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Non-Chemical Management of Banana Nematodes and its Impact on Smallholder Communities in Central Uganda

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Abstract: Bananas are the most important food crop in Uganda. However, a decline in yields has resulted in a spatial shift from the traditional banana growing areas of central and eastern Uganda to the south-west. Plant parasitic nematodes are among the major factors responsible for the decline in yields. In an on-farm trial to evaluate the use of break-crops to manage nematodes and their impact on smallholder farmer communities in Uganda, bananas were removed completely from some plots that were planted with either cassava or sweet potato before bananas were replanted. The cassava break-crop reduced soil populations of *Radopholus similis* and *Helicotylenchus multicinctus* to negligible levels in a period of 15 months. Cassava roots supported minimal levels of the banana nematodes with the exception of *Meloidogyne* spp. which increased to levels higher than those observed in banana. Provision of planting materials of a variety resistant to the African cassava mosaic virus influenced choice of the break-crop. None of the banana nematodes seemed to multiply readily on the sweet potato as a break-crop. However, the observations were too few to be conclusive. Soil nutrient analysis indicated rapid depletion of soil potassium and calcium under the break-crops. In the 3-year period of participation, farmers' perception of nematodes as one of the causes of banana decline rose from zero to 41%. However, the purpose of the trial was still not well understood, with only 32% relating it to pest management. Participating farmers were introduced to new technologies particularly the use of clean planting materials generated through tissue culture, improved their knowledge on banana production and consequently, a change in mindset from considering banana production only for food security, but also as a business venture.

Keywords: Banana · Break-crop · Cassava · *Helicotylenchus multicinctus* · *Meloidogyne* spp. · *Pratylenchus goodeyi* · *Radopholus similis* · Sweet potato

INTRODUCTION

Uganda is the world's second largest producer of bananas/plantains (*Musa* spp.), after India, with an estimated annual production of 9.77 million tonnes, accounting for more than 9% of world production [1]. Uganda is also the world's largest consumer of bananas. It is estimated that within the country, more than 7 million people subsist on bananas and 65% of the urban population have a meal of the cooking bananas, the East African Highland bananas (*Musa* AAA-EA), locally known as 'Matooke', at least once a day. Average per capita consumption of bananas is estimated at close to 1 kg per person per day [2].

Bananas occupy the largest cultivated area among staple food crops in Uganda and are primarily grown on small subsistence farms, very often on plots of less than 0.5 ha. Over 75% of the country's farmers grow bananas on 1.8 million hectares(ha) [1]. In addition to being a major food staple, bananas are an important source of income, with surplus production sold in local markets.

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Although there has been some increase in banana production in Uganda, a gradual decline in yields during the last four decades was recorded. While total production increased from 7.7 million tonnes in 1970 to 8.4 and 9.8 million tonnes in 1988 and 2013 respectively, yields decreased from 8.4 tonnes/ha in 1970 to 6.0 and 5.4 tonnes/ha in 1988 and 2013, respectively. The increase in production therefore, is attributed to increased area under banana, which increased from 0.91 million ha in 1970 to 1.4 and 1.8 million ha in 1988 and 2013, respectively [1, 3].

Although bananas are one of the most important food crops in Uganda, the decline in yields has caused a change in production patterns. There has been a spatial shift from the traditional banana growing areas of central and eastern Uganda to the south-west. According to the 2008/2009 census conducted during the second planting season of 2008 and the first season of 2009, production of the cooking banana crop was 68% in the Western Region, followed by the Central Region at 23%, the Eastern Region at 8% and the Northern Region with less than 1%.The highest average yields were recorded in the Western Region at 6 tonnes/ha and the lowest in the Central Region at 3.3 tonnes/ha [4].

In addition, a shift from banana cultivation to root crops, particularly cassava (*Manihot esculenta* Crantz) and sweet potato (*Ipomoea batatas* (L.) Lam. has occurred in the central and parts of eastern Uganda. A significant increase in the area under cassava and sweet potatoes as well as total production has been observed. The area under cassava increased from 0.28 million ha with total production of 1.06 million tonnes in 1971 to 0.38 and 0.44 million ha with total production of 3.42 and 5.2 million tonnes in 1994 and 2013, respectively. Similarly, the area under sweet potato increased from 0.33 million ha in 1971 to 0.48 and 0.55 million ha in 1994 and 2013, respectively. Consequently, sweet potato production increased to 2.2 and 2.6 million tonnes in 1994 and 2013, respectively [1, 5].

During investigations aimed at elucidating the major production constraints of banana in Uganda, plant parasitic nematodes were identified among the major factors responsible for the decline in production. The nematodes of *Radopholus similis* (Cobb) Thorne, *Helicotylenchus multicinctus* (Cobb) Golden and *Pratylenchus goodeyi* Sher & Allen are the most important species responsible for the decline in banana production and productivity in Uganda [7, 8].

The decision to employ one nematode management practice over another is often based on an understanding of the crop production system and the ecology of its principal pests. Nematode management options such as nematicides, biological control, crop resistance and crop rotation, must be evaluated before recommendations are made. However, some of these management alternatives such as nematicides are expensive, while biological control agents have limited commercial effectiveness and therefore limited use to tropical subsistence farmers. In many agricultural systems, cultural methods are considered the most economic means of control, because nematode-resistant crops are not usually available, or crop values are too low to justify cost of treatments [9].

In areas where bananas are grown continuously without replanting, the opportunity for controlling nematodes by cultural techniques is limited. However, in replanted crop systems, nematode populations can be controlled by either making a fallow or rotating with non-host crops [10]. In Uganda where banana is grown as a subsistence crop, on small plots of soil by resource-poor farmers, a bare fallow would not be feasible because it does not contribute to household food security or income and yet it utilizes resources, namely, soil and labours to keep the plot free of vegetation. Therefore, use of a break-crop grown as a secondary crop to provide diversity, may be productive and subsequently reduce pest and disease pressure in a field.

