STUDIES ON HOST-PARASITE RELATIONSHIPS BETWEEN THE ROOT-KNOT NEMATODE (*MELOIDOGYNE INCOGNITA*) (KOFOID AND WHITE, 1919) CHITWOOD, 1949, AND TOMATO (*LYCOPERSICON ESCULBNTUM* MILL.) IN NORTHERN NIGERIA

BY

PAUL SULE CHINDO

A thesis submitted to the Postgraduate School, Ahmadu Bello University in partial fulfillment of the requirements for the Degree of Master of Science in Crop Protection

DEPARTMENT OF CROP PROTECTION
FACULTY OF AGRICULTURE
AHMADU BELLO UNIVERSITY
ZARIA, NIGERIA

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DECLARATION

I hereby declare that this thesis **is written** by me and that it is a record of my own research work. It has not been presented before in any previous application for a higher degree.

PAUL SULE CHINDO
(M.Sc. Candidate)

The above declaration is confirmed.

Dr. F. A. KHAN
(Major Supervisor)

Date. 1st. Dec., 1986....

CERTIFICATION

This thesis entitled "Studies on Host-parasite relationships between the Root-knot nematode (Meloidogyne incognita (Kofoid and White, 1919) Chitwood, 1949) and Tomato (Lycopersicon esculentum Mill.) in Northern Nigeria" by Paul Sule Chindo meets the regulations governing the degree of Master of Science of Ahmadu Bello University Zaria, and is approved for its contribution to scientific knowledge and literary presentation.

Prof. A.M. Emechebe
Head of Department

Dr. F.A. Khan
Internal Examiner

Prof. I.D. Erinle
Internal Examiner

Prof. A.C. Ebenebe
Internal Examiner

Prof. G.E. Osuide
Dean, Postgraduate School

Date 25/V/87

AHMADU BELLO UNIVERSITY, ZARIA

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ABSTRACT

Although a lot of investigations in Nigeria have shown that it pays to control root-knot nematodes, the economic justification for doing so in tomato production has not been well documented. It is against this background that the concept of economic loss threshold was adopted, Based on this investigation, it was established that a population of between 1000 to 2000 larvae/kg of soil of Meloidagyne incognita (Kofoid and White Chitwoed, 1949 was capable of causing economic loss. The estimated economic loss threshold was based on the average market value of the tomato crop during the two experimental years, 1 984 and 1985, and the cost of control.

The root-knot nematode, M. incognita was found to increase the severity of two vascular diseases (fusarium and bacterial wilt) of susceptible tomato cultivars. Severity was highest when the nematode was inoculated simultaneously with the vascular pathogens. Vascular discolouration was observed when cultivars resistant to the vascular pathogens were inoculated with M. incognita and vascular pathogens. Wilting was not observed in treatments which were inoculated with the vascular pathogens alone except for slight discolouration in tomato cv. CL-119-1-2-0-0.

Investigations with poultry manure showed that it is very effective in controlling the root-knot nematodes. An optimum level for both nematode control and plant growth appears to be around 4- t/ha.

TABLE OF CONTENTS

CHAPTER		PAGE
	Declaration	i
	Certification	ii
	Dedication	iii
	Acknowledgements	iv
	Abstract	v
	Table of contents	vi
	List of Tables	x
	List of Figures	xii
	List of Plates	xiii
	Abbreviations, Glossaries and Symbols.	xiv
1.0	INTRODUCTION	1
2.0	REVIEW OF LITERATURE	6
2.1	Taxonomy, host-range and distribution of *Meloidogyne* spp.	6
2.2	Importance of *meloidogyne* spp.	10
2.3	Host-Parasite relationships	13
2.4	Factors influencing the host-parasite relationships.	19
2.5	Control of root-knot nematodes	33
2.5.1.	Cultural control	34
2.5.2.	Physical control	39
2.5.3.	Biological control	41
2.5.4.	Chemical control	42

