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SITUATIONAL ANALYSIS OF ABIOTIC AND BIOTIC FACTORS INFLUENCING ABUNDANCE OF TISSUE CULTURE AND NON-TISSUE CULTURE BANANAS IN SMALLHOLDER FARMS IN WESTERN UGANDA

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ABSTRACT

Bananas are, in Uganda primarily, grown for domestic consumption and regional trade. Production is constrained by several factors such as declining soil fertility, pests and disease, and erratic rainfall. Tissue culture banana were introduced partly to solve some of the challenges in banana production, though uptake of such technologies by smallholder farmers is still low. A survey on plant parasitic nematodes, banana weevils, and selected soil factors was done to analyse their effect on the abundance of tissue culture banana (TCB) and non-tissue culture banana (NTCB). Soil and banana root samples were collected from heterogeneous on-farm orchard conditions in smallholder farms. Composite banana root samples and composite soil samples were collected from banana orchards already established by farmers. A total of 1,280 genets from 20 orchards were obtained. Composite soil samples were analysed for pH, potassium, phosphorus, nitrogen, and organic matter. Endo-parasitic *Helicotylenchus multinctus*, *Platylenchus goodeyi*, *Radopholous similis* and *Meloidogyne spp* were isolated from the composite root samples. Banana weevils were captured using the disc-on-stamp and split-pseudo stem traps. Redundancy Analysis (RDA) and logistic regression were run to ascertain the relationship between variations in biotic [Nematodes and weevils] and abiotic [pH, K, Av.P, N, and OM] factors affecting the abundance of the banana type. Canonical eigenvalues showed that both biotic and abiotic variables significantly affected the abundance of TCB and NTCB banana types. Abundance of TCB was influenced by the banana weevil ($P<0.05$) than it was by nematodes in the same farmers' fields. Infestation with nematodes for TCB and NTCB banana types was not different ($P<0.05$). The banana weevils were significantly ($P<0.05$) distributed within the districts. Relative abundances for the pH, phosphorus, potassium, nitrogen (%), organic matter (%) within districts were significant ($P<0.05$). Variations in soil pH and nitrogen availability resulted in significant interactions ($P<0.05$) that affected the abundance of the TCB types more than their contribution to the abundance of NTCB. The awareness that the interactions between nematodes, banana weevils, phosphorus, nitrogen, potassium and pH determine the abundance of banana types is important in shaping the adoption and production of the adopted banana technology. Mitigation of acidic pH, K, Av.P, N, and OM for soil fertility and reduction of the abundance of nematodes and weevils below the threshold will enhance banana production among small holder farmers in Uganda.

Key words: abundance, banana weevil, nematodes, eigenvalues, interactions, tissue culture, genet, heterogeneous

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BACKGROUND

The banana is a perennial monocotyledonous herb whose importance and level of production are vindicated by bananas' distinctive support to food, feed, and fuel and, fibre production in East Africa [1]. Most production of the banana takes place in homestead gardens where the production fields are non-uniform but heterogeneous [2]. Due to harmful biotic and abiotic interactions, banana production is susceptible to yield decline in some agro-ecological zones in Uganda since the 1940s [3, 4]. In other studies, farmers cite soil fertility decline, as well as pests and diseases as factors responsible for yield decline [5, 6]. Efforts to solve the problem through the use of organic and mineral fertilizer applications have not yet been fully exhausted to sufficient success. Banana yield declines provoked scientific research on technologies to solve the pest-disease-yield challenge worldwide [7]. Tissue culture banana (TCB) technologies were introduced in Uganda for plant cleaning, and to increase the yield and productivity of the banana. However, adoption of TCB technology at smallholder farmer level in Uganda has been slow since the late 1990s, with NTCB production exceeding that of TCB by 83 % in Uganda [8].

The biotic and abiotic factors are biophysical environmental aspects surrounding an organism [9]. They influence the survival, development, evolution, some of which lead to the destruction of interacting organisms [10,11]. Variability in mineral nutrients, organic matter and human migrations occasionally affect banana production in East African countries [12]. The banana weevil, *Cosmopolites sordidus* (Germar) of the order *Coleoptera*, family *Curculionidae* and the parasitic nematodes are biotic risk factors of economic importance in banana production [13, 14]. The severity of banana damage by weevils depends on the prevailing environmental factors [15, 16]. Interactions between the banana weevil, nematodes and other environmental factors may be fatal to orchard development, as they may damage the roots, distort plant stability, and expose the plant to pathogens. The grubs of banana weevil tunnel the corms causing decay and exposing the plant to fungal infection. Nematodes clog into the root and corm tissue, causing topling as a result of destruction of roots [17, 18]. For tropical crops such as banana, nematode parasitism in roots is characterized by simultaneous infestations by several genera including *Radopholus similis, Pratylenchus goodeyi, Helicotylenchus multicinctus,* and *Meloidogyne spp* as the most common nematodes found in banana plantations at different altitudes in Africa. Most investigations have concentrated on yield loss factors in bananas. These investigations often consider single-constraint-on station trials with very few studies focusing on multifaceted constraints in homestead gardens [19]. Interactions between such complex factors need to be adequately investigated to provide answers for the surging abundance and low adoption of tissue culture technology. The current study sought to determine whether the abundance of TCB or non-tissue culture banana (NTCB) depends on interactions between banana weevil, nematodes as "biotic factors" and pH, nitrogen, potassium, phosphorus and organic matter as "abiotic factors".

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MATERIALS AND METHODS

SITES DESCRIPTION

The study was undertaken in western Uganda districts of Mbarara (00° 36′S 30° 36′E) Ibanda (00° 07′S 30° 30′E), Isingiro (00° 50′S 30° 50′E), and Kiruhura (00° 12′S 31° 00′E) (Figure 1). The area is elevated up to 5,900 ft. above sea level. Currently, moist evergreen planted and natural forests, banana plantations, small-scale agriculture, and animal pasturelands, as well as national parks, are the dominant land cover in the area. The area receives bimodal rainfall occurring from March to May and from September to November. The mean annual rainfall in the region is 1450 mm whereas the mean daily minimum and maximum temperatures are 17 ˚C and 30˚C, respectively [20]. The soils are mainly classified by farmers following the epipedon characteristics such as color, thickness, surface gravel and clay and sand. The soils are mainly black in color with scattered surface gravels. The soil characteristics vary along the different landscape summits. Averagely, the soils are highly weathered ferralsols [21], which are fertile due to manure deposits especially from historical livestock farming activities. High temperatures assist in inorganic chemical reactions and biological activity [22]. Undulating hills and shallow flatlands characterise the area. The proportions of water bodies, compared to the arable land vary considerably but about six percent of the total land is covered with lakes, rivers, and gazetted swamps.