Furthermore, although bananas are considered a perennial crop, plantation life has reduced from over 50 years to only as low as 4 years in central and eastern Uganda [11, 12]. This makes use of break-crops a viable option for management of banana nematodes. Since cassava and sweet potato which rank second and third, respectively, in importance as food staples are already being grown as replacements to banana. Their host status to the important banana nematodes, as well as the ability to reduce banana nematode populations in a banana-root crop sequence have been investigated. Observations from pot experiments indicate that cassava and sweet potato are non-hosts of *H.multicinctus, R.similis* and *P.goodeyi* and a recommendation of a banana-cassava-sweet potato-banana cropping sequence and use of clean banana planting material is made from an on-station field trial [13].

The objectives of this study were therefore, to generate more information on the host status of cassava and sweet potato to banana nematodes, to assess the effectiveness of cassava and sweet potato as break-crops and use of clean planting materials in the control of banana nematodes under field conditions, to determine the effective duration for the break-crops to control the key nematodes and to assess the impact of these technologies on smallholder farmer communities in Uganda.

MATERIALS AND METHODS

An on-farm trial was established on 27 farms in Kayunga sub-county, Kayunga district in central Uganda, at a latitude 0°42'09″ N, longitude 32°53'18″ E and elevation 1071 metres above sea level (m.a.s.l) [14]. The selected farms were those which had poorly growing banana plots previously confirmed as nematode-infested ones.

A subplot of 20 x 20 m was marked out of each of the old banana plots to cater for the planned replanting plot of 25 banana mats. Farmers completely uprooted banana plants from their devastated banana plots and the fleshy banana pseudostems and corms were chopped into very small pieces to enable rapid drying. The plots were then planted with a break-crop of their own choice, either cassava or sweet potato. However, each farm had to have a plot where bananas were not removed, to represent the continuous banana cropping sequence which was served as control. Each participating farmer planted two crop cycles of cassava and/or sweet potato in the experimental plots, giving a maximum of two years under the break-crop.

Before farm selection, several meetings were conducted between the National Banana Research Programme team and the other principal stakeholders, namely, farmers, District Agricultural officers and Local administrators. The aim of the meetings was to introduce the study and its objectives to the stakeholders; understand farmers' attitudes to the technology and their willingness to participate in the study and to collect additional information to be used in developing better farmer selection criteria. A baseline survey of farms and households was done to identify factors that would be influential in implementing and execution of the study. All households selected for participation in the research were interviewed. A follow-up study was made 12 months later to seek views from the participating farmers regarding strengths, weaknesses, opportunities and threats to the research project.

Planting of the break-crops on all farms was completed within six months. At the time, the African Cassava Mosaic Virus (ACMV) was a very serious problem devastating cassava fields in Uganda. Therefore, an ACMV- resistant variety SS4 was provided to the farmers for the cassava break crop. Those farmers who planted sweet potato were allowed to use their own planting materials and varieties of their choice. Since it is common practice in Uganda to harvest food crops piecemeal, farmers harvested their crops as and when they wanted and they replanted with the same crop immediately after harvesting the old crop.

Replanting with banana was done, approximately 24 months after planting the initial break-crop on all the farms. Clean planting materials, mainly tissue culture plantlets and in a few instances, pared corms of the banana cultivars Nakitembe and Ndibwabalangira, were provided to the farmers. The banana corms were obtained from a mother garden established at the research institute using tissue culture plantlets, specifically for that purpose. Cultivar selection was based on data collected on farmer preferences during the baseline survey [15].

Prior to the removal of the bananas, soil and root samples were taken from the trial fields to determine the banana nematode population levels. Regular soil and root sampling to monitor banana nematode population fluctuation from both the break-crop and control plots did not commence until about 6 months later when break-crops had developed adequate root systems. Five samples, each comprised of soil and roots, were collected from every plot. In addition, composite soil samples were collected from the experimental plots for soil nutrient analysis on three occasions; pre-treatment, 12 months and 24 months after the initial break-crop planting to assess the level of nutrient depletion so as to enable making recommendations for replenishment before bananas are replanted. Supplementary data on soil nutrient changes were collected from an on-station trial which was similar but with a wider range of break-crop species.

Extraction of migratory nematodes from soil and roots was done by the filtration and maceration-filtration technique, respectively, using a modification of the Baermann-funnel technique [13, 16, 17]. Means and standard errors of the means of nematode count data were computed using Addinsoftware XLSTAT 2012 [18]. The soil samples were analysed for the main nutrient levels namely, phosphorus (P), calcium (Ca), potassium (K), magnesium (Mg), sodium(Na) and nitrogen (N), clay, silt and sand content and pH, to determine changes in soil nutrient levels over time.

Before planting the break-crop and during the course of the study, participating farmers were trained in banana production techniques including crop and pest management as well as soil fertility improvement practices. All farmers were advised to apply organic manures at, or immediately after replanting banana.