CHAPTER		PAGE
3.0	EXPERIMENTS CARRIED OUT	47
	THE EFFECTS OF DIFFERENT POPULATION DENSITIES OF MELOIDOGYNE INCOGNITA ON THE GROWTH AND YIELD OF TOMATO	47
3.1	INTRODUCTION	47
3.2.	MATERIALS AND METHODS	48
3.21.	Preparation of inoculum of M. incognita	48
3.2.2.	Experimental procedure	49
3.3	RESULTS	51
3.4.	DISCUSSION AND CONCLUSION	60
4.0	INFLUENCE OF THE ROOT-KNOT NEMATODE, M. INCOGNITA ON THE SEVERITY OF TWO VASCULAR DISEASES OF TOMATO INCITED BY PSEUDOMONAS SOLANACEARIUM AND FUSARIUM OXYSPORUM f.sp. LYCOPERSICI	65
4.1	INTRODUCTION	65
4.2	Influence of the Root-knot nematode M. incognita on the severity of bacterial wilt of tomato incited by P. solanacearum E.F. Smith.	66
4.2.1	Materials and Methods	66
4.2.1.1.	Preparation and standardization of inoculum of P. solanacearum	66

CHAPTER	PAGE
4.2.1.2. Inoculation of Plants	67
4.2.1.3 Results	69
4.3 Influence of the root-knot nematode M. incognita on the severity of fusarium wilt of tomato.	70
4.3.1 Materials and methods	70
4.3.1.1 Preparation and Standardization of inoculum of F. oxysporum f. sp. lycopersici	70
4.3.1.2 Inoculation of plants	72
4.3.1.3. Results	
4.4 Interaction between M. incognita, P. solanacearum and F. oxysporum f.sp. lycopersici on tomato cv. Hunkuyi local	72
4.4.1 Materials and methods	73
4.4.1.1 Preparation and standardization of inocula of P. solanacearum and F oxysporum f.sp. lycopersici	73
4.4.1.2 Inoculation of plants	75
4.4.1.3. Results	76
4.5 Discussion and conclusion	78
5.0 EFFECTS OF POULTRY MANURE ON THE DAMAGE CAUSED BY THE ROOT-KNOT NEMATODE, M. INCOGNITA ON TOMATO	84
5.1 INTRODUCTION	84
5.2 INFLUENCE OF POULTRY MANURE ON THE SEVERITY OF DAMAGE CAUSED BY THE	84

CHAPTER		PAGE
	ROOT-KNOT NEMATODE, M. INCOGNITA ON TOMATO-GLASSHOUSE EXPERIMENTS.	85
5.2.1	MATERIALS AND METHODS	85
5.2.2	RESULTS	86
5.3	EFFECT OF SOIL AMENDMENT WITH POULTRY MANURE ON THE DAMAGE CAUSED BY THE ROOT-KNOT NEMATODE, M. INCOGNITA ON TOMATO, cv. ENTERPRISER, IN THE FIELD.	90
5.3.1	Experimental site:	90
5.3.2	Materials and methods	90
5.3.3	RESULTS	91
5.4	EFFECT OF WATER-SOLUBLE FRACTIONS (WSF) OF POULTRY MANURE ON THE HATCH AND SURVIVAL OF LARVAE OF M. INCOGNITA IN VITRO.	96
5.4.1	MATERIALS AND METHODS	96
5.4.2	RESULTS	97
5.5	DISCUSSION AND CONCLUSION	97
6.0	SUMMARY AND CONCLUSIONS	103
	LITERATURE CITED	106
	APPENDICES	124

LIST OF TABLES

TABLE		PAGE
1	Galling Index (after Daulton and Nusbaum, 1961).	50
2	Effect of various intial population densities of M. incognita on its reprod-ction and on root growth of tomato L. esculentum cv. Enterpriser	52
3.	Effect of M. incognita on the severity of bacterial wilt of tomato (L. esculentum incited by P. solanacearum, 40 days after inoculation	71
4	Effect of M. incognita on the severity of fusarium wilt incited by F. oxysporum f.sp. lycopersici on two cultivars of table (L. esculentum).	74
5	Effect of M. incognita on the severity of wilt incited by mixed populations of P. solanacearum and F. oxysporum f. sp. lycopersici on tomato cv. Hunkuyi local	77
6	Effect of M. incognita on the severity of wilt incited by either P. solanacearum, F. oxysporum f.sp lycopersici or mixed populations of P. solanacearum and F. exysporum f.sp. lycopersici.	82.

LIST OF FIGURES

FIGURE		PAGE.
1.	Effect of various population densities of M. incognita on plant height (at midseason) of tomato cv. Enterpriser.	54
2.	Effect of various population densities of M. incognita on the number of fruits of tomato cv. Enterpriser at harvest.	55
3.	Effect of various population densities of M. incognita on the marketable yield (fruit weight) of tomato cv. Enterpriser at harvest.	56
4.	Effect of various population densities of M. incognita on the mean weight/fruit of tomato cv. Enterpriