Annals of Tropical Research 37[1]:84-96(2015)

Effects of *Meloidogyne incognita* on the Yield and Quality of Sweet Potato in the Humid Lowlands of Papua New Guinea

Macquin K. Maino and Shamsul Akanda

Department of Agriculture, Papua New Guinea University of Technology, PMB, Lae 411, Morobe Province, Papua New Guinea.

ABSTRACT

Field experiments were conducted in 2012 and 2013 to study the effects of inoculum densities of *Meloidogyne incognita* applied at 10, 100, 1000, 5000, and 10000 juveniles/eggs per 500 cm^3 along with un-inoculated control treatments, on a susceptible sweet potato variety, K9. At the highest initial inoculum (Pi), an average marketable tuber yield of 991 kg ha^{-1} was recorded compared to 3495.5 kg ha^{-1} from un-inoculated control, accounting for 72% relative yield reduction. Significant ($p \leq 0.05$) yield reduction of 37% was also recorded from the lowest Pi of 10 juveniles/500 cm^3. Probit analysis projected that 50% loss to marketable tubers are likely to occur at populations as low as 40 nematodes/500 cm^3. There was a high positive correlation ($r = 0.87^{**}$) between percentage relative yield loss and initial inoculum densities.

There was significant ($p \leq 0.01$) impairment in marketable tuber quality with 4% cracking at 10 *M. incognita* per 500 cm^3, increasing to 37% at the highest Pi of 10,000. Highly significant positive correlations were also observed for cracked tubers ($r = 0.93^{**}$) and non-marketable tubers ($r = 0.96^{**}$), when tested against the Pi densities of *M. incognita.* Nematode population was monitored during the cropping season revealed an overall significant increase ($p \leq 0.05$) in juvenile populations at mid-season (60 days after inoculation) from the initial inoculum populations. A reverse in trend of juvenile numbers was observed at harvest (120 DAI).

Keywords: *Meloidogyne incognita*, yield and quality, sweet potato, Papua New Guinea.

Correspondence : M. K. Maino *Address:* Department of Agriculture, Papua New Guinea University of Technology, PMB, Lae 411, Morobe Province, Papua New Guinea. *Tel.*:+(675) 473 4451/4469 *Fax*: +(675) 4734477. *Email:* mmaino@ag.unitech.ac.pg
DOI: 10.32945/atr3716.2015

INTRODUCTION

Sweet potato, *Ipomoea batatas* (Lam.) is an important staple food crop in Papua New Guinea (PNG) and 95% of the population in the Highlands Provinces of PNG grow the crop (Allen *et al.,* 2001). In 1995, an average urban dweller consumed 75 kg of sweet potato (Gibson 1995), whilst the average rural highlander consumed 150 kg (Bang and Kanua, 2001). Traditionally, sweet potato remained as a subsistence crop, but a trend has now emerged where this crop has become a significant cash crop. From 1989-99, there was an increase in shipment of 600 tonnes per year to over 2000 tonnes per year from the highlands to the capital city (Port Moresby) for sale (Bang and Kanua, 2001). Since the devastation of taro by leaf blight in the lowlands region of PNG, sweet potato was being increasingly adopted by farmers as a staple crop, and is now second to either banana or taro (Allen *et al.* 2001).

These changing trends would mean increasing cropping acreages of sweet potato, or continuous cultivation of the crop on limited available lands. Both farming practices can lead to the increase in pests and diseases and of particular interest is the dominant soil-borne sweet potato parasite, *Meloidogyne incognita*. Loss of yield and quality of sweet potato due to *M. incognita* has been studied in other countries where this crop is grown (Thomas and Clark, 1983a, 1983b; Lawrence *et al.*, 1986; Clark and Moyer, 1988; Johnson *et al.,* 1996; Tateishi, 1998).