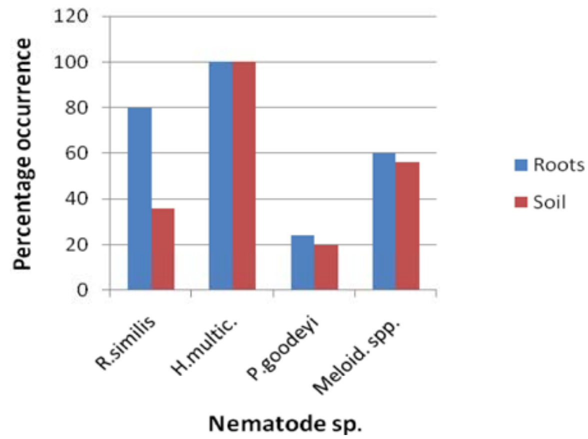
An impact assessment study was done, 36 months after the midterm socio-economic study to evaluate improvement in farmers' knowledge and effectiveness of the break-crop technology. Participatory evaluation techniques were used to assess both the effectiveness of the non-chemical control of banana nematodes using break- crops and the impact made on farmers, both participating and non-participating. Two groups of farmers participating in the study, one from Ntooke village and another from Ntenjeru, were involved in the appraisal. Each group comprised nine participants. One group interview was also conducted with nine non-participating farmers to evaluate their perception of the break-crop technology and the impact made relating to knowledge spill over. In addition, farmers' experimental plots were assessed by the researchers and ranked as very good, good, fair, poor and very poor depending on the type of management and performance of the banana plants.

RESULTS

Farmers' Preference of Break Crop: Of the 27 selected farmers, 21 opted for cassava, two opted for both cassava and sweet potato, while two opted for the sweet potato break-crops. One farmer dropped out before the break-crop was planted, while another one sold the plot on which the experiment had been established. The total number of farms, from which cassava root samples were collected, fluctuated, since the cassava crop was not planted at same time and yet root samples were collected from only fields where the cassava root system was well developed. Of the four farmers who opted to have a sweet potato break-crop, only two continued with the trial to the end and therefore, data collected from the sweet potato plots were not conclusive due to the small number of observations. Most of the farmers had inter-planted the young cassava with beans and/or maize and groundnuts. Although intercropping had not been anticipated by the researchers, the farmers were not stopped, since it is a common practice.

Distribution of Nematode Species in Banana Fields Prior to Planting the Break Crop: Pre-treatment soil and root sampling showed that all the four important banana nematode species namely, *R. similis*, *H. multicinctus*, *P. goodeyi* and *Meloidogyne* spp. (must be identified to species). were present in the area. However, *H.multicinctus* was the most frequent, occurring on all farms, while *P. goodeyi* was the least frequent, detected from roots and soil from only 24 and 20 percent of the farms, respectively (Figure 1). *H. multicinctus* was also the most abundant nematode species in soil and roots (Figure 2).

Effect of Break Crops on the Distribution of Nematodes Species: In both continuous banana and the cassava break-crop plots, nematode populations in soil and roots were observed to fluctuate over time. Soil nematode population densities of *R.similis* and *H.multicinctus* were consistently much lower in the cassava break-crop than in the control plots. On the contrary, population densities of *P.goodeyi* and *Meloidogyne* spp. in soil were higher in the cassava break-crop than the control plots on three and four sampling dates, respectively. However, no *R.similis*, *H.multicinctus* and *P. goodeyi* were recovered from soil under the cassava break-crop, 21 months after the initial planting of the break-crop, just before removal of the break-crop to replant the plots with banana (Figure 3).

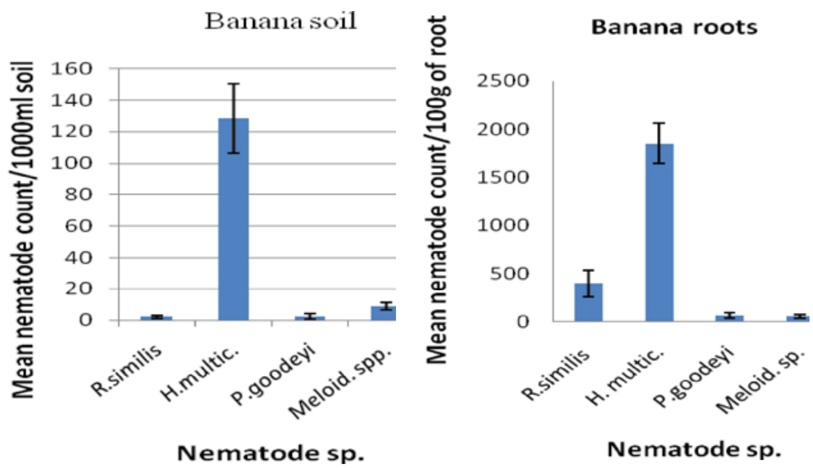


Total number of sampled banana plots (n) = 23.

Fig. 1: Percentage occurrence of banana nematode species in banana plots at the initial sampling.

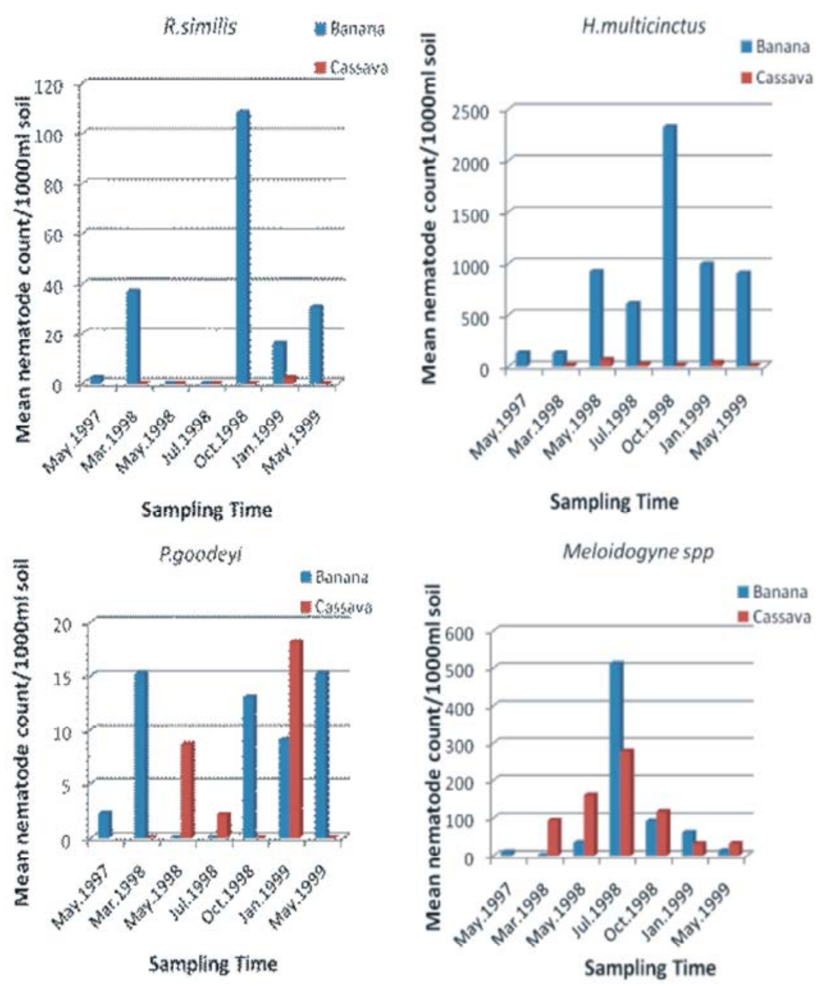
Population densities of *R.similis*, *H.multicinctus* and *P.goodeyi* in cassava roots were constantly negligible compared to those recovered from banana roots. However, *Meloidogyne* spp. densities were constantly much higher in cassava roots than in banana roots (Figure 4).

