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Research Paper

Effects of Poultry Litter on Establishment of Cocoa Seedlings and Plantain infected with Parasitic Nematodes

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Abstract: *The potential of poultry litter to ameliorate nematode parasitism's induced dieback of cocoa (Theobroma cacao) seedlings and toppling of plantain (Musa spp.) was evaluated in nursery and field experiments between 2005 and 2012. The experiments were conducted to determine if applying poultry litter as soil amendment suppressed parasitic nematode populations and improved soil and plant health compared to carbofuran treatments. Poultry litter (PL) significantly ($p \leq 0.05$) stimulated growth of cocoa seedlings, mitigated root galling and suppressed population densities of plant-parasitic nematodes five months after planting in the nursery. PL treatment with or without carbofuran at 0.3 and 0.4 t/ha led to 100% establishment of cacao in the field while the un-amended control had 65% survival ($p<0.05$). These surviving seedlings in control plots were stunted and unthrifty, with above-ground hypocotyl swellings twenty weeks after transplanting. Significant reduction in the percentages of toppled plantains and necrotic root damage in PL-amended plots was observed compared to the un-amended plots. The addition of poultry litter had beneficial effects on the chemical properties of the soil, fungal and bacteria population densities, contrary to the adverse effects of carbofuran treatments on the environment. It is therefore concluded that the use of poultry litter as soil amendment not only enhanced soil fertility but also increased microbial diversity, depressed population densities of plant-parasitic nematodes, and ultimately increased crop health and yields with improved environment.*

Keywords: Cocoa establishment, soil amendment, parasitic nematodes, carbofuran, plantain, crop health

Introduction

Cocoa (*Theobroma cacao* Linnaeus) and plantain (*Musa* spp. Linnaeus) play important roles in the agricultural sector of the Nigerian economy. Cacao and plantain intercropping, where the latter is used as shade crop, has been the usual practice of the low-income cocoa farmers in Nigeria, West and Central Africa [1-2]. The two crops contribute significantly to food security, employment, diversification of income sources in rural and urban areas, and contribution to the gross national product [3]. Nigeria is the world's fourth largest cocoa producer, after Cote d'Ivoire, Ghana and Indonesia, with an estimated production of 363, 610 metric tons of cocoa in 2009 [4]. In the same vein, plantain occupies a prime place as a staple in the diet of the Nigerian populace and is grown in 52 countries with world production of 33 million metric tons [5]. However, in the past years cocoa and plantain production has witnessed a downward trend because of pests and disease, ageing trees and falling soil fertility. Cocoa and plantain production increased by new plantings, but a build-up of plant-parasitic nematodes and deteriorating soil fertility have caused many farmers to lose heart and abandon the crops.

Plant-parasitic nematodes have caused losses in cocoa and plantain around the world including dieback with chlorotic symptoms, sudden death, retardation of cocoa seedlings growth in nurseries and young plantations [6,7], damage of roots and corm of plantain, rotting of the root system and plant toppling resulting in yield reduction [8,9]. Regrettably, Cacao genotypes and edible Musa varieties currently grown by many farmers in Nigeria and West Africa are susceptible to nematode diseases [10-13].

Although the use of clean planting material obtained through corm paring and / or hot water treatment of plantain suckers [14] and soil sterilization for raising cocoa seedlings [15] are attractive management options available to the small-scale farmers in the nursery, there is the need to control the nematodes in established plantations on the field. While chemical control can reduce the impact of nematode infestations [16,15], effective nematicides are too expensive for resource-poor farmers and often results in a noticeable decrease of many soil biological processes, notably by suppressing predators and parasites of these nematodes [17], contamination of aquifers [18] and negative shifts such as health hazards, environmental pollution and potential atmospheric ozone depletion [19]. However, soils, especially those with a low microbial population, are more vulnerable to reinvasion of pathogens even after fumigation [20]. Nematode populations might become sensitized or resistant to repeated applications of nematicides [21]. With increased social and legislative pressure to restrict the use of Methyl Bromide, an effective soil fumigant used extensively to control a broad spectrum of pests [22] and the recent ban of carbofuran on cocoa and plantain [23-24], there is the need to evaluate alternative approaches for management of plant-parasitic nematodes.

Organic soil materials that are generally used for increasing agricultural productivity have been shown to have a suppressive effect on plant-parasitic nematodes [25-27]. Poultry is an important segment of agricultural production in Nigeria [28] and the industry generates enormous quantities of wastes in form of manure or litter that require environmentally acceptable means of disposal. Disposal by using it as soil amendments in agricultural land is a desirable option. Litter, if used appropriately, can be substituted for mineral fertilizers [29] . This research was conceived to study the effect of poultry litter soil amendment on plant-parasitic nematodes of cacao and plantain during the first four years of cacao establishment in the field. The hope is that the current level of frustration faced by farmers through poor cocoa seedlings establishment, toppling and reduced yield of plantain caused by plant-parasitic nematodes and declining soil fertility can be ameliorated.

Material and Methods

Nursery and field experiments were carried out at the Cocoa Research Institute of Nigeria (CRIN) in Ibadan, Nigeria. Ibadan lies between the latitude 7^0 30' N and longitude 3^0 54' E at an altitude of 200 m above sea level. It is located in the tropical rain forest ecosystem with mean solar radiation of 18mj/m^2/day and an annual average rainfall of 2000 mm with a bimodal pattern.

