S = significant at 5% probability, PPS = pared plantain sucker, HW = hot water, PM = poultry manure.

In the second cropping cycle (ratoon plant), similar trends were observed with the emergence of another nematode genus, *Hoplolaimus,* recovered from 10 g of root and 250 cm^3 of soil sub-sample. The population of *Hoplolaimus* was not significantly (P > 0.05) different across all treatments in the ratoon plants in the 2019 cropping season (Table 4). Also, in 2019, plant parasitic nematodes increased significantly (P < 0.05) in ratoon plants that emerged from untreated (control) suckers compared with the ratoon plants from suckers treated with hot water and fertilizer additives. In the hot water-treated ratoon plants, the population of *Meloidogyne* ranged from 1,518.30 ± 74.00 to 2,208.30 ± 192.10, *Pratylenchus* ranged from 1,155.00 ± 54.10 to 1,356.70 ± 137.30), *Helicotylenchus* ranged from 2,270.80 ± 325.30 to 3,180.00 ± 382.90, *Radopholus* ranged from 313.30 ± 74.60 to 1,093.30 ± 149.70, and *Hoplolaimus* ranged from 90.80 ± 12.70 to 137.90 ± 27.10 while in the control, plant-parasitic nematodes population was 3,700.00 ± 472.30, 1,746.70 ± 184.40, 7,733.30 ± 1,317.40, 1,285.80 ± 255.60, and 122.50 ± 11.20 in that order (Table 4).

At harvest, in the 2020 cropping season, nematode reproduction in the ratoon plants varied across nematode genera. *Meloidogyne* recovered from 10 g root and 250 cm^3 of soil significantly (P < 0.05) increased in population compared with ratoon plants derived from hot water-treated suckers with fertilizer applied at different rates (Table 4). Similar trends were observed in the population of other nematode genera (*Pratylenchus, Helicotylenchus*, and *Radopholus*) recovered from root and soil except in the population of *Hoplolaimus* where reproduction was not significantly (P > 0.05) different in both control and the ratoon plant from the treated suckers (Table 4).

Furthermore, four different plant-parasitic nematodes were detected in low quantities at the initial sampling of the plots during the study before planting. The presence of these nematode genera; *Meloidogyne, Pratylenchus, Helicotylenchus*, and *Radopholus* suggest a threat to yield of inflorescence dichotomous plantain when strategic management is not in place. This observation is consistent with Speijer *et al.* (2001), who reported the predominance of *Radopholus similis, Pratylenchus coffeae, Hoplolaimus pararobustus, Helicotylenchus multicinctus,* and second-stage juvenile *Meloidogyne* spp. representing 46, 50, 64, and 68% of sampled sites, respectively in the southern part of Nigeria. In the first cropping cycle (mother plant), *Hoplolaimus* was not present in the initial sampling but at the end of the first cycle (harvest), *Hoplolaimus* emerged in low quantities. It is possible that the nematode was in a state of hibernation as the conditions were unfavorable for survival.

The data indicated that pared hot-water treated plants perform better in all the parameters evaluated than unpared non-treated plants (control). This implies that hot-water-treated plants may have reduced the population of plant parasitic nematodes, thereby promoting the availability of healthy roots for nutrient uptake. It also confirmed that hot-water-treated suckers resulted in the reduction of nematodes in regenerated and ratoon crops, as reported by Hauser (2007). The reduction of plant-parasitic nematode population among pared hot-water treated plants may also be due to pre-treated suckers with hot water before planting and amendment of soil environment with adequate nutrients. This implies that hot-water treatment is essential therapy for the sanitation of propagules before planting and establishment of plantain plantation. It corroborates the reports of Prasad and Seshu Reddy (1994) as well as Oso (2017) that the use of pest-free propagules in the establishment of plantain promotes a healthy rooting system for better growth and yields.

CONCLUSION

The combined applications of hot-water therapy and fertilizer additives reduced the population of nematodes and promoted growth and yields in dichotomous plantains. These findings will go a long way to create awareness among local farmers in southeastern Nigeria and the global community to utilize the cost-effective strategy in managing nematodes that may infect dichotomous plantain propagules. Thus, using poultry manure at 20 t ha^{-1} to pared hot-water treated plants is recommended to increase dichotomous plantain yield and sustainability for all-year-round food availability and security.

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