No *P.goodeyi* and *Meloidogyne* sp. were recovered from roots taken from both the sweet potato break-crop and continuous banana (control) plots. *R.similis* was recovered from roots of only one sample taken from a control plot at a population density of 1000 and 1500 nematodes /100g of root, 11 and 13 months, respectively, after the initial planting of the break-crop. No *R.similis* was recovered from soil collected from the control plots; neither it was recovered from soil or roots under the sweet potato break-crop. Therefore, neither *R.similis* nor *P.goodeyi* were included in the analysis. *H.multicinctus* on the other hand, was recovered at relatively high but fluctuating population densities from roots and soil taken from almost all control plots at the various sampling dates, but from only one root sample taken from a plot under the sweet potato break-crop, 13 months after



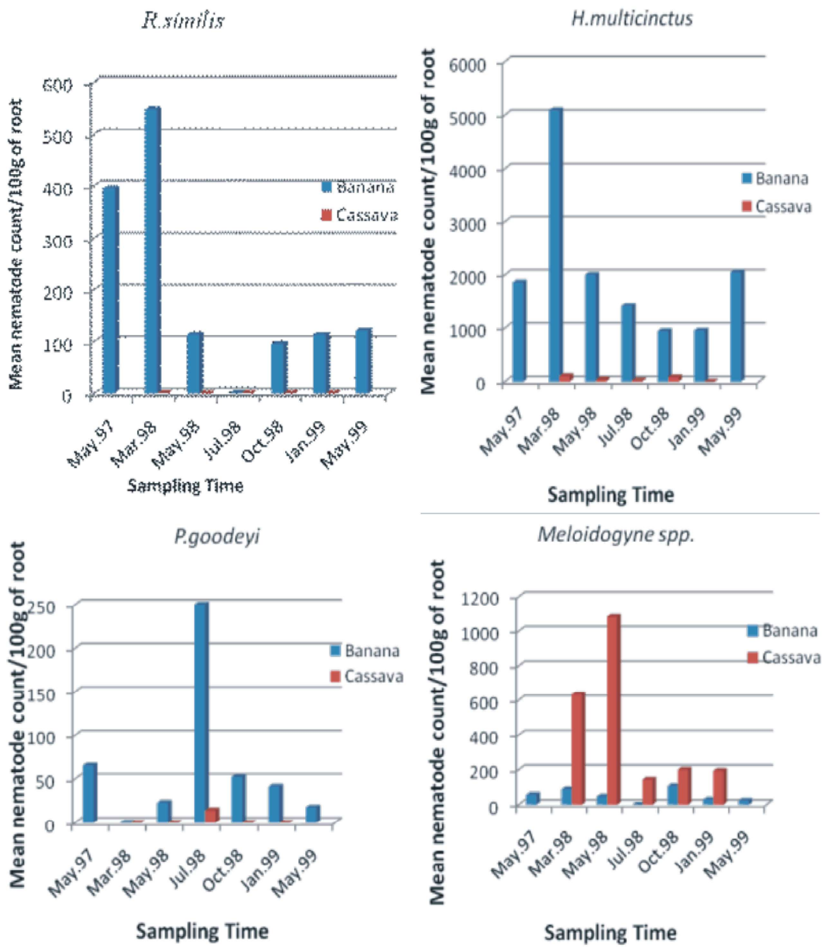
The number of sampled plots (n) =23

Fig. 2: Mean initial banana nematode soil and root population densities from selected banana plots



Values are means of 23 plots, each consisting of 5 samples per plot. The values for May'97 were the initial counts from banana before the cassava break-crop was planted and the values for cassava in May '99 are for soil samples collected from plots where the cassava break-crop had just been removed but before banana replanting.

Fig. 3: Mean nematode soil population density under continuous banana and cassava break-crop sequences over time



Values are means of nx5 samples where n is the number of sampled plots and 5 samples were collected from each plot as follows: May ’97, n=23; March ’98, n=17; May’98, n=12; July ’98, n=14; October ’98, n=12; January ’98, n=16; May ’98, n=23. There was no cassava crop in May’97 and May ’99.The values for May’97 were the initial counts from banana before the cassava break-crop was planted.

Fig. 4: Mean root nematode population density under continuous banana and cassava break-crop sequences over time

Table 1: Mean nematode population densities (count per 100g of roots or 1000ml of soil) recovered from plots under a sweet potato break-crop and continuous banana (control) at different sampling times.