Top soil normally used for raising cacao seedlings in the nursery was collected in bulk from the CRIN research field naturally infested with plant parasitic nematodes. It was thereafter thoroughly mixed and distributed into 2-litre black polyethylene bags hereafter called pots - the type normally used for raising cacao seedlings commercially. Poultry litter used in the experiment was collected from coops with good farm sanitation and air-dried. Analysis was carried out to determine the macro and micro nutrient content of the poultry litter [30]. Soil samples were analysed for physico-chemical properties and nematodes assay [31-32].

The nursery experiment was set as a randomized complete block design of a 4x3 factorial arrangement with four rates of poultry litter (0, 5, 7, 10g/pot) and three rates of carbofuran (0, 1, 2g/pot) comprising twelve treatments from the set-up. Each treatment had six replications. The different treatment combinations were mixed with top soil and kept moist 14 days before cacao seeds were planted. Three seeds of *T. cacao* cv. F_3 Amazon were planted in each pot and later thinned to one per pot one week after emergence. Weeding and watering of cacao seedlings were carried out. The experiment was terminated five months after planting of cacao seeds.

After sowing, regular observations were made monthly to record data on possible phytotoxic effects of any treatment on plants and disease symptoms. Plant height, stem girth and number of leaves per plant were recorded. Leaf areas were determined per plant using electronic leaf meter terminally in the lab. At the end of the nursery experiment, five months after planting, assessment for root galling of cocoa seedlings was done on six randomly selected samples per treatment. To assess infection by root-knot nematodes, the roots were carefully freed of soil, washed under a gentle stream of cool tap water, mopped and galls counted using a hand lens at 3-5 X magnification. Root galling was rated using the 0-5 gall index scale [33-34]. Nematode eggs and juveniles were collected from each root system using sodium hypochlorite method (NaOCl) of Hussey and Barker [35] for estimation of nematode population in the roots of the cocoa seedlings. Aliquots of 100g sub-sample soil from each pot were assayed for population of nematodes using the Whitehead & Hemming [36] tray modification of Baermann [37] technique as described by Coyne et al. [32].

The field experiment was conducted over four crop cycles on the False horn plantain (*Musa* spp. L., AAB – group cv. Agbagba) as intercrop (and shade crop) planted with cacao (*T. cacao* cv. F_3 Amazon) in Zone Six of CRIN research farm. The experiment was set as a randomized complete block design of a 4x3 factorial arrangement with four rates of poultry litter (0, 0.2, 0.3, 0.4t/ha) and three rates of carbofuran (0, 1.25, 2.50kg a.i/ha). Each treatment had 3 replications. The poultry litter in the relevant treatments were incorporated into the soil by mixing the litter with the soil at planting time and again at 3, 6 and 9 months after planting, while the carbofuran treatments were applied by mixing it with soil at planting and repeated after three months around the plants. There were twelve treatments in all. Healthy sword suckers of plantain of approximately uniform size (50-60cm tall, 30-40cm pseudostem girth) pared to remove lesions was planted at a spacing of 3x3m. The suckers were planted in holes 40cm deep and 30cm wide and firmed up with soil. Cocoa seedlings were planted four weeks later at the same spacing. The unit plot size was 31.5m^2 accommodating 8 plant stands, each of the cacao and plantain. Weeding of the entire plots were done at three months intervals, while mulching and watering of cocoa seedlings (during dry season) were done at the first year of establishment.

Twenty-four soil samples were taken from each experimental unit with a soil auger at 15cm depth within a 25cm radius from the base of cacao stems. Root samples were taken only from plantain plants at the time of harvesting from an excavation of 20 x 20 x 20cm extending outward from the corm of the plant [38]. Soil and root samples were transported in plastic bags to the laboratory for assessment, extraction, identification and quantification of nematodes [38, 32]. Counts of bacteria and fungi were determined by serially plating the soil-litter suspensions and controls onto selective media in 9-cm-diameter petri dishes with a Spiral Plater (Spiral Systems, Bethesda, MD). Soil (2 g) was weighed and placed into a whirlpac blender bag with 18 ml of deionized sterile water for the first dilution. Each sample then was placed in a Stomacher blender (Seward Medical, London) and agitated for 30 seconds. Further dilutions were made in a laminar flow hood and the suspensions were plated onto selective media for microbial enumeration [39] .

Survival counts of plantain and cocoa were recorded at 6 months after planting (MAP). Aerial growth data measured on each plant included plant height (PH, m), pseudostem circumference of plantain at soil level (PC, cm), stem girth of cacao (SG, cm), number of leaves (NL) of cacao and that of mother plant of plantain at flowering and at harvest of plantain, number of days (DF1) from field planting of plantain to first flowering, number of days (DF2) from first to second flowering, number of suckers (NS), and height of the tallest suckers (HS, m). In addition, leaf area (LA, cm^2) of cacao was determined using electronic leaf area metre, while that of plantain was calculated according to Kumar *et al.* [40] by counting the number of leaves (N), measuring the length (L) and breadth (B) of the third leaf from the top and calculating the leaf area as follows: TLA = L x B x 0.80 x N x 0.662. At harvest of plantain, records were taken on the weight of bunches (WB, kg) and rachis (WR, kg), number of hands (NH) and fingers (NF) per bunch.

Nematode population densities were log10(x + 1) transformed and percentage data were square-root transformed prior to analysis [41] . Analyses of variance (ANOVA) were carried out to test for main effects and interactions. Pre-planned comparisons between treatment combinations were tested with linear contrasts. Regression analyses were used to develop linear models relating nematode numbers and rate of poultry litter applications to cacao and plantain growth. All analyses were performed using GENSTAT (version 7.1, VSN International Ltd., Lawes Agricultural Trust, Hempstead, UK).

Results and Discussion

The nutrient content (%) of poultry litter that was used to amend soil was Nitrogen 3.24, Carbon 27.9, Phosphorus 1.86, Potassium 0.05, Calcium 1.40, Magnesium 0.64, Sodium 0.02, Manganese 0.08, Iron 0.10, Copper 0.09 and Zinc 0.04. Cocoa seedlings in the poultry litter treatment combinations were healthier compared with un-amended pots. Poultry litter amendment and their interactions significantly improved seedling growth and establishment as measured by plant height, shoot weight, root weight and stem girth. Increasing rate of poultry litter applied resulted in a linear increase in plant height of the cocoa seedlings in nematode-infested soil (Figure 1). In addition, Poultry litter amendment and their interactions had significant suppressive effect on nematode populations (Figure 2). This result was consistent with the report of Riegel and Noe [42] showing that the application of litter 14 days before planting was optimal for effects on nematode population densities. Plant height, leaf area, dry shoot and root weights of cacao seedlings were all stimulated by the addition of litter in *M. incognita* infested soil. Agronomic studies on the plant growth enhancing effects of poultry litter have shown an increase in the stem and leaf biomass of plants [43]. Phosphorus uptake is enhanced by the application of poultry litter, and this could be attributed to the greater leaf biomass yield in poultry litter-treated soil [43].

Poultry litter at 7 and 10g/pot alone or combined with carbofuran consistently reduced cacao root galling and the nematode population densities. Stunted growth, chlorosis, reduction in leaf size, and wilting of cacao seedlings were observed in the control. This was in agreement with observations by previous workers [44-45, 13]. The addition of poultry litter to soil leads to a better environment for the growth of plant roots. This enhances the utilization of soil nutrients, as a consequence of which the nematode damage might have been markedly reduced [46]. A significant increase in root mass of plants in soil amended with poultry litter and subsequent decrease in number of nematodes observed in this experiment may be responsible for the increased growth of the cacao seedlings. This is in agreement with previous report [46] that such decrease means fewer disturbances to the seedlings resulting in an unhindered growth.

There was 100% survival of cacao plants six months after transplanting in the poultry litter-amended plots in the field as against 65% survival in un-amended plots in this study. Subsequent growth of cacao in the poultry litter amended plots revealed the manurial and nematicidal potential of the litter (Table 1). Cacao seedlings parasitized by the nematode in un-amended plots began to show

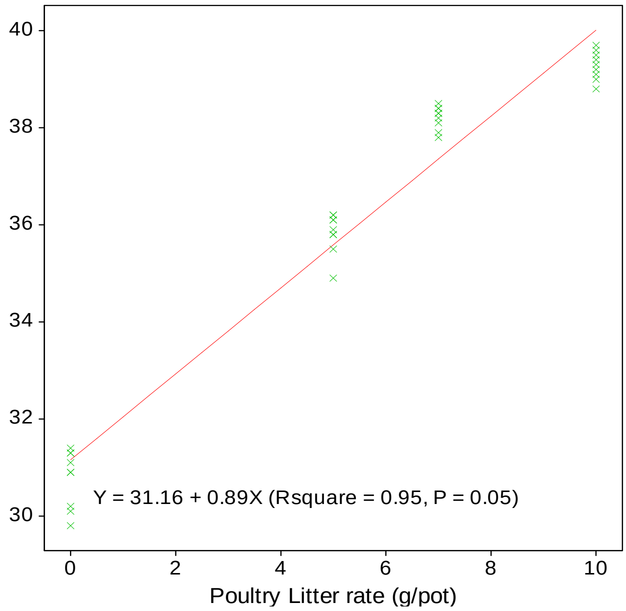

Figure 1: Influence of poultry litter applications at different rates on plant height of nematode-infested cacao seedlings*

* Each asterisk is the mean of 6 replications

Transformed data [$\log_{10}(x+1)$] used in statistical analysis, back-converted means of *M. incognita* second-stage juveniles/100g of soil shown. chlorotic symptoms and leaf wilting 8 weeks after transplanting. When the wilted leaves dropped from the stem, new leaves emerged from the base of the plant (Figure 3). Twelve weeks after transplanting, some of the cacao seedlings had died back from the meristematic bud to the lower leaves, permanently wilted with the leaves dried up and remained hanging (Figure 4).