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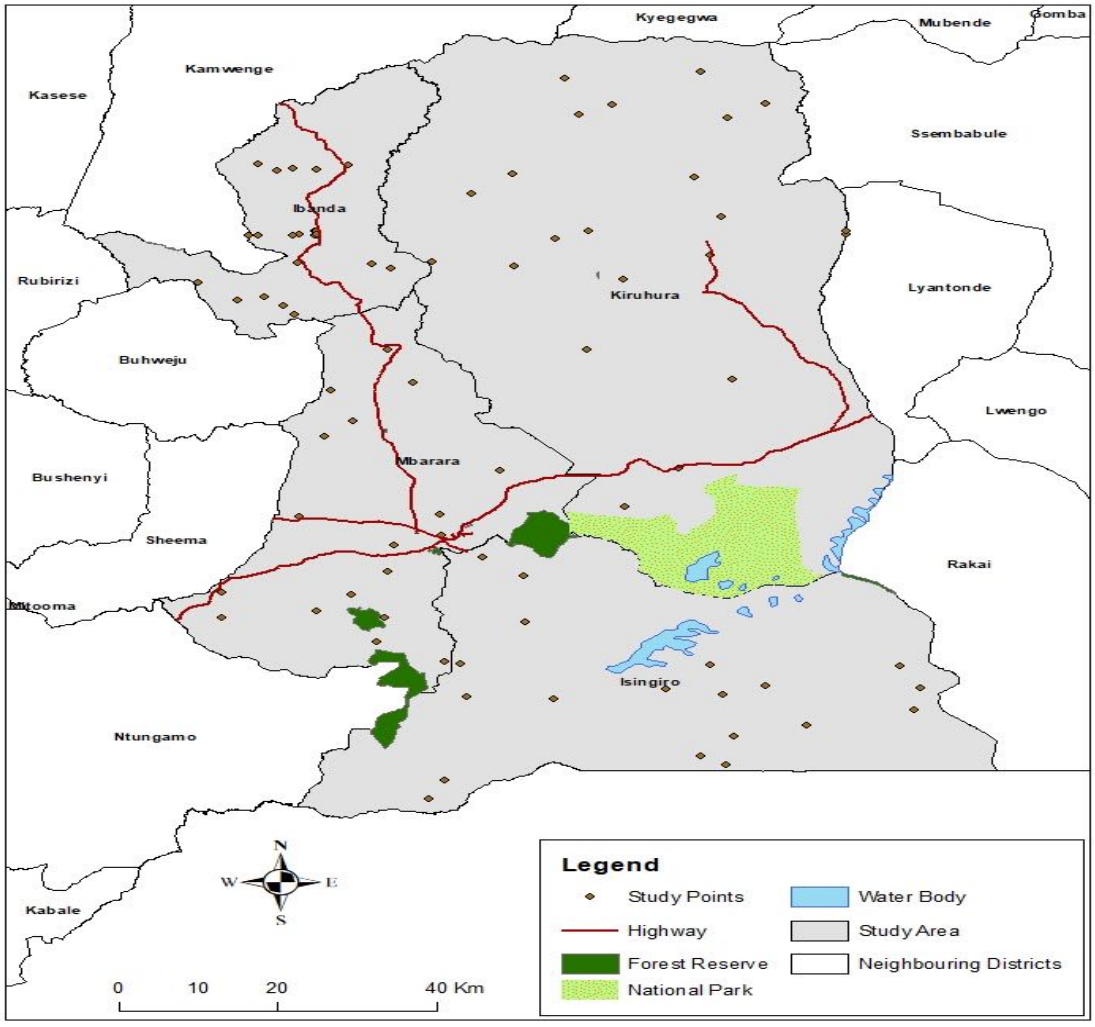

Figure 1: Location and physical characteristics of the study area

The area has good infrastructure such as highway roads and feeder roads, aerodrome, and lakes for road, air and inland water transport which facilitate efficient connectivity, and ease the movement of agro-produce, and the provision of services.

STUDY DESIGN

The biological components of economic importance to this study were banana weevils and nematodes. Composite soil samples were collected from banana orchards already established by smallholder farmers. Composite root samples for extraction of nematodes were obtained from banana genets already established by the farmers. Weevil traps were set up only on those genets around which soil samples and root samples were collected in the same fields to establish the average weevil density in the plantations. Twenty (20) orchards were purposively selected by taking five farms per district from Mbarara, Ibanda, Isingiro, and Kiruhura districts on the basis that the orchards had tissue culture and non-tissue culture banana types. A Mat is a horticultural term that specifically refers to the clump formed by the rhizome, the fruit-bearing stem and the suckers of banana. This is sometimes called a *stool*, but the botanical term is of

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the stool or mat is a ***genet***. Five *genets* per orchard were randomly selected. Five roots per *genet* were obtained from each orchard. The five roots per *genet* were put together to form a composite sample such that, each orchard per district provided five samples for nematode extraction. The composite root sample was standardized to a five gram weight root sample.

Determination of Banana weevil population density

Two basic approaches were used to quantify the banana weevils; the Disc on Stump (DOS), and the Split Pseudo Stem (SPS) traps. The two approaches were used to maximise capture of banana weevils. The DOS was suitable for old genets with harvested stumps while the SPS was suitable for genets that are young; where there has not been any harvest done to create stumps. The DOS was made by cutting a harvested stump, 5-10 cm above ground, and placing a 15-30 cm thick pseudo stem disc on top of the stump. The DOS traps' lengths were limited to 30 cm long and placed horizontally onto the harvested stump surface. The SPS was made from pseudo stem pieces split longitudinally and placed near a target plant with the split surface inverted onto the ground. Five traps each for DOS and SPS were randomly laid in each of the five selected plantations per district. The weevils were collected after 24, 36 and 48 hours to maximise duration and catch of trapped weevils [23]. The totals for the three collections were put together to form one single *genet* count. The average banana weevil density were collated to tissue culture and non-tissue culture banana on which the trap was set to determine the effect of the relationship on the abundance of the banana type.