	H.multicinctus		*Meloidogyne* spp.	
Sampling date	Banana Roots	Banana Soil	Banana Soil	Sweet Potato Soil
Oct-97	2500.00	250.00	0.00	0.00
Jan-98	2500.00	250.00	0.00	0.00
Mar-98	500.00	166.67± 83.33	0.00	83.33± 46.72
May-98	3666.67± 833.33	333.33± 166.67	166.67 ± 83.33	0.00
Jul-98	3666.67± 1833.33	3000.00± 1000.00	0.00	100.00±47.56
Oct-98	733.33± 354.79	4116.67± 1317.89	66.67 ± 45.43	16.67± 16.67
Jan-99	1500.00± 449.87	283.33± 124.08	0.00	0.00
May-99	1200.00± 357.90	300.00± 142.68	0.00	0.00

planting the break-crop, at a population density of 133.3 nematodes/100g of root. *Meloidogyne* spp. was recovered from a few soil samples collected from both sweet potato break-crop and control plots (Table 1).

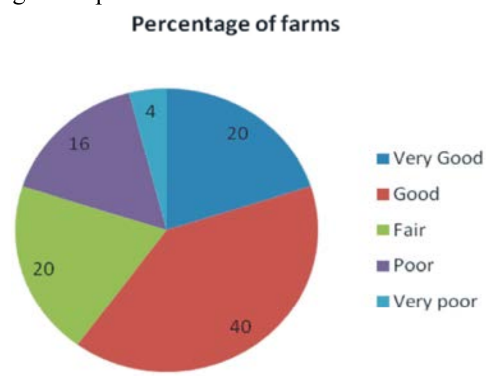
Comparative Depletion of Soil Nutrients by Break Crops: On-farm results indicated no consistent effects of cassava and sweet potato on the levels of nutrients in soil. However, analysis of soil samples and data collected from a similar on-station trial show that maize and cassava deplete soil of K and Ca, falling year by year, compared with banana. The level of K fell by 63.5% after one year and by 76.3% after two years of continuous cultivation of cassava in a field previously under banana. The level average of K in the cassava plots after two years was reduced by 69% compared with continuous banana plots. In the first year, K level average under sweet potato fell by 46.6% and Ca levels by 19.5%, but did not fall further in the second year. There was also a significant increase in soil pH under cassava, but not in sweet potato [19].

The Impact of Using Breakcrops on Smallholder Banana Farmers: Farmers' perception of nematodes as one of the causes of banana decline rose from zero in 1997 to 41% of the participating farmers in 1999, although at the time only 14% reported being aware of methods for controlling nematodes [15, 20]. Despite the pre-trial sensitization and training during the course of the trial, the purpose of the break-crop was still not well understood. Of the participating farmers, 14% understood it to be concerned with soil improvement, 46% thought it was meant to promote cassava and only 32% related it to pest control. Visual assessment of management practices and crop performance is given in Figure 5.

Expectations of the participants during the impact assessment meeting were almost the same for both groups of the participating farmers and these were: (i) to analyze the positive and negative attributes of the study (ii) to assess the constraints/problems encountered while implementing the trial (iii) to identify knowledge gaps regarding banana production (iv) to receive research findings from scientists (v) to share experience from the on-farm trial with other farmers, both participating and non-participating (vi) to devise ways of disseminating the technology to other farmers and areas.

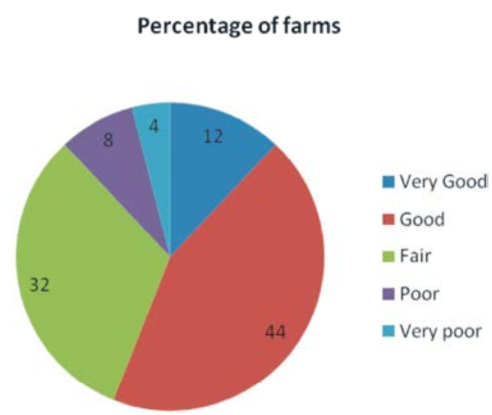
All participating farmers admitted having benefitted from hosting the trial through improved knowledge in banana production, especially in the following aspects: (i) mulching to improve soil moisture retention and fertility; previously only 37.7% of the farmers had applied some form of mulch, mainly banana trash and the rest did not mulch because they did not know the importance of the practice (ii) detrashing by removing only dry leaves and leaf sheaths; previously only 3.5% of the farmers detrashed their plants and they did so by removing a lot of green leaves and fresh leaf sheaths (iii) spacing of 3 m between lines and between mats; previously spacing was not regular (iv) construction of contour bands to control soil erosion; previously the practice was unknown

Management practices



Very good = weed free; mulch and manure added; all sanitation practices applied.
Good = weed free; mulch added; all sanitation practices applied.
Fair = weed free; some sanitation practices applied
Poor = some weeds present; some sanitation practices applied
Very poor = no management practices applied

Crop performance



Very good = over 60% flowering; some big bunches; high sucker production; very healthy plants
Good = 50 - 59% flowering; high sucker production; healthy plants
Fair = 25 – 49% flowering; average sucker production; healthy plants
Poor = very little or no flowering; poor sucker production; stunted plants
Very poor = 0-2 suckers produced; very stunted plants

Fig. 5: Visual assessment of management practices and crop performance of replanted banana plots

(v) reducing plant population by leaving the mother, daughter and grand-daughter plants on the mats; previously only 3.4% of the farmers practised desuckering, while the rest removed suckers only if they were needed for planting material (vi) control of weevils by trapping (vi) removal of leaves infested with Black Sigatoka; previously farmers were not aware that leaf drying was caused by a disease (vii) use of break crops to control banana nematodes; (viii) use of compost manure to improve soil fertility and plant vigour.