In PNG, studies on yield losses due to *Meloidogyne* are not conclusive. In 1980s, sixteen yield loss trials were conducted in the Southern Highlands Province. In one experiment involving comparative use of carbofuran (insecticide and nematicide), yield loss of 28% was recorded, but was considered inconclusive due to a 'single-case' data (D'Souza *et al.*, 1986). In other investigations, no significant yield responses were observed on sweet potato when carbofuran was used to control *Meloidogyne* spp. (D'Souza *et al.*, 1986). *Meloidogyne* infestation of 10-15% was reported in sweet potato gardens in the Highlands of PNG, with *M. incognita* and *M. javanica* as the dominant species (Bridge and Page, 1984). In the late 1990s, a multidisciplinary research into yield decline in sweet potato revealed that infestation from parasitic nematodes, *Meloidogyne* spp. and *Rotylenchulus reniformis* were the contributing factors to the yield decline in sweet potato in the humid lowlands of PNG (Hartemink *et al.,* 2000).

This study was conducted to investigate the loss in yield and quality of sweet potato due to infection from *M. incognita*, as well as to assess the level of damage caused by this pathogen on the marketable root tubers.

MATERIALS AND METHODS

Experimental Site and Period

Experiments for field evaluation were conducted in three repeated trials at the Department of Agriculture farm, PNG UniTech, Lae, Morobe Province during the months of July to December, 2012 and February to June, 2013. The experimental farm (6°41' S, 146°98'E) is located 9 km north of Lae on a nearly flat alluvial plain at an altitude of about 65 m.a.s.l. Mean total annual rainfall is about 3789 mm but in the past 25 years it varied from 2594 to 4918 mm (Hartemink et al., 2000). The average daily temperature is 26°C and has a silt loamy soil, friable and loose. The UniTech farm has 85% average relative humidity with an average of 10 h sunshine per day (Wamala, 2008).

Field Preparation and Experimental Design

Experimental plots were chisel-ploughed to a depth of about 0.4 m and then harrowed to fine tilth. Plot sizes were 2.5 m x 2.0 m with an allowance of 0.5 m and 1.0 m spacing in-between the plots and replicates, respectively. The experiments had six treatments at 10, 100, 1,000 5,000, and 10,000 eggs and juveniles/500 cm^3 along with an un-inoculated control and arranged in a randomised complete block design (RCBD) with four replications.

Soil Sampling and Plot Fumigation

Presence of plant-parasitic nematodes in each plot was determined prior to fumigation. Soil samples were collected from nine locations from each plot in a zigzag fashion as described by (Barker and Campbell, 1981) using an Edelman auger. Soil from each location was mixed in a bucket and 250 cm^3 of the composite sample was retained for processing. Samples were evenly spread on a tissue paper supported by a mesh wire sitting in a Baermann's tray. Tap water was poured from the edge of the tray until the soil was just moist and then left at 28-29°C for 72 h. Nematodes were extracted by filtering the water through a 38 μm sieve into a vial. Extracts from each plot were quantified using a nematode counting slide under a dissecting microscope at 40x magnification.

Plots were later treated with granular nematicide (Nemacur, a.i.: 50g/kg fenamiphos) at 25g/m^2. The granules were sprinkled evenly over soil, lightly raked in and then watered before covering with visqueen plastic sheet and left for 2 weeks. At the duration of fumigation, plastics were removed and plots tilled twice using garden forks to release any remaining toxic gas. Soil samples were again collected from each plot and processed as done previously to confirm the efficiency of fumigation prior to planting.

Planting of Propagules

A highly susceptible sweet potato variety, K9, with maturity duration of 4 months was used in all the experiments. Planting materials were obtained by cutting the vines, approximately 30 cm from the terminal end of the vines. The cuttings were planted at a spacing of 0.5 m x 0.5 m. Plants were allowed to establish for one week before inoculation with *M. incognita* inoculum.