Determination of Nematode population density

The samples were collected twice per month, for two months during a rainy season, and two months in a dry season. Nematodes were extracted from fresh banana roots following the modified Baermann's Funnel technique [24]. Collecting samples more than once, and in different climatic conditions was meant to maximize extraction of nematodes. This is because some nematode characteristics such as size, surface structure and motility are shaped by time, plant and soil sample composition, compactness and organic matter content, all of which could be affected by climatic conditions [25]. The modification of Baermann's Funnel technique was devised to facilitate the collection of large numbers of nematodes in a small volume of water with the slightest of plant fragments present [26]. This study followed details of modification described by Adl [27].

ASSESSMENT OF THE ABIOTIC FACTORS

Soil sampling

Soil sampling was done using the soil auger at a depth of 32 cm to obtain samples for soil nutrient determination. Random soil samples were taken in a zigzag pattern across the field, and 20 samples from homogeneous [with no major variation in slope, drainage, or previous off-farm input history] farmers' field were collected and formulated into a composite soil sample for analysis. Soil samples were collected from 20 orchards, selecting five orchards per district basing on the homogeneity observations. From each selected orchard, six composite soil samples were obtained

bringing the total number of composite soil samples for the four districts to 120 samples.

Determination of nitrogen, phosphorus and potassium

The soil samples were air-dried, pounded in a ceramic motor with a pestle, screened through a 2.0 mm sieve to remove any debris. The Total nitrogen (%) was determined by Kjeldahl digestion and semi-micro Kjeldahl distillation [28]. Available phosphorus was extracted using the Bray 1 procedure, and determined using the molybdenum blue colorimetric method and quantified by the spectrophotometer (TUV, 2500; TRULAB INDIA) while potassium was extracted using ammonium acetate at neutral pH and determined using a flame photometer (ANALAB Flame Photometer, FlameCal10, India).

Organic Matter

Soil organic matter was determined by first determining soil organic carbon [29]. The resultant soil organic carbon was converted to soil organic matter by multiplying the SOC by the"van Bemmelen factor,"of 1.724 [30].

Soil pH

The pH meter method was used in the determination of soil pH. About 20 gm. of 2.0 mm air-dry soil was weighed and placed into a beaker. To the air-dry soil in the beaker were added 50 ml of distilled water and the mixture stirred with a glass rod thoroughly for about 5 minutes. The mixture was kept for half an hour. Meanwhile, the pH meter (Model PX-104, Panomex Inc., India) was turned on and allowed to warm up for 15 minutes. The glass electrode was standardized using standard buffer of pH = 7 and calibrated with the buffer pH = 9.2. The electrodes were dipped in the beakers containing the soil-water suspension with constant stirring. While recording pH, the pH meter was switched to pH reading 30 seconds before sample pH recording was done. The pH values were recorded to the nearest 0.1 unit [30].

DATA ANALYSIS

The total Nematode counts, banana weevil counts, potassium (ppm), phosphorus (ppm), nitrogen (%), organic matter (%) data were normalised to a Z-score; [mean=0 and standard deviation=1] hence all the variable values were on an equal pedestal. The standardised data were subjected to Detrended Correspondence Analysis (DCA) using R i386.3.3.1 version to direct whether Redundancy Analysis (RDA) for the constrained variables was possible (Table 2). Data were further subjected to correlation and covariance analyses to identify the factors affected by multi-collinearity (Figure 1). In each case where multi-collinearity occurred, only one variable was selected for further analysis unless there were justifications for the retention of a given factor. The study sought to determine whether the abundance of TCB and/or NTCB is dependent on variations between selected "biotic factors" and "abiotic factors". Logistic regression was used to model a relationship between the total nematode counts, banana weevil counts, potassium (ppm), phosphorous (ppm), nitrogen (%), organic matter (%) as predictor variables and the abundance of a dichotomy of TCB and NTCB as categorical

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response variables. The terms fitted in the model were, Constant + Banana weevil population + nematode Counts in 5g of composite root sample + pH + Percentage Nitrogen + Phosphorous (ppm) + Potassium (ppm) + Percentage Organic Matter. The logistic model was run using Genstat; VSNi, 2012 version.

RESULTS AND DISCUSSION

Abundance of biotic and abiotic factors

Results in Table 1 summarise descriptive and inferential data for banana weevils, *H. multicinctus, R. similis P. goodeyi* and *Meloidogyne spp*., and their relative abundance in Tissue Culture Banana (TCB) and Non Tissue Culture Banana (NTCB) types in the districts of Ibanda, Isingiro, Kiruhura and Mbarara. Both banana types were infested with banana weevil and nematodes with different abundances across all the districts (Table 1). Although there were more nematodes extracted from TCB than the NTCB, the infestation for both banana types were significant (P-value <0.05). There were more banana weevils captured in Isingiro and Kiruhura districts than in Ibanda and Mbarara districts. However, the distribution for banana weevils was significant (P-value <0.05) within the districts. According to Nyombi[5], bananas are susceptible to banana weevil and nematode attack under a wide range of interacting conditions. Therefore, the type of banana, the location and the variations in abundance of soil factors form part of the wide range of conditions that may enhance attack on bananas by the weevils.

Table 1 shows that pH, phosphorus, potassium, nitrogen (%), organic matter (%) within districts were significant (P-value <0.05). The pH recorded for NTCB orchards was 6.6 which was closer to the neutral. This pH is preferred for the growth and productivity of banana since it does not contribute to the highly acidic soils (pH<4) that have been known to significantly affect banana yields since the 1940s [5]. Phosphorus levels were higher for the districts of Kiruhura (89.32 ppm) and Mbarara, (82.56 ppm) respectively and slightly lower for Isingiro and Ibanda (Table 1). Slightly higher concentrations of phosphorus (411.67 ppm) were prevalent in NTCB orchards than in the TCB orchards (400.37 ppm). As supported by, the presence of phosphorus in smallholder banana orchards may arise from the utilisation of old and dry banana leaves as mulches [31]. The soil potassium concentrations (ppm) were higher in NTCB compared to TCB orchards. Nitrogen contents varied slightly from one district to another, with Isingiro district recording the highest mean percentage of 0.25 %. The nitrogen content recorded for NTCB orchards was higher (0.2 %) than the (0.1%) found in the TCB orchards (Table 1). The organic matter content was higher for Isingiro and Ibanda districts than for the districts of Kiruhura and Mbarara. Such differences may be due to the location and the orchard management dynamics by the smallholder farmers, such as fertilization practice, type of fertilizers used, timing of fertilizer application, and method of placement of the fertilizer. However, the differences in the availability of nutrients, could be attributed to the location of the orchards and the cultivar efficiency with probably TCB slightly more efficient in utilisation of the nutrients than NTCB [23].