The participating farmers also highlighted some negative aspects such as small bunch sizes. They, however, attributed the size of bunches to the severe dry weather conditions experienced during the trial period as well as the agronomic characteristics of the selected banana cultivars. The farmers, also, concurred that the cultivar Ndibwabalangira generally produces small bunches. They admitted that it had emerged second in preference (preferred by 50% of the respondents) after Nakitembe (preferred by 57.1% of the respondents) during the baseline study simply because it is believed to be tolerant to their environmental conditions and produces very good food (soft with a good flavor and a deep yellow colour when steamed). It is also early maturing. They argued that by then, their main problem was food security and those were the attributes that were most appealing. They pointed out that now production for business was being taken seriously, they would prefer a cultivar that produces big bunches which would fetch a good market price.

The participating farmers reported challenges during implementation. These included: (i) prolonged drought (ii) difficulty of raising enough quantities of compost manure (iii) lack of wheelbarrows to transport the manure (iv) lack of adequate quantities of mulch (v) pests, mainly the banana weevil, black ants, locally known as" kaasa" and termites that destroy the mulch and (vi) black Sigatoka disease.

The high suckering rate of the replanted banana plots was regarded as a negative attribute by a few farmers because of the increased labour requirement for desuckering. In addition, a few farmers regarded discouragement from removal of green banana leaves as well as intercropping as negative attributes. This was so because green leaves are traditionally harvested and used for steaming bananas, while intercropping is a diversification practice aimed at minimizing risks and maximizing benefits.

Drought was also given as a major limiting factor for newly planted suckers to get established, especially for pared corms. They, however, appreciated tissue culture plants that were reported to recover easily from drought shock. This was indeed a positive development because at the time of replanting bananas, almost all the farmers rejected the tissue culture plantlets because they did not believe that such small plantlets would ever develop into big plants. The farmers were persuaded to plant them only with an assurance to have them replaced with big suckers should the performance of the tissue culture plantlets be rated unsatisfactory after one month. Afterwards, the farmers did not wish to use any other type of planting material other than tissue culture plantlets.

The participating farmers reported having realized the following benefits : (i) improved food security and income from the harvested cassava stems and tubers as well as banana bunches, adding that the bananas harvested from the trial plots made "good" food (ii) a higher rate of sucker production and therefore more planting materials for both expansion of existing fields and giving to neighbours and/or selling(iii) faster maturing bunches from the trial plot (iv) reduced weeding and detrashing labour costs resulting from mulching and removal of only dry leaves and sheaths respectively (v) reduced soil requirements due to closer spacing of bananas (vi) new techniques of banana production including rehabilitation of debilitated plantations, rapid multiplication of banana suckers and keeping records, especially bunch weight.

Expectations of the non-participating farmers during the impact assessment meeting were to learn about farming practices and how to grow bananas. They did, however, have some knowledge about banana management because when asked what they knew about banana production, they mentioned the following: (i) spacing of 10ft, 3m, or 2 paces between plants; those farmers who use a spacing of 10ft or 3 m gave their source of information as the Uganda National Farmers' Federation (UNFFE), while those who use paces quoted their parents as their source of information (ii) addition of soil amendments such as compost, crop residues and animal manure at the time of planting (iii) planting pest-free suckers (iv) detrashing by removing only old and damaged leaf sheaths. There was no mention of the break-crop technology, although five of the non-participating farmers admitted knowing some farmers who grew bananas using practices that were different from the traditional ones. The practices referred to included use of contour bands, reduction of sucker population, mulch application and corm and sheath removal and through mentioning names, it was confirmed that the farmers referred to were those participating in the break-crop trial. Although they had no idea about the break-crop technology, the non-participating farmers admitted that they knew two farmers in the area that had planted bananas immediately after removal of a cassava crop.

The values for October 1997 and January 1998 are means of two composite samples (each made up of five subsamples) taken from two farms while those for the remaining sampling times are means of 10 subsamples collected from two farms (5 subsample per farm). *H.multicinctus* was recovered from roots of only banana, but was recovered from soil in both the sweet potato break-crop and continuous banana plots. *Meloidogyne* sp. was recovered from only soil taken from both sweet potato and banana plots. No *P.goodeyi* was recovered from either soil or roots taken from any of the plots. *R.similis* was recovered from roots of only one sample taken from a control plot in January and May 1999 respectively. No *R.similis* was recovered from soil collected from the control plot; neither was it recovered from either soil or roots under the sweet potato break-crop. Therefore, neither *R.similis* nor *P.goodeyi* was included in the analysis.

DISCUSSION

It was not surprising that all the four major nematode species, namely, *R.similis*, *H.multicinctus*, *P.goodeyi* and *Meloidogyne* spp. were encountered. While the first three species are both widespread and abundant in Uganda, *P.goodeyi* occurs at all elevations and is the only species found on banana above 1600 m.a.s.l; *H.multicinctus* occurs at all sites below 1600 m.a.s.l and *R.similis* occurs primarily in central and eastern Uganda [8]. Kayunga, the trial site, is located in central Uganda at an elevation of 1071 m.a.s.l.

Meloidogyne spp. densities in cassava roots continued multiplying to levels much higher than in banana roots. This was because cassava is a good host of *Meloidogyne* spp. [13, 21, 22, 23]. These observations, therefore, suggest that cassava is a more suitable host for *Meloidogyne* spp. than banana. Although observations on the sweet potato as a break-crop were not conclusive in this study, the suggestion of planting a sweet potato crop immediately after the cassava break-crop to reduce *Meloidogyne* populations before banana is replanted [13] perhaps still holds since there was no indication of sweet potato being a good host to *Meloidogyne*.