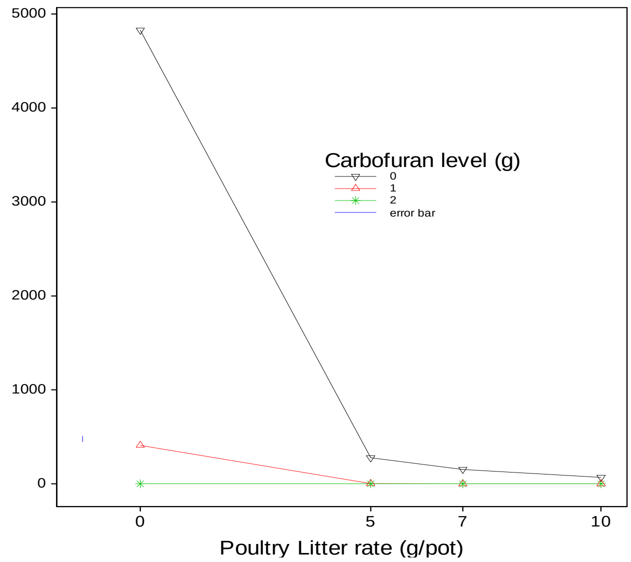

Figure 2: Effects of poultry litter and carbofuran soil amendments on the soil populations* of *Meloidogyne incognita* in infested cacao seedlings in the nursery

***Table 1**

Effects of poultry litter and carbofuran soil amendments on the growth of cacao in the field naturally infested with plant-parasitic nematodes

Treatments	Plant height[1] (cm)	Stem girth[1] (cm)	Number of Branches[1]	Number of Leaves[1]	Leaf area[1] (cm^2)
PL at 0.4t/ha	252.3a	4.38a	33.8a	342.8a	246.3a
PL at 0.4t/ha + C at 2.50kg a.i./ha	252.7a	4.39a	32.3a	341.7a	246.7a
PL at 0.4t/ha + C at 1.25kg a.i./ha	253.3a	4.39a	32.8a	340.8a	246.3a
PL at 0.3t/ha	228.7c	3.98c	24.3b	256.3b	224.3b
PL at 0.3t/ha + C at 2.50kg a.i./ha	234.0b	4.03b	24.3b	257.0b	224.3b
PL at 0.3t/ha + C at 1.25kg a.i./ha	234.7b	4.05b	25.0b	257.0b	224.7b
PL at 0.2t/ha	157.0d	3.15d	19.7c	154.0c	143.7c
PL at 0.2t/ha + C at 2.50kg a.i./ha	155.3d	3.17d	19.7c	152.3c	143.7c
PL at 0.2t/ha + C at 1.25kg a.i./ha	155.3d	3.12d	19.7c	152.7c	143.3c
C at 2.50kg a.i./ha	131.7e	2.90e	12.0d	105.0d	120.3d
C at 1.25kg a.i./ha	101.3f	2.10f	6.8e	67.3e	91.7e
Control (no amendments)	79.7g	1.81g	4.3f	44.0f	66.7f

PL = Poultry litter.
C = Carbofuran.
[1]Means followed by the same letter in the same column do not differ significantly according to Fisher's LSD test (5%).

According to Sharma and Sher [47], when the dieback conditions occur, the trees die down to their roots, which remain alive and send up shoots in the following growing season. The syndrome of sudden death disease is permanent wilting, the green leaves suddenly turn yellow and brown, and then dry up to remain hanging. Jimenez-Saenz [48] and Sharma and Sher [47] associated the occurrence of sudden death with root knot nematodes. The surviving seedlings in un-amended plots were stunted and unthrifty, with fewer and smaller leaves compared to the amended plots. Twenty weeks after transplanting, there were above-ground hypocotyl swellings of some cacao seedlings in un-amended plots (Fig. 5). This is in agreement with Asare-Nyako and Owusu [49] observation on 10 months old cacao seedlings hybrid T63/967 X Sca 6 in the nursery in Ghana. Microscopic examination of sections of the hypocotyl swelling and galls on the roots revealed swollen *Meloidogyne* females and second stage juveniles.

The results of this study demonstrate the highly-damaging nature of plant-parasitic nematodes to plantain production in Nigeria (Table 2). Severe plant toppling during the first crop cycle (mother crop, which arises from the planted sucker) and rapidly diminishing yields of the successive ratoon crops (second and third cycles) revealed the parasitic effects of nematodes. Observations made on the corms of the uprooted plants revealed no weevil damage, but lesions of nematodes, indicating that nematodes were responsible for the toppling disease observed in this study. There was low incidence of snapped and broken plants at 1 and 2% respectively. Toppling occurs especially at bunch filling [38] when the weight of the maturing fruit creates an additional weight burden to plants with poor root anchorage.

The percentage of dead roots and root necrosis was positively correlated with *Pratylenchus coffeae*, *Radopholus similis*, *Helicotylenchus multicinctus* and *Meloidogyne incognita* in this experiment (Table 3). *R. similis* together with *P. coffeae* are amongst the most important biotic constraints of plantain in Nigeria [50], *H. multicinctus* and *P. coffeae* amongst the most important in Ghana [51], *P. goodeyi* and *Meloidogyne* spp. amongst the most important in Rwanda [52] and *R. similis* amongst the most important in lowland Cameroon [53]. *Meloidogyne* spp., though initially multiplied at the first cycle, remained at low population density during the ratoon crops in this experiment. Similar observation was made by Rotimi [54] during the first crop cycle. There is the possibility that the nematodes might have moved to cacao, which is a good host of *Meloidogyne* spp.