Relationships between Biotic and Abiotic factors

Table 2 shows the DCA segments rescaled to four iterations. The gradient axes of DCA1 to DCA4 is less than four, thus supporting RDA [3]. The correlation matrix

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(Figure 1) indicate that both positive and negative correlations between study parameters were weak, further supporting RDA and Logistic regression. Weak correlations indicated that there was no multicollinearity among independent variables.

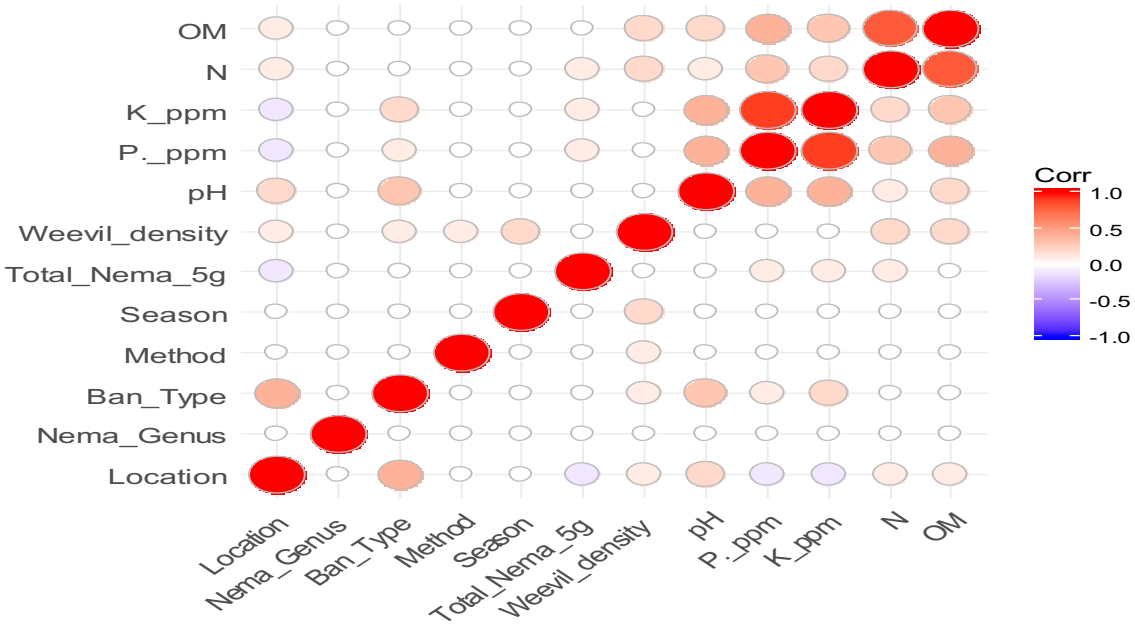

Figure 1: Correlation coefficients for the P-values for the biotic and abiotic parameters: *Positive correlations are displayed in red and negative correlations in blue. The intensity of the colour and the size of the circles are proportional to the correlation coefficients for the P values* The initials "Location" represent the districts, "Nema_Genus"=Nematode genera, "Ban_Type"= the Banana type, "Method"= DOS and SPS,, "Season"= the dry and wet seasons, "Total_Nema_5g"=the nematode population density in 5g of the root sample "Weevil_density"=banana weevils desnsity "P_ppm" represents the measure of Phosphorous in parts per million, K_ppm, is Potassium in parts per million, "N" is the measure of percentage Nitrogen, " OM" is the measure of percentage organic matter

Organic matter content and total nitrogen in the soil were collinear (Figure 1). The organic matter content cannot be increased without simultaneously increasing its nitrogen content hence the interdependence of C and N cycles on soil organic matter organic matter plays other roles important in banana production [32].

The sum of all canonical Eigenvalues showed that both biotic and abiotic variables influence the distribution of banana types in the farmers' fields, (Table 3). The Eigenvalues for the first and second RDA constrained to location and the type of banana in the farmers' fields were 0.122 and 0.023 respectively, explaining 14.54 % of the variance (1.4598) in the distribution of banana cultivars vis-à-vis interactions that are either biotic or abiotic (Figure 2). The x-axis (PC1) explains 79.7 %, and (PC2) 10.1 % of the total inertia respectively. However, the percentage variance explained by the y-axis RDA1 (8.3 %) and RDA2 (1.5 %) is minute. The proportion of

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unconstrained variation (90 %) is larger than the constrained variation, implying that environmental constrained factors are largely non-redundant. For this study therefore, the interactions between the banana type and parasitic nematodes, banana weevils, soil pH, phosphorus, potassium, nitrogen and organic matter, [explanatory variables] were non-redundant in affecting the abundance of banana types in Western Uganda.

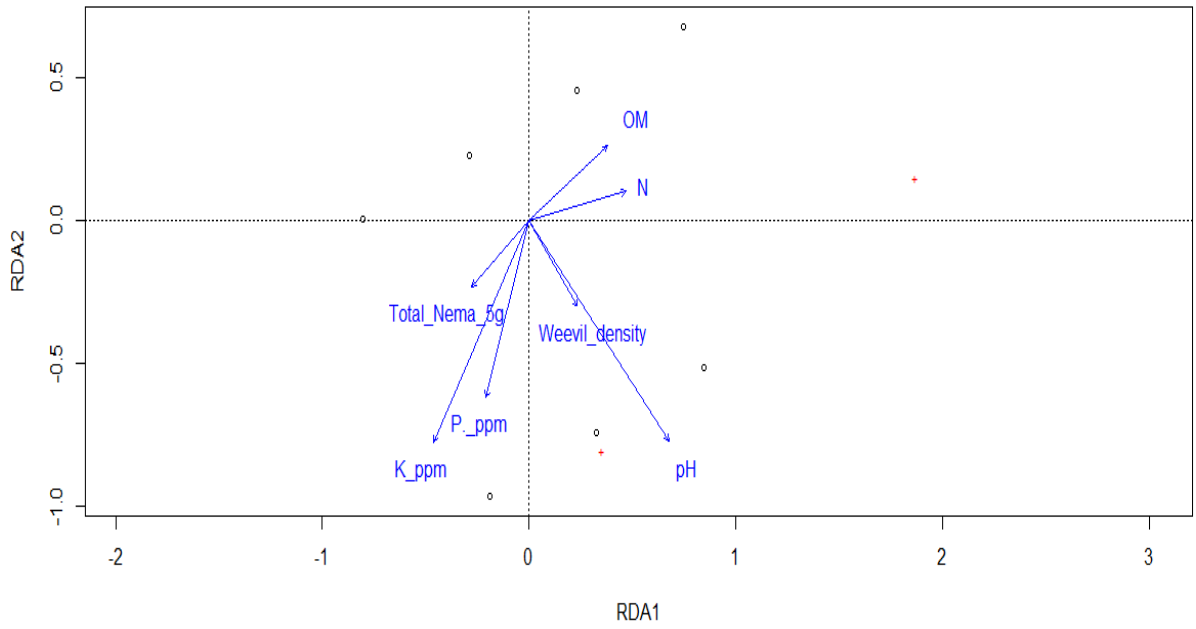

Figure 2: RDA with two response variables; Banana type and location. Parameter representations; Total Nematode counts in 5 g of composite root sample (Total_Nema_5 g), Potassium ppm (K_ppm), Phosphorus ppm (P.ppm), Banana Weevil population density (Weevil_density), Percentage Nitrogen, (N), Percentage organic matter (OM). The red and grey plain dots represent the banana type and location, respectively

Results presented in Figure 2 indicate a positive relationship between organic matter, nitrogen, and pH with banana weevils. Variations in pH enhance the population of banana weevils, than the variations between organic matter and nitrogen. At the average pH of 6.4, and the average percentage of organic matter and nitrogen of 5 % and 0.2 %, respectively, the population of banana weevil was high (Table 2). Increase in weevil population results in high banana orchards', and the *genets*' infestation hence low banana productivity [33].

There was a negative relationship between phosphorus (ppm) and potassium (ppm) and parasitic nematodes. Variations in the concentrations of potassium and to lesser extent phosphorus negatively affected the abundance of parasitic nematodes. The concentration of phosphorous and potassium was high at 70.5 (ppm) and 400.3 (ppm) respectively (Table 2), in TCB orchards. However, the concentration (ppm) of the same elements in NTCB was higher, at 75.89 (ppm) and 411.66 (ppm) respectively. Declines of phosphorus and potassium (Table 2) corresponded with high population of nematodes in the same location. Consequently, nematodes are destructive to banana

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orchards thus, the increased nematode populations negatively affects the TCB abundance. The high susceptibility of TCB to these factors negatively affects the preference by smallholder farmers to adopt TCB, hence reduced abundance. The environment of the crop plays a significant role in the availability of soil nutrients and the abundance of organisms important in that crop's productivity [34]. The availability of Phosphorus, potassium, organic matter and nitrogen enhance the location of the orchards. The location may determine the abundance of weevils and nematodes.

Significance of factors in banana distribution

Table 4 shows varying interactions between biotic and abiotic factors determining the abundance of the banana type as a response variable. The dichotomy was between the NTCB and TCB distribution. High banana weevil and nematode population reduced the abundance of TCB ($P<0.001$). Variations in soil pH and N (%) significantly ($P<0.001$) influenced the distribution of tissue culture type. soil pH was a significant factor in the distribution and abundance of banana. It affects the availability of phosphorus and other interacting factors especially banana weevils. At pH above 8.0 phosphorus becomes unavailable to plants, but may also be a reason for the increase in the total population of the nematodes in the field. The significance of nitrogen cannot be dissociated from the high percentage of organic matter availability. Organic matter has a favourable effect upon soil physical properties, hence the amount of organic carbon in soil serves indirectly as a measure of available nitrogen. The critical value for total nitrogen in soils for East African Highland banana in Uganda on average is 0.2 % [29]. The estimated value for nitrogen in TCB fields is too deficient to sustain the production of the banana type.

Banana weevils significantly affected the production of both TCB ($P=0.001$), and NTCB ($P=0.006$). (Table 4.). Nematodes on the other hand, significantly ($P=0.001$), affected the production of TCB, but their effect appeared non-significant ($P=0.097$) for NTCB production. This probably is one of the reasons why there is high preference for NTCB by smallholder farmers. The results implied that individually, banana weevils negatively affect the production of both tissue culture and NTCB orchards, although the effect is more serious with TCB types. Presence of nematodes in larger populations and their interaction with banana cultivars poses a greater negative effect on the TCB types compared to NTCB types. Therefore, the adoption and distribution of NTCB cultivars were linked to the banana weevils' presence in the farmers' fields ($P<0.05$) than they were linked to nematode population in similar fields ($p>0.05$).

The study established that the production of TCB is significantly affected by plant-parasitic nematodes that live in soil and roots. The most damaging species of the nematodes in banana production spend most of their life cycle in the roots and corms tissues [32]. Multitudes of individual nematodes of various genera develop in root tissues and consequently alter the physical and functional aspects of the plant the effect of which is reduced productivity of the plant. The proliferation of endo-parasitic plant-parasitic *R.similis, P.goodeyi, H.multicinctus* and *Meloidogyne ssp* in the roots of banana disrupt the uptake of Phosphorous, Potassium and nitrogen, in a well-manured orchard. Whereas, *R.similis, P.goodeyi, H.multicinctus* and *Meloidogyne ssp* form polyspecific communities of millions of individual nematodes within the roots, they

may not develop a resting stage for long-term persistence in soils. The study established the existence of a strong relationship between Nitrogen and organic matter in the farmers' orchards (Figure 1), and Nitrogen was significant in the production of TCB (P=0.001), and NTCB, (P=0.009); an indicator of sufficient organic matter in the farmers' orchards in Western Uganda. Application and accumulation of organic matter is a soil prophylaxis that may be efficient in slowing down population dynamics of endoparasitic *R.similis, P.goodeyi, H.multicinctus* and *Meloidogyne ssp* in banana production.

Heterogeneity in backyard orchards varies from observable improved fallows, water management channels, and plant biodiversity within the orchards and management practices such as spreading wood ash from the kitchens. The study established that banana weevil affected the productivity of both TCB and NTCB with the effect appearing rather more severe with TCB types. Improved fallows may clean the soil of the endo-parasitic nematodes thus reducing re-infestation of plantlets when the fallowed gardens are replanted with banana. It is practical to systematically remove the volunteer suckers as they can host and multiply residual nematode populations but the practice may not be effective in removing the banana weevil eggs, and the adults which, unlike the nematodes, can survive better and longer in the soil. Therefore, the introduction of cleaned tissue culture plantlets will be infested faster from the pest reserves resting in the soil. Section 2.1 indicates that farmers' orchards are situated in undulating hills. According to the area also receives bimodal rainfall patterns with the minimum range between 800-1500 mm [20]. This rainfall results in runoff water that must be managed by smallholder farmers. Runoff water is a source of contamination for both nematodes and banana weevil. Some farmers dig channels up to 100 cm deep around plots efficiently prevent the dispersion of not only the plant-parasitic nematodes but also the adult, larvae and eggs of banana weevils in runoff from contaminated orchards to relatively sanitized orchards. Where isolation channels are dug by farmers, re-infestation of banana fields by parasitic nematodes and weevils is delayed, however, further studies need to be conducted on whether re-infestation by these two risk factors is rather virulent in cleaned TCB than in the conventional suckers. Finally, smallholder farmers rarely plant sole banana crop. A variety of so many other crops including weeds exist in the production process of the banana at the field level. Non-host and alternative-host plants contribute to soil sanitation and prophylaxis against banana weevils and nematodes. Non-host plants break the cycle of both the banana weevil and the nematode. Sanitation plant-parasitic nematodes in banana agro systems is achievable through planting nematode-resistant plants as rotational or associated crops. Alternative host plants share the burden of the banana weevil and the nematodes on the main crop by enabling a wider ecological niche. Plant biodiversity in banana cropping systems promotes more beneficial soil biota some of which such as. Fungi are antagonistic to nematodes [34, 35, 36, 37].

Smallholder banana orchards have diverse plant biodiversity as part of heterogeneous environment. Plant biodiversity is a further step towards sustainable control of nematodes. Some Nematodes species have a broad host range thus lessening the risk of perishing with the one host, however, as they move from host to host, such nematodes get exposed to predators or pathogens, and while they may survive in the alternate host

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they reduce the burden on the banana [38]. The banana weevil is monophagous, hence solely depends on the banana plant corms, pseudo stems, leaves and roots [6]. This behavior contributes less to reducing the burden of banana weevil whether on TCB or NTCB. This forms a basis to why the banana weevil is linked to destruction of banana in smallholder banana orchards. However, the weevil more aggressively destroys the TCB upon re-infestation than the NTCB suckers. The causes for this variation need to be further investigated.

CONCLUSION

Under heterogeneous conditions in smallholder banana farms, high banana weevil and nematode population densities independently limit the abundance of both TCB and NTCB. While nematodes were widespread in Western Uganda, with *H.multicinctus* and *P.goodeyi* as the most prevalent, TCB orchards were more infested with nematodes than NTCB orchards in a similar environment. Interactions between nematodes, banana weevils, phosphorus, nitrogen, potassium and pH affect banana production, and shape the adoption of banana production technology. Comprehension of the interactions that affect the abundance of banana types should form a basis for developing strategic and affordable management approaches to prevent faster degeneration of banana orchards.

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Table 1: Descriptive and inferential prevalence of biotic and abiotic parameters from banana orchards surveyed from Western Uganda

Parameter	Orchard Location						Banana type				Nematode genus					
	Ibanda	Isingiro	Kiruhura	Mbarara	Pvalue[X]	SED[Y]	TCB	NTCB	Pvalue[X]	SED[Y]	*1*	*2*	*3*	*4*	Pvalue[X]	SED[Y]
Nematode_D	890a	768b	729c	715d	***	0.43	850a	591b	**	1.5	486b	53d	2315a	247c	***	0.53
Weevil_D	97d	132a	124b	118c	***	0.81	113a	131b	*	1.15	118a	118a	118a	118a	NS	0.71
pH	5.8b	6.4ab	6. 4a	6.7a	*	0.16	6.3	6.6	*	0.16	6.4a	6.4a	6.4a	6.4a	NS	0.17
P(ppm)	56.04d	60.32c	89.32a	82.56b	***	0.4	70.5b	75.89a	**	0.02	72.07a	72.07a	72.07a	72.07a	NS	0.38
K(ppm)	262.09d	566.02a	371.6c	414.74b	***	0.03	400.4b	411.6a	NS	0.56	403.6a	403.6a	403.6a	403.6a	NS	0.09
N (%)	0.19b	0.26a	0.18b	0.18b	*	0.11	0.11a	0.19a	NS	0.01	0.20a	0.20a	0.20a	0.20a	NS	0.1
OM (%)	5.05b	5.53a	4.86c	4.03d	***	0.01	4.90a	4.78a	NS	0.06	4.87a	4.87a	4.87a	4.87a	NS	0.06

*SED[Y] and Pvalue[X] Significant effects were obtained from one-way analysis of variance: *, **, *** significant at P < 0.05, P < 0.01, and P < 0.001, respectively; Means followed by the same letter in each column are not significantly different at p ≤ 0.0 5 using Tukey HSD.* Nematode_ D and Weevil_ D refer to nematode and banana weevil densities respectively, OM= Organic Matter, numbers 1, 2, 3, and 4, represent *R.similis, P.goodeyi, H.multicinctus, and Meloidogyne spp* in that strict order

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Table 2: Results of Detrended Correspondence Analysis (DCA) with 26 segments, rescaling of axes with 4 iterations

	DCA1	DCA2	DCA3	DCA4
Eigenvalues	0.3809	0.3343	00.16108	0.08508
Decorona values	0.3935	0.3208	0.06535	0.04533
Axis Lengths	2.5618	2.7338	1.70473	1.64218

*Decorana, refers to Detrended correspondence analysis. The gradient axis lengths for DCA 1, 2, 4 and 4 are less than 4 thus supporting running of Redundancy Analysis (RDA)

Table 3: Eigenvalues for the constrained and unconstrained environmental variables

RDA (X = Response, Y = Explanatory)				**Eigenvalues for constrained axes**		**Eigenvalues for unconstrained axes**	
	Inertia*	Proportion	Rank	RDA1	RDA2	PC1	PC2
Total	1.45598	1.00000					
constrained	0.14474	0.09941	2	0.12201	0.02273	1.1638	0.1475
Unconstrained	1.31124	0.90059	2				

*Inertia is variance

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Table 4: Summary of regression analysis of individual interactions between biotic and abiotic factors in the distribution of the banana