At least, 15 months of break-crop cultivation is required to reduce banana nematodes to negligible levels [13, 24]. In this study, however, the optimum period required under break-crops to clear the banana nematodes could not reliably be determined since farmers continued interplanting the break-crop with crops that are hosts of the banana nematodes. Beans and maize, for example, are known hosts of *Pratylenchus goodeyi* [13]. The full benefits of this technology therefore, cannot be fully realized on-farm unless there is thorough training of the farmers, as well as close collaboration between research scientists and extension workers in the area so as to avoid giving contradicting messages to the farmers. In this case, the farmers claimed that they were encouraged by extension workers to plant intercrops in the break-crop. Inter-cropping cassava with other crops is a tradition in the area, with an aim of generating some products during the period when cassava is not yet ready. However, this perception can be overcome if the principles of the introduced technology are well understood by all stakeholders.

Over decades, small-scale farmers have removed large quantities of nutrients from their soils without using sufficient quantities of manure or fertilizer to replenish the soil. This has resulted in a very high average annual depletion rate amounting to 22 kg of nitrogen (N), 2.5 kg of phosphorus (P) and 15 kg of potassium (K) per hectare of cultivated land over the last three decades in 37 African countries [25, 26]. Break-crops could seriously deplete important soil nutrients of banana. Inconsistence in the effects of cassava and sweet potato on the levels of nutrients in soil was most likely due to the considerable soil variation within and between farmers' plots as a result of different histories including crops grown on the plots before and their cropping patterns as well as crop, soil and water management practices. The particular location of the farms within the subcounty was also a source of variation. The on-station experiment, on the other hand, was set up on a small piece of land and was therefore more homogeneous and analysis of nutrient levels provided an indication whether commonly grown alternative crops had any significant depleting effects on nutrients required by banana plants in a given cropping sequence.

The observation that maize and cassava deplete soil of K and Ca, falling year by year, compared with continuous banana was quite similar to that made in earlier reports where the maize/cassava cropping systems have the highest depletion of N, P and K at both small scale and large scale farming [27]. Reversing soil fertility depletion has been identified as one of the three requirements for increasing per capita agricultural production [28]. However, it is evident from this study that the most required soil amendments, namely, mulch, manure and compost are less available, limiting the productivity of bananas. The strategy for national agricultural research and extension should be to make appropriate recommendations of both organic and inorganic fertiliser inputs and mulches to compensate for the nutrient and physical imbalance in the replanted banana crop.

Farmers noted that drought was a major limiting factor for newly planted suckers to get established and failure to harvest bigger bunches. However, this was not unique to the trial period. Annual precipitation in Kayunga is only about 950 mm [29]. This is relatively little rainfall considering that most of the country receives an annual rainfall of at least 1000 mm, for example Entebbe which is within the Lake Victoria crescent receives mean annual rainfall of 1620 mm [30]. Mulching, the recommended practice for soil moisture conservation, may therefore not be enough to sustain the desired banana productivity. Some form of irrigation to supplement mulching needs to be given some consideration.

It is clear that promotion of a single technology may not result in adoption. Choice of break-crop was greatly influenced by scarcity of mosaic- resistant cassava cultivars in the area. Farmers regarded this as an opportunity to be provided with planting material of such cultivars by the researchers. Provision of mosaic resistant cassava planting material and the consequent improved food security as well as income realized from sale of both stems and tubers were cited among the positive attributes of the study. Even those farmers who had refused to participate in the trial, on seeing the performance of the ACMV- resistant variety, requested to be included. However, they were only advised to obtain cassava cuttings from their participating neighbours, since it was rather late to bring them on board. Access to ACMV-resistant planting material and availability of free clean banana planting material was a major motivation for farmers to participate in this study. The farmers opted to plant a sweet potato break-crop lost interest, since it was not offering any new technology. It is important, therefore, to have the technologies in an integrated crop management package before any promotion attempts are made.

Nevertheless, some impacts were made from the study through increasing farmers' awareness of new banana production techniques such as tissue culture planting material, compost making, mulching and non-chemical control of pests. This is reflected in the higher percentage of farms where these practices were employed, as well as farms that were rated as very good in terms of crop performance. The improved knowledge in banana management resulted in change of the mindset of the participating farmers. They started appreciating banana production not only for food security, but also as a business venture. This is evident from their request for banana cultivars with bigger bunches that would have a better market price.

Although some impact was made, it is clear that the benefits from the break-crop technology had not yet been fully internalized by some of the participating farmers, while the non-participating farmers hardly had any exposure. Farmers' preferences for technology attributes need to be considered, together with attributes based on perceptions and interests of other stakeholders such as environmental concerns, input and post-harvest issues. In order to benefit farmers on a larger scale, it is important that a technology promotion strategy is worked out well in advance. This would require forging a close collaboration between scientists, extension workers, farmers, local leaders and any other stakeholders. Involvement of all the stakeholders right from the beginning would be vital for ownership of the technology by all. Much as this realization is made, it is difficult to keep stakeholders involved with many commitments [31] and the limitations on stakeholders' time resulted in the process being less participatory than planned.

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REFERENCES

1. FAOSTAT Crop Production data, 2014. *http://faostat3.fao.org/* Retrieved on 19 February 2015.
2. Edmeades, S., M. Smale and D. Karamura, 2006. Biodiversity of Bananas on farms in Uganda: In Promising Crop Biotechnologies for Smallholder Farmers in East Africa: Bananas and Maize, Eds., Smale M., S. Edmeades and H. De Groote. IFPRI Brief, pp: 24.