Preparation of Inoculum and Inoculation

M. incognita inoculum was obtained from infected roots of a highly susceptible tomato variety, beefsteak, maintained in a greenhouse. Infected tomato roots with *M. incognita* were standardised according to the procedure described by Lawrence *et al*. (1986). The roots were chopped into pieces, mixed with sterile soil and the population rechecked to ensure that treatment rates were correct. The inoculum mixtures were added to furrows of 10-15 cm deep made near the rooting zones in each plot, except the control and covered with soil. The treatment rates of 10, 100, 1,000, 5,000 and 10,000 eggs and juveniles/500 cm^3 were taken as respective initial populations (*Pi*).

Monitoring Population Development

Over a 4 months growing period, soil samples were collected to extract the nematodes to monitor the population at mid-season (*Pm*) and at harvest for the final population (*Pf*). Samples were collected at 60 and 120 days after inoculation (DAI) using an Edelman auger as described previously. Soil from nine cores per plot was mixed thoroughly and composite samples of 250 cm^3 were set on Baermann's trays to assess the nematode population as explained previously.

Assessment of Yield and Quality

Fresh weights were recorded for marketable (>100 g) and non-marketable (<100 g) root tubers (Powell et al., 2001). Marketable root tubers were rated for cracking severity on a 0-4 scale as described by Lawrence *et al*. (1986) as follows: 0 = no cracks; 1 = trace; 2 = slight cracking; 3 = moderate cracking, and 4 = severe cracking. Average percentages for cracking on marketable root tubers as well as non-marketable tubers relative to total number of tubers were determined for each inoculation rates.

Data analysis

Data were analysed by analysis of variance (ANOVA) using STATISTIX version 8.0. As no significant interaction between the seasons and the treatment (inoculation densities) was found, a combined analysis of the yield over the seasons was done. Least Significance Difference (LSD) was used to separate the treatment means. A probit analysis was done to determine the dosage of *M. incognita* at which 50% of marketable tuber occurred.

RESULTS

Nematode Population Development during Cropping Seasons

Over the respective cropping seasons of 4 months, development of *M. incognita* population was assessed at mid-season (*Pm*) and at the harvest (*Pf*) (Table 1). Significant increases ($p \leq 0.05$) in juvenile population from all inoculation densities were observed at mid-season (60 DAI) compared to the initial population (*Pi*) densities. A reverse in juvenile numbers was observed at the harvest (120 DAI) where counts were significantly ($p \leq 0.05$) reduced.

Table 1. Juvenile population at 60 and 120 days after inoculation.

Pi[1]	*Pm*[2]	*Pf*[3]
0	0	0
10	3634	1013
100	11367	2099
1000	18088	2472
5000	24503	3530
10000	32987	3993

Pairwise comparison
Pi vs *Pmp* < 0.05
Pm vs *Pf p* < 0.05

[1]Initial population at inoculation[2]Recorded population at mid-season[3]Recorded population at harvest (final population)

Effect of Meloidogyne incognita on Tuber Yield

The effects of different inoculum levels of *M. incognita* on marketable yield of sweet potato tubers are shown in Table 2. A pooled average of yield over the seasons was recorded at 991.0 kg ha^{-1} and 3495.5 kg ha^{-1} for plots that received the highest initial inoculum and un-inoculated control plots, respectively. Significant difference (p≤0.05) in mean yield of marketable tubers was observed amongst the nematode inoculum rates. Un-inoculated sweet potato plots had highest yield of 3493.5 kg ha^{-1} and was significantly (P≤0.05) higher than all nematode inoculated plots. Inoculation at 10 juveniles/500 cm^3 had significantly (p≤0.05) higher yield than the rest of the plots inoculated at higher levels of inocula. However, this yield was significantly (p≤0.05, LSD) lower than that of the control plots (Table 2). The yield at inoculum level of 100 juveniles/eggs was significantly higher than the yield at inoculum level of 10,000 juveniles/eggs per 500 cm^3. Yield differences amongst the plots that received the inocula at 1000, 5000 and 10,000 juveniles/eggs were insignificant. Overall, average yield of marketable tubers progressively decreased with increasing level of initial inoculum of *M. incognita*.