Over recent years, plantain yield and plantation longevity in West Africa have been gradually declining [3]. Numerous constraints, including soil fertility depletion, high soil acidity, various pathogens, and lack of suitable planting material are held responsible for this decline and the resultant escalation in the price of plantain regionally [55]. Plant parasitic nematodes are responsible for a significant decrease in yield of plantains [53, 50]. Plantain is a nutrient-demanding crop requiring high soil fertility [56], the observed increase in the growth and yield of plantain in this experiment in poultry litter amended soils (Table 4 and 5) compared to both the carbofuran treated and untreated soils may be attributed to, among others, the increase in nutrients supply to the soil, resulting from the addition of organic amendments and reduction in population densities of plant-parasitic nematodes.

Many factors could affect the response of nematode communities to nutrient sources. Most importantly, nematode communities were often affected by the nutrient composition, particularly the C:N ratio, of the organic amendments [57]. In general, amending the soil with a low C:N ratio (less than 20:1) substrate resulted in an abundance of enrichment-opportunist antagonistic microbes [58] and rapid mineralization of N in the form of NH^{4+} or NO^{3-} for absorption and uptake by plant roots. The poultry litter used in this experiment has a low C:N ratio (9:1) and this resulted in the suppression of nematode population on cacao seedlings and plantain.

The addition of organic amendments to the soil has previously been shown to increase microbial diversity [59]. With this increase in microbial diversity and numbers, it becomes more likely that bacteria and fungi capable of parasitizing specific nematode life stages or producing substances toxic to nematodes may be involved in the resulting nematode control [60].

Bacteria identified from the litter amended soil included *Arthrobacter globiformis, A. ilicis, A. pascens, Bacillus macerans, B. thuringiensis, Cellulomonas fimi, Pasteuria penetrans, Pseudomonas fluorescens, P. corrugata and P. vesicularis*. Species of *Arthrobacter, Bacillus* and *Pseudomonas* were the most numerous species identified. Fungi identified included *Arthrobotrys dactyloides, Aspergillus niger, A. flavus, Trichoderma harzianum, T. viride, Paecilomyces lilacinus* and *Verticillium chlamydosporium*. Bacteria are quite diverse in nutritional requirements, and several species identified in the genera *Arthrobacter, Bacillus and Cellulomonas* have the ability to use ammonium salts or nitrates as their sole source of nitrogen. Poultry litter has high levels of nitrogen in the organic and inorganic forms [61] that would be readily available to these organisms. Bacteria, such as *B. macerans*, use compared to plant in plot amended with poultry litter (B).

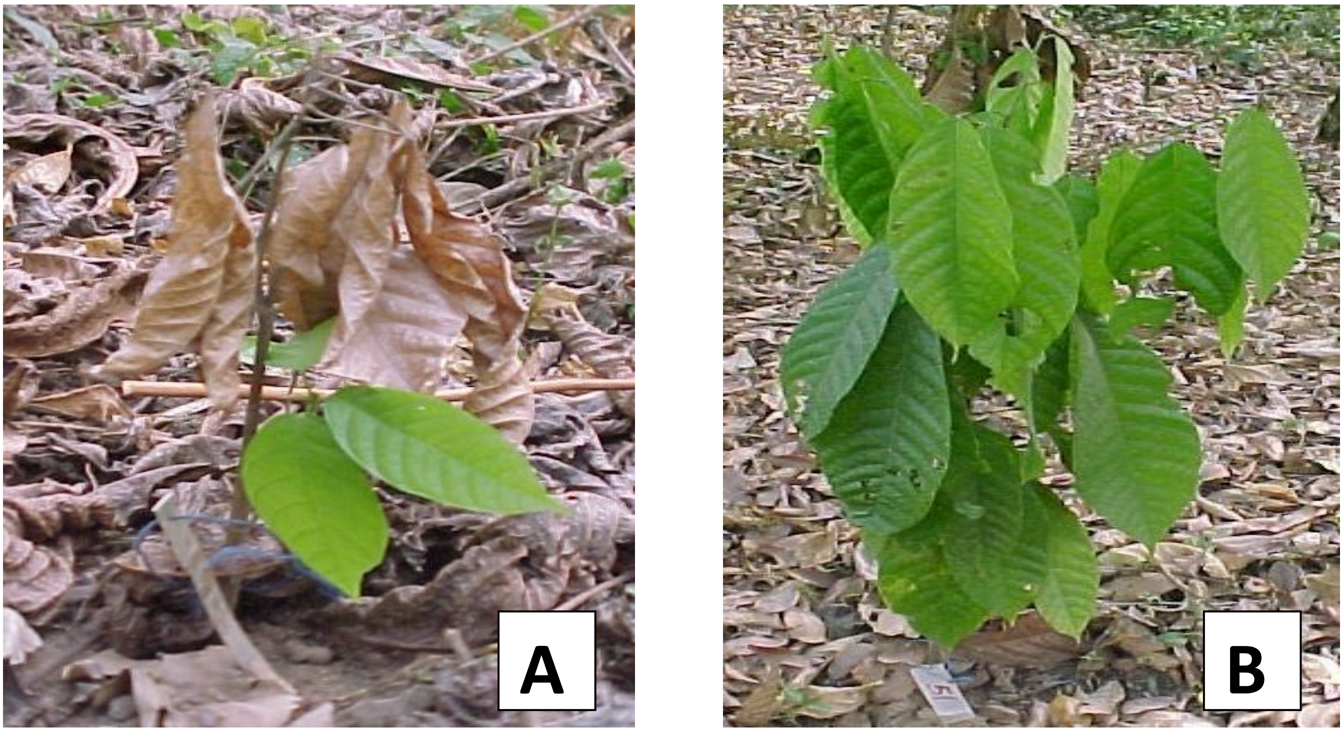

Figure 3: Dieback conditions of cacao seedlings in the field caused by plant-parasitic nematodes 8 weeks after transplanting (A)