3. Ministry of Agriculture, Planning Division, Entebbe, Uganda, 1989. Crop Area and Production Report.
4. Uganda Bureau of Statistics (UBOS), 2010. Uganda Census of Agriculture 2008/2009, Volume IV. Crop Area and Production Report.
5. FAO, Production Yearbook 1982
6. FAO, Production Yearbook, 1995
7. Gold, C.S., M.W. Ogenga-Latigo, W. Tushemereirwe, I. Kashaija and C. Nankinga, 1993. Farmer perception of banana pest constraints in Uganda: Results from a rapid rural appraisal. In Proceedings of a Research Coordination Meeting for Biological and Integrated Control of Highland Banana and Plantain Pests and Diseases, Cotonou, Benin, 12 - 14 November, 1991, Eds. Gold C.S. and B.Gemmill: pp: 3-23.
8. Kashaija, I.N., P.R. Speijer, C.S Gold and S.R. Gowen, 1994. Occurrence, distribution and abundance of plant parasitic nematodes of bananas in Uganda. African Crop Science Journal, 2(1): 99-104.
9. Ferris, H. and J.W. Noling, 1987. Analysis and prediction as a basis for management decisions. In Principles and Practice of Nematode Control in Crops, Eds., Brown R. H. and B. R. Kerry. Academic Press, New York, pp: 49-85.
10. Gowen, S. and P. Quénéhervé, 1990. Nematode parasites of bananas, plantains and abaca. In Plant Parasitic Nematodes in Subtropical and Tropical Agriculture, Eds., Luc, M., R.A. Sikora and J. Bridge. CAB International, Wallingford, pp: 431-460.
11. Sebasigari, K. and R.H. Stover, 1988. Banana diseases and pests in East Africa: report of a survey made in November, 1987. INIBAP, Montpellier, France.
12. Kalyebara, R., J.M. Nkuba, M.S.R. Byabachwezi, E.M. Kikulwe and S. Edmeades, 2007. Overview of the Banana Economy in the Lake Victoria Regions of Uganda and Tanzania. In An Economic Assessment of Banana Genetic Improvement and Innovation in the Lake Victoria Region of Uganda and Tanzania, Eds., Smale M. and W. K. Tushemereirwe. International Food Policy Research Institute, Research Report, 155: 25-36.
13. Namaganda, J.M., 1996. Nematode parasites of banana-root crop systems in Uganda. PhD Thesis, University of Reading, Reading, UK.
14. *http://dateandtime.info/citycoordinates* London, retrieved on 19 February 2015
15. Bagamba, F., 1998. Non-chemical Control of East African Banana nematodes: Socioeconomic baseline report for 1996/97
16. Hooper, D.J., 1986a. Extraction of free-living stages from soil. In Laboratory Methods for Work with Plant and Soil Nematodes, Ed. Southey J.F., Reference Book 402, pp: 5 - 30.
17. Hooper, D.J., 1986b. Extraction of nematodes from plant material. In Laboratory Methods for Work with Plant and Soil Nematodes, Ed. Southey J.F. Reference Book 402: 51-58.
18. Addinsoftware XLSTAT 2012
19. Maslen, R., 2001. Non-chemical control of banana nematodes in East Africa.NRI/DFID Crop Protection Programme. Project R6580 (ZA 0038), Final Technical Report.
20. Bagamba F., 2000. Non-chemical Control of East African Banana nematodes: Impact assessment report.
21. Bridge, J., W. Otim-Nape and J. Namaganda, 1991. The root-knot nematode, *Meloidogyne incognita*, causing damage to cassava in Uganda. Afro-Asian Journal of Nematology, 1(1): 116-117.
22. Coyne, D.L. and J.M. Namaganda, 1994. Root-knot nematodes, *Meloidogyne* spp., incidence on cassava in two areas of Uganda. Roots, 1(1): 12-13.
23. Coyne, D.L. and J.M. Namaganda, 1996. Plant-parasitic nematode pests of root and tuber crops in Masindi district of Uganda. African Journal of Root and Tuber Crops, 1(2): 4-7.
24. Namaganda, J.M., S.R. Gowen, P. Namanya, I.N. Kashaija and F. Bagamba, 2003. Management of nematodes in banana systems in Uganda. Uganda Journal of Agricultural Sciences, 8: 101-106.
25. Sanchez, P.A., K.D. Shepherd, M.J. Soule, F.M. Place, R.J. Buresh, N. Izac, A. Uzo Mokwunye, F.R. Kwesiga, C.G. Ndiritu and P.L. Woomer, 1997. Soil Fertility Replenishment in Africa: An Investment in Natural Resource Capital. In Replenishing Soil Fertility in Africa, Eds., Buresh, R. J., P. A. Sanchez and F. Calhoun, Soil Science Society of America, Inc.. American Society of Agronomy, Inc., 5585 Guilford Rd., Madison, WI 53711 USA, Special Publication, 51: 1-46.
26. Sanchez, P.A., 2002. Soil Fertility and Hunger in Africa. Policy Forum *www.sciencemag.org* Science 29: 2019-2020.
27. Folmer, E.C.R., P.M.H. Geurts and J.R. Francisco, 1998. Assessment of soil fertility depletion in Mozambique. Elsevier Agriculture, Ecosystems and Environment, 71: 159-167.

28. Sanchez, P.A. and R.R.B. Leakey, 1997. Land use transformation in Africa. Three determinants for balancing food security with natural resource utilization. European Journal of Agronomy 7: 1 – 9.
29. *http://en.climate-data.org/* retrieved on 2 March 2015
30. *http://www.nationsencyclopedia.com/Africa/Uganda-CLIMATE* retrieved on 2 March 2015
31. Lamboll, R.I., S.R. Gowen, J.K. Ssemwanga, J.F. Asaba, F. Bagamba, E. Robinson, M.A. Rutherford, W.K. Tushemereirwe and M. Arinaitwe, 2000. In Proceedings of a workshop on the factors affecting uptake and adoption of Department for International Development (DFID) Crop Protection Programme (CPP) research outputs, 21-23 June 2000, Imperial College at Wye, Kent, UK. Eds., Hainsworthand S.D. and S.J. Eden-Green, pp: 49-64.