Relative Yield Reduction

Results on relative percentage loss in marketable yield of tubers are shown in Table 2. A 37% loss in tuber yield was recorded at the lowest initial inoculum of 10 juveniles and eggs per 500 cm^3 of soil and the highest

Table 2. Effect of *Meloidogyne incognita* on marketable sweet potato.

Nematode rates (per 500 cm^3)	Average Yield ($kg\ ha^{-1}$)^x	Relative yield loss (%)
0	3493.5 a	-
10	2205.0 b	37.0
100	1459.2 c	58.0
1000	1238.2 cd	65.0
5000	1288.7 cd	63.0
10000	991.0 d	72.0
	$p < 0.05$	
Critical yield for comparison	461.0	

Means followed by same letters in a column are not significant different at $p \leq 0.05$ (LSD).

DISCUSSION

The objective of this study was to quantify the effects of a dominant root-knot nematode, *M. incognita* on the tuber yield and quality of sweet potato. While knowledge on the effects of *M. incognita* from other sweet potato growing countries is available, effects of the native population of this economic pathogenic species on this important staple food crop is lacking in PNG.

Field experiments conducted in 2012 and 2013 using varying inoculum levels of *M. incognita* on sweet potato revealed significant losses in marketable tuber yield and quality. The highest initial inoculum population (10,000 juveniles/eggs per 500 cm^3) accounted for 72% relative reduction in yield of marketable tubers. Even at the lowest nematode population of 10 juveniles/eggs per 500 cm^3 resulted in significant yield loss of 37 per cent.

Investigation into the effects of *M. incognita* on the yield and quality of sweet potato begun in early 1900s (Krusberg and Nielsen, 1958; Nielsen and Sasser, 1959) and this effort has continued (Thomas and Clark, 1982; Lawrence *et al.*, 1986; Hall *et al.*, 1988; Johnson *et al.*, 1992; Johnson *et al.*, 1996; Hartemink *et al.*, 2000; Olabiyi, 2007). The current study recorded an average loss in marketable tuber yield in the range 991 kg ha^{-1} – 2205 kg ha^{-1}, and was comparable to an average of 1905 kg ha^{-1} – 2260 kg ha^{-1} from infested sweet potato reported previously (Onwueme, 1978; Olabiyi, 2007). An average marketable tuber yield of 3493.5 kg ha^{-1} from healthy sweet potato was similar to 3864 kg ha^{-1} as reported by Olabiyi (2007).

Lawrence *et al.* (1986) reported that Pi of 10 and 100 juveniles per 500 cm^3 was enough to affect the marketable root weight, and yields can be of 72% yield loss with the inoculation level of 10,000. There was a positive correlation (r = 0.87**) between percentage relative yield loss and initial inoculation densities. Probit analysis revealed that population of *M. incognita* at 40 juveniles per 500 cm^3 of soil had the potential of causing 50% yield loss in marketable tubers.

Table 3. Average percentage of cracked and non-marketable tubers.

Nematode rates (per 500 cm^3)	Cracking severity index	Cracks on marketable tubers (%)	Non-marketable tubers (%)
0	0	0 d	3 e
10	2	4 d	5 de
100	2	10 cd	9 d
1000	3	15 bc	20 c
5000	4	24 b	28 b
10000	4	37 a	34 a
		$p < 0.01$	$p < 0.01$
Critical percentage for comparison		11.126	5.1079

*Means followed by same letters in a column are not significantlydifferent at $p \leq 0.05$ (LSD).