TISSUE CULTURE BANANA PARAMETERS														
	Biological parameters										Chemical parameters			
Parameter	**Const.**	**Weevil_D**	**Const.**	**TNC (5g)**	**Const.**	**pH**	**Const.**	**OM (%)**	**Const.**	**N (%)**	**Const.**	**P (ppm)**	**Const.**	**K (ppm)**
Est.(E)	-8.1035	$3.202*10^{-3}$	-7.6331	$-1.090*10^{-4}$	-9.097	0.2149	-7.443	-0.0546	-6.881	-4.189	-7.7405	$4.56*10^{-4}$	-7.7329	$6.4*10^{-5}$
s.e	0.0792	$5.37*10^{-4}$	0.0414	$3.19*10^{-5}$	0.266	0.0402	0.147	0.0297	0.142	0.718	0.0474	$3.95*10^{-4}$	0.0561	$1.03*10^{-4}$
t(*)	-102.34	5.96	-184.59	-3.42	-34.14	5.34	-50.74	-1.84	-48.35	-5.83	-163.18	1.16	-137.80	0.62
t pr.	<.001	**.001**	<.001	**.001**	<.001	**.001**	<.001	0.066	<.001	**.001**	<.001	0.248	<.001	0.534
^E	$3.025*10^{-4}$	1.003	$4.841*10^{-4}$	0.9999	$1.120*10^{-4}$	1.240	$5.853*10^{-4}$	0.9468	$1.027*10^{-3}$	0.01516	$4.349*10^{-4}$	1.000	$4.382*10^{-4}$	1.000

NON-TISSUE CULTURE BANANA PARAMETERS														
	Biological parameters										Chemical parameters			
Parameter	**Const.**	**Weevil_D**	**Const.**	**TNC (5g)**	**Const.**	**pH**	**Const.**	**OM (%)**	**Const.**	**N (%)**	**Const.**	**P (ppm)**	**Const.**	**K (ppm)**
Est.(E)	-7.3284	$-1.670*10^{-4}$	-7.6331	$3.50*10^{-5}$	-6.922	-0.0898	-7.598	0.0216	-7.807	1.530	-7.4784	$-1.94*10^{-4}$	-7.7329	$6.4*10^{-5}$
s.e	0.0776	$6.08*10^{-4}$	0.0414	$2.11*10^{-5}$	0.239	0.0374	0.133	0.0262	0.126	0.585	0.0424	$3.75*10^{-4}$	0.0561	$1.03*10^{-4}$
t(*)	-94.49	-2.75	-184.59	1.66	-29.01	-2.40	-57.32	0.82	-61.90	2.61	-176.44	-0.52	-137.80	0.62
t pr.	<.001	**0.006**	<.001	0.097	<.001	**0.016**	<.001	0.410	<.001	**0.009**	<.001	0.604	<.001	0.534
^E	$6.566*10^{-4}$	0.9983	$4.841*10^{-4}$	1.000	$9.857*10^{-4}$	0.9141	$5.016*10^{-4}$	1.022	$4.070*10^{-4}$	4.619	$5.652*10^{-4}$	0.9998	$4.382*10^{-4}$	1.000

Parameter descriptions; *Constant-(**Const.**), Banana Weevil density-(**Weevil_D**), Total Nematode counts in 5 g of composite root sample-**TNC(5g)**, Percentage organic matter in the soils -**OM(%)**, Percentage Nitrogen availability-**N(%),** Phosphorus in parts per million-**P(ppm**), Potassium in parts per million-**K(ppm).** Est. (E) refers to Estimates of the parameters in the model, s.e, standard error, ^E, is the antilog of estimates of parameters, t pr. (test-probability), are t probabilities for the parameter estimates*

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REFERENCES

1. **Van Asten PJA, Wairegi LWI, Mukasa D and NO Uringi** Agronomic and economic benefits of coffee-banana intercropping in Uganda's smallholder farming systems. Agricultural Systems, 2011; **104** (**4**): 326–334.

2. **Komarek MA, Fredoun Z and E Ahmadi** The impact of changing marketing conditions on Ugandan banana farmers. *Journal of Agribusiness in Developing and Emerging Economies*, 2013; **2** (**1**): 74–88.

3. **Ayuke FO, Brussaard L, Vanlauwe B, Six J, Lelei DK, Kibunja C and MM Pulleman** Soil fertility management: impacts on soil macrofauna, soil aggregation and soil organic matter allocation. *Applied Soil Ecology.* 2011b; ***48***: 53-62.

4. **Pawar DR and KM Shah** Laboratory Testing Procedure for Soil and Water Sample Analysis. Government of Maharashtra Water Resources Department, Directorate of Irrigation Research and Development 2009.

5. **Nyombi K** Towards Sustainable Highland Banana Production in Uganda: Opportunities and Challenges. *African Journal of Food Agriculture, Nutrition and Development*, 2013; **13**(**2**): 7544–7561.

6. **Arinaitwe IK, Hilman E, Ssali R, Barekye A, Kubiriba J, Kagezi G and H Talwana** Response of banana hybrids to the banana weevil (Cosmopolites sordidus Germar) (Coleoptera : Curculionidae) in Uganda. *Uganda Journal of Agricultural Sciences*, 2014; **15**(**1**): 73–85

7. **Gaidashova SV, Asten PV, Waele D and B Delvaux** Relationship between soil properties, crop management, plant growth and vigour, nematode occurrence and root damage in East African Highland banana-cropping systems : a case study in Rwanda. *Nematology*, 2009; **11**(**6**): 883–894.

8. **Murongo MF, Ayuke OF, Mwine TJ and KJ Wangai** Farmer - based dynamics in tissue culture banana technology adoption: a socio-economic perspective among smallholder farmers in Uganda. *African Journal of Agricultural Research*, 2018; **13**(**50**): 2836–2854.

9. **Mahajan S and N Tuteja** Cold, salinity and drought stresses; an overview, *Arch. Biochem. Biophys*. 2005; **444**: 139–158.

10. **Ayuke OF** Effects of soil management on aggregation and organic matter dynamics in sub-Saharan Africa, *Afr. J. Food Agric. Nutr. Dev*. 2019; **19** (**1**):13992-14009

11. **Speijer PR** East African highland banana production as influenced by nematodes and crop management in Uganda. *International Journal of Pest Management*, 2017; **45** (**1**): 41–49.