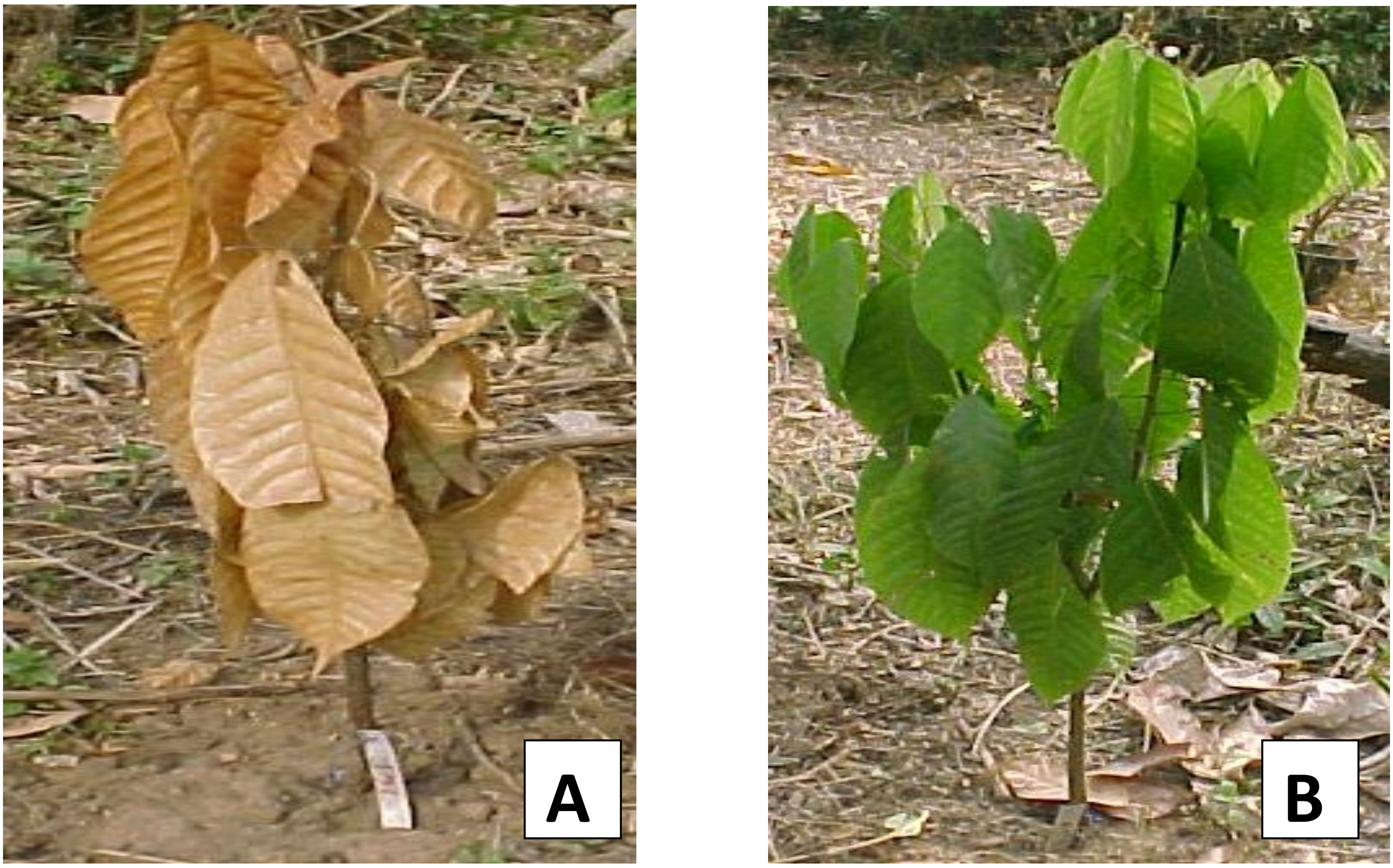

Figure 4: **Sudden death of cacao seedlings in the field caused by plant-parasitic nematodes 12 weeks after transplanting (A) compared to plant in plot amended with poultry litter (B)**

Figure 5: An enlarged above ground hypocotyl swelling of young cacao 2 years after transplanting in un-amended plot

Table 2
Effects of poultry litter and carbofuran soil amendments on root and corm damage of plantain cv. Agbagba (*Musa* spp., AAB-group) mother plant measured at harvest in nematode-infested soil

Treatments	Dead[†1] roots (%)	Root[†1] necrosis (%)	Gall[†1] Index (%)	Large[†1] Lesion (%)	Small[†1] Lesion (%)
PL[*] at 0.4t/ha	20.33d	18.33e	5.67d	33.67e	66.33a
PL at 0.4t/ha + C[#] at 2.50kg a.i./ha	20.34d	18.33e	5.33d	33.33e	66.67a
PL at 0.4t/ha + C at 1.25kg a.i./ha	20.33d	18.37e	5.65d	33.67e	66.33a
PL at 0.3t/ha	20.53d	20.43d	7.67c	37.33d	62.67b
PL at 0.3t/ha + C at 2.50kg a.i./ha	20.67d	20.33d	7.53c	37.67d	62.33b
PL at 0.3t/ha + C at 1.25kg a.i./ha	20.65d	20.46d	7.69c	37.67d	62.33b
PL at 0.2t/ha	28.67c	34.33c	10.33b	45.39c	54.61c
PL at 0.2t/ha + C at 2.50kg a.i./ha	29.33c	34.00c	10.67b	45.67c	54.33c
PL at 0.2t/ha + C at 1.25kg a.i./ha	29.31c	33.76c	10.67b	45.33c	54.67c
C at 2.50kg a.i./ha	34.33b	41.67b	10.00b	62.27b	37.73d
C at 1.25kg a.i./ha	40.45a	52.33a	10.33b	64.43a	35.57e
Control (no amendments)	40.65a	52.67a	12.33a	64.43a	35.57e

[*] Poultry Litter, [#] Carbofuran
[†]Analysis undertaken on square root transformed data, back-converted data shown.
[1]Means followed by the same letter in the same column do not differ significantly according to Fisher's LSD test (5%).

Table 3

Linear correlation matrix (half) of mean values for nematode population densities / 5g fresh root weight, percentage dead roots, gall index, root necrosis, large lesions and small lesions of plantain cv. Agbagba (*Musa* spp., AAB-group)

	Pc	Mi (J2)	Hm	Dead roots (%)	Gall index (%)	Root necrosis (%)	Large lesions (%)	Small lesions (%)
R. similis	0.96***	0.41*	0.67***	0.88***	0.25	0.91***	0.65***	-0.66***
P. coffeae	-	0.46**	0.72***	0.95***	0.24	0.96***	-0.12	0.78***
M. incognita (J2)		-	0.84***	0.39*	0.58***	0.36*	0.15	-0.18
H. multicinctus			-	0.56**	0.46**	0.62***	0.15	-0.17
Dead roots (%)				-	0.16	0.89***	0.16	-0.22
Gall index (%)					-	0.21	-0.13	0.29
Root necrosis (%)						-	0.28	-0.26
Large lesion (%)							-	-0.99***

Pc: *Pratylenchus coffeae*, Mi: *Meloidogyne incognita*, Hm: *Helicotylenchus multicinctus*.
*, **, ***: correlation coefficient significant at $P \leq 0.05$, 0.01 or 0.001, respectively.

ammonia to fix Nitrogen under anaerobic conditions [61]. In addition, the genus *Cellulomonas* has been isolated from substrates high in cellulose and has the ability to reduce nitrate to nitrite [61]. Chicken litter is composed of poultry droppings and wood shavings [22], which would provide both cellulose and nitrogen to *Cellulomonas* spp.

Carbofuran is a systemic, broad spectrum N-methyl carbamate insecticide and nematicide first registered in the United States in 1969 for control of soil and foliar pests on a variety of field, fruit, and vegetable crops. Nearly one million pounds of carbofuran are applied annually. As with other N-methyl carbamate pesticides, the critical effect of carbofuran for various exposure durations is cholinesterase inhibition, that is, it can over stimulate the nervous system causing nausea, dizziness, confusion, and at very high exposures (e.g. accidents or major spills), respiratory paralysis and death. Carbofuran is very highly toxic to mammals, birds, freshwater and estuarine/marine fish and invertebrates on an acute basis. Results from this experiment revealed suppression of beneficial fungi and bacteria abundance in the soil. Based on the assessment of ecological and human health risks associated with carbofuran uses, the United States Environmental Protection Agency (EPA), in an Interim Reregistration Eligibility Decision (IRED) document, has determined that all uses of carbofuran are ineligible for reregistration [24]. Currently, the use of carbofuran on cacao has been banned [23]. Poultry litter, as shown in this experiment, provides an alternative to the chemical.

Organic soil amendment is a nematode management option, and numerous aspects of research would have practical applications in commercial agriculture for the amelioration of pest problems. Organic amendments alone and/or in combination with other tactics like resistance management may meet some of the food production demands. For example, with large livestock production entities, countries like Brazil, the USA and even Nigeria will have plenty of organic sources of fertilizer supply [62]. Relationships between parasitic nematodes, the soil environment, organic amendments and plant host health are obviously complex and make it difficult to assess the activities occurring in soil. However, use of poultry litter as soil amendment has been shown in this experiment to reduce plant-parasitic nematode infection on cacao and plantain. The observed increase in other soil borne microbial populations may have an essential role in nematode suppressive mechanisms. More detailed studies of microbial population dynamics in litter-amended soils are needed to identify the specific roles that fungi and bacteria may have in nematode control.

Poultry is an important segment of agricultural production in Nigeria [28] and the poultry litter generated by this industry will require improved disposal methods as environmental regulations become more limiting. Chicken litter is potentially environmental contaminants of water. Disposal by using it as soil amendments in agricultural land is a desirable option. Litter, if used appropriately, can be substituted for mineral fertilizers [29]. Use of such organic amendments would not only enhance soil fertility, but also would increase microbial diversity, decrease population densities of plant-parasitic nematodes, and ultimately increase crop yields.

Conclusion

Poultry litter soil amendment as a nematode management tool, as demonstrated in this experiment, not only enhanced soil fertility, but also increased microbial diversity, decreased population densities of plant-parasitic nematodes, and ultimately increased crop yields. This technology, which is the first definitive work on the field management of plant-parasitic nematodes of cacao and plantain and a major contribution to knowledge, if put into practice, may be a switch to unconventional, less competitive and cheap alternative source of ameliorating nematode attacks on cacao and plantain and thus enhancing plant performance.

Table 4
Effects of poultry litter and carbofuran soil amendments on the growth of plantain cv. Agbagba (*Musa* spp., AAB-group) during the first cycle

Treatments	Days to 50% flowering[1]	Plant height at flowering[1] (m)	Plant height of tallest sucker[1] (m)	Pseudo-stem girth[1] (cm)	Number of leaves at flowering[1]	Number of leaves at harvest[1]	Leaf area[1] (cm^2)
PL at 0.4t/ha	278.7c	2.67a	1.67a	64.13a	13.67a	9.67a	121233.1a
PL at 0.4t/ha+C at 2.50kg a.i./ha	278.7c	2.67a	1.63a	64.14a	ns	ns	121232.9a
PL at 0.4t/ha+C at 1.25kg a.i./ha	278.9c	2.69a	1.67a	64.13a	ns	ns	121233.3a
PL at 0.3t/ha	279.3c	2.64a	1.63a	63.17b	13.67a	9.67a	121183.3b
PL at 0.3t/ha+C at 2.50kg a.i./ha	279.3c	2.63a	1.65a	63.15b	ns	ns	121183.5b
PL at 0.3t/ha+C at 1.25kg a.i./ha	279.3c	2.67a	1.65a	63.15b	ns	ns	121183.7b
PL at 0.2t/ha	284.3b	2.51b	1.31b	60.73c	11.00b	7.00b	119101.3c
PL at 0.2t/ha+C at 2.50kg a.i./ha	284.4b	2.50b	1.31b	60.73c	ns	ns	119101.7c
PL at 0.2t/ha+C at 1.25kg a.i./ha	284.3b	2.63a	1.33b	60.69c	ns	ns	119101.5c
C at 2.50kg a.i./ha	284.4b	2.47c	1.17c	51.33d	ns	ns	98122.3d
C at 1.25kg a.i./ha	291.3a	2.27d	1.03d	51.31d	ns	ns	98024.1e
Control (no amendments)	291.4a	2.27d	1.07d	51.31d	10.89b	7.00b	98024.4e

PL = Poultry litter.
C = Carbofuran.; [1]Means followed by the same letter in the same column do not differ significantly according to Fisher's LSD test (5%).; ns = not significant.

Table 5
Effects of poultry litter and carbofuran soil amendments on the yield of plantain cv. Agbagba (*Musa* spp., AAB-group) during the first cycle

Treatments	Fingers/bunch[1]	Hands/bunch[1]	Rachis weight[1] (kg)	Bunch weight[1] (kg)	Yield[1] (t/ha)
PL at 0.4t/ha	30.33a	7.33a	0.97a	11.86a	15.06a
PL at 0.4t/ha+C at 2.50kg a.i./ha	30.35a	7.34a	ns	11.86a	15.06a
PL at 0.4t/ha+C at 1.25kg a.i./ha	30.32a	7.33a	ns	11.87a	15.07a
PL at 0.3t/ha	30.29a	7.14b	0.93ab	11.28b	14.32b
PL at 0.3t/ha+C at 2.50kg a.i./ha	30.28a	7.13b	ns	11.25b	14.29b
PL at 0.3t/ha+C at 1.25kg a.i./ha	30.31a	7.15b	ns	11.29b	14.34b
PL at 0.2t/ha	25.33b	6.83c	0.90b	8.13c	10.32c
PL at 0.2t/ha+C at 2.50kg a.i./ha	25.37b	6.83c	ns	8.14c	10.34c
PL at 0.2t/ha+C at 1.25kg a.i./ha	25.34b	6.83c	ns	8.18c	10.39c
C at 2.50kg a.i./ha	20.33c	6.57d	ns	6.13d	7.78d
C at 1.25kg a.i./ha	20.33d	6.57d	ns	5.78e	7.34e
Control (no amendments)	20.34d	6.53d	0.81c	5.73e	7.28e

PL = Poultry litter, C = Carbofuran, ns = not significant.
[1]Means followed by the same letter in the same column do not differ significantly according to Fisher's LSD test (5%).

Poultry litter soil amendment applied at 0.3 and 0.4t/ha is, therefore, recommended as an alternative source of ameliorating the parasitism of nematodes on plantain and cacao and enhancing field establishment and yield of the crops ultimately.

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