Effect of Meloidogyne incognita on Tuber Quality

Quality of marketable tubers was determined by assessing the severity of cracking on tubers and quantity of non-marketable tubers (Table 3). Highly significant differences (P≤0.01) were recorded amongst the treatment means with an average percentage of cracked tubers from 0 to 37% from the un-inoculated and the highest inoculum of 10,000 juveniles and eggs, respectively. Highly significance differences (p≤0.01) were also observed in non-marketable tubers with 3% and 34% recorded from un-inoculated and plants that received the highest initial inoculum, respectively (Table 3). Highly significant positive correlations were observed for cracked tubers (r = 0.93**) and non-marketable tubers (r = 0.96**) when tested Pi densities of *M. incognita*.

significantly suppressed at higher Pi. The economic threshold (ET) for *M. incognita* on sweet potato was reported to be 30 juveniles per 1,000 g loamy soil and 5 per 1,000 g sandy soil (Ferris, 1978). Field experiments for current investigation were established on silty loam soil (Hartemink et al. 2000). At the lowest Pi, 37% yield reduction was recorded with projected 50% yield loss likely at Pi of 40 juveniles/eggs per 500 cm^3, based on probit analysis. Economic analysis was not done to establish an ET for local conditions, but observed yield data is sufficient to suggest that ET from this study would be in the vicinity of figures provided by Ferris (1978).

The quality of marketable tubers of sweet potato is also affected by cracking of tubers due to *M. incognita*. Lawrence *et al.* (1986) reported Pi of about 10 *M. incognita* per 500 cm^3 was the damage threshold for two susceptible varieties of sweet potato (Centennial and Jasper) in the USA. The current study recorded significant impairment in sweet potato tuber quality with 4% cracking at 10 *M. incognita*, increasing to 37% at highest Pi of 10,000 *M. incognita*. Soil moisture can influence the magnitude of cracking caused by nematodes to developing roots and tubers (Thomas and Clark, 1983a; Lawrence *et al.*, 1986). Early work showed dry soil conditions followed by relatively high soil moisture during the period of fleshy root enlargement can result in increased cracking to tubers (Ogle, 1952). Rainfall condition that supports this assertion was observed during the periods of experimentation in 2012 and 2013.

The development of nematode population densities generally reached highest levels at around mid-season and declined near the harvest (Lawrence et al., 1986; Johnson *et al.,* 1996). Our data supports these reports, where significant increases from Pi to Pm was recorded and then declined at the harvest. Maximum nematode reproduction is reported to coincide with maximum sweet potato root growth (Lawrence *et al.,* 1986), and then decline as a result of root senescence leading to reduced food supply (Trudgill, 1973). Ecological factors (climate and soil) at the site of experimentation are generally conducive for plant growth and development (Hartemink *et al.*, 2000), hence, host-pathogen relationship and development would follow patterns observed by Lawrence *et al.* (1986) and Trudgill (1973).

In PNG, effects of the four major root-knot nematode species, *M. incognita*, *M. javanica*, *M. arenaria* and *M. hapla* on yield and quality of sweet potato have not been fully researched to provide appropriate advice and derive specific management strategies. The outcome of this investigation provides some useful information regarding *M. incognita*, the most dominant species of *Meloidogyne* spp.

CONCLUSION

Meloidogyne incognita is a dominant root-knot nematode and a serious soil-borne pathogen affecting sweet potato throughout the world. This pathogen is present in several Pacific Island countries including PNG. There are a few available reports that suggest that *M. incognita* could be one factor causing yield loss on sweet potato in PNG. Thirty seven per cent losses to marketable sweet potato tubers are possible even at initial inoculum population of 10 *M. incognita* per 500 cm^3 while yield losses of 50% are expected at populations as low as 40 *M. incognita* per 500 cm^3. Under conducive growth conditions, *M. incognita* can multiply rapidly and reach peak population around mid-season of the cropping cycle.

The outcomes of this study generally support findings pertaining to this host and pathogen from other countries throughout the world. Farmers and interest groups in PNG are now able to utilize available local information to assist in decisions relating to farming systems and application of appropriate disease management.

ACKNOWLEDGEMENT

The authors would like to acknowledge funding assistance received from the Department of Agriculture through the Papua New Guinea University of Technology towards the completion of this study.

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