12. **Wachira PM, Kimenju JW, Kiarie JW, Kihurani AW and WS Mwaniki** Occurrence and Diversity of Nematode Destroying Fungi in Banana Production Zones in Maragua, Kenya; *Journal of Agricultural Science*; 2013; **5** (**12**). https://doi.org/10.5539/jas.v5n12p180

13. **Gowen SR, Quénéhervé P and R Fogain** Nematode Parasites of Bananas and Plantains; in Plant Parasitic Nematodes in Subtropical and Tropical Agriculture: Second Edition. 2005. https://doi.org/10.1079/9780851997278.0611

14. **Nankinga CM and D Moore** Reduction of Banana Weevil Populations Using Different Formulations of the Entomopathogenic Fungus Beauveria bassiana. 2016; **3157** (September). https://doi.org/10.1080/095831500750016442

15. **Dubois T, Dusabe Y, Lule M, Van Asten PJ, Coyne D, Hobayo JC and J Mugisha** Tissue culture banana (Musa spp.) for smallholder farmers: Lessons learned from East Africa. *Acta Horticulturae*, 2013; **986** : 51–60.

16 **Huang BQ and EC Yeung** Chemical and Physical Fixation of Cells and Tissues : An Overview. 2015; 23–33. https://doi.org/10.1007/978-3-319-19944-3

17. **Alou IN, van Asten PJA and MM Tenywa** Biophysical and crop management gradients limiting yields of East African highland banana. *International Journal of Agricultural Science and Research*, 2014; **4** (**3**): 27–44.

18. **Ocan D, Mukasa HH., Rubaihayo PR, Tinzaara W and G Blomme** Effects of banana weevil damage on plant growth and yield of East African Musa genotypes. *Journal of Applied Biosciences*, 2008; **9** (**2**): 407–415.

19. **Sabiiti G, Ininda JM, Ogallo L, Opijah F and A Nimusiima** Empirical Relationships between Banana Yields and Climate Variability over Uganda. *Journal of Environmental and Agricultural Sciences*, 2016; **7** (**3**): 3–13.

20. **Majaliwa JGM, Twongyirwe R, Nyenje R, Oluka M, Ongom B, Sirike J, Mfitumukiza |D, Azanga E, Natumanya R, Mwerera R and B Barasa** The Effect of Land Cover Change on Soil Properties around Kibale National Park in South Western Uganda, *Applied and Environmental Soil Science*, vol. 2010, Article ID 185689, 7 pages, 2010. https://doi.org/10.1155/2010/185689

21. **Kyebogola S, Lee CB, Bradley AM, Semalulu O, Russell SY Tenywa M, Andrew WL, Kyomuhendo P, Christopher S, Luswata CK, Mwanjalolo JGM, Lance G, Carol JPC and RE Mazur** Comparing Uganda's indigenous soil classification system with World Reference Base and USDA Soil Taxonomy to predict soil productivity; Geoderma Regional 22; 2020 e00296.

22. **Lysenko EG** Environmental and ecological sciences, engineering and technology resources. In: Encyclopedia of Life Support Systems (EOLSS). *Eolss Publishers, Oxford*. 2004. Available at http://www.eolss.net *Accessed in April 2020.*

23. **Jallow M and DT Achiri** Performance of three trap types for monitoring plantain weevil (Cosmopolites sordidus, Germar) in plantain cropping systems in Ghana. *Journal of Agriculture and Veterinary Science*, 2016; **9** (**2**): 17–23.

24. **Coyne DL, Nicole MJ and B Claudius-Cole** Practical Plant Nematology**:** *A Field and Laboratory Guide* SP-IPM Secretariat, International Institute of Tropical Agriculture (IITA), Cotonou, Benin 2007; p. 82.

25. **EPPO.** European and Mediterranean plant protection organization: PM 7/119 (1) Nematode extraction. 2013 EPPO Bull 43:471–495. https://doi.org/10.1111/epp.12077

26. **Staniland L** A Modification of the Baermann Funnel Technique for the Collection of Nematodes from Plant Material. *Journal of Helminthology, 1954;* ***28*****(2)**: 115-118. https://doi.org/10.1017/S0022149X00032739

27. **Adl SM** Enchytraeids, **In**: Carter, **MR**., Gregorich, **EG**. (Eds.), Soil Sampling and Methods of Analysis. Second ed. Canadian Society of Soil Science, 2008; pp.445–453.

28. **Okalebo JR, Gathua KW and PL Woomer** Laboratory methods of soil and plant analysis: A working manual. 2nd edn, 2002; TSBF-CIAT/SACRED Africa, Nairobi, Kenya.

29. **Wakley A and IA Black** An examination of the Degthareff method for determining soil organic matter and a proposed modification of the chromic acid titration method, Soil Science, 27; 1934, pp. 29-38.

30. **Douglas WP** A critical review of the conventional SOC to SOM conversion factor, Geoderma, Volume 156, Issues 3–4, 2010, Pages 75-83, ISSN 0016-7061. https://doi.org/10.1016/j.geoderma.2010.02.003

31. **Doran I, Sen B and Z Kaya** The effect of compost prepared from waste material of banana plants on the nutrient contents of the banana leaves; J. Environ Biol. 2003; **24 (4):**437-44.

32. **Yagi R, Ferreira ME, Cruz M, Cristina P, Barbosa JC and LAN Araújo** Soil organic matter as a function of nitrogen fertilization in crop successions. *Scientia Agricola*, 2005; 62**(4)**: 374-380. https://doi.org/10.1590/S0103-90162005000400011

33. **Twesigye CK, Ssekatawa K and A Kiggundu** Variation among banana weevil *Cosmopolites sordidus* (Germar) populations in Uganda as revealed by AFLP markers and corm damage differences. *Agric & Food Secur* **7,** 76 2018. https://doi.org/10.1186/s40066-018-0227-8

34. **Risede J** Integrated management of banana nematodes; Lessons from a case study in the French West indies, From Science to the field, 2010; 1-8; available at https://agritrop.cirad.fr/553878/1/document_553878.pdf *Accessed April 2020.*

35. Seenivasan N Management of *Radopholus similis* and *Helicotylenchus multicinctus* in Ratoon Banana Grown under High Density Planting Systems, *International Journal of Fruit Science*, 2017; **17**(**1**): 41-62.

36. Hennessy C, Walduck G, Daly A and A Padovan Weed hosts of Fusarium oxysporum f. sp. cubense tropical race 4 in northern Australia, *Australasian Plant Pathology* 2005;**34.** https://doi.org/10.1071/ap04091

37. **Sjakir M, Manaf AA, Hussain MY and Z Ramli** Learning and Technology Adoption Impacts on Farmer ' s Productivity. 2015; **6** (**4**). https://doi.org/10.5901/mjss.2015.v6n4s3p126

38. Lambert, K. and S. Bekal. 2002. Introduction to Plant-Parasitic Nematodes. *The Plant Health Instructor*, 2009 by the Education Center Editorial Board. https://doi.org/10.1094/PHI-I-2002-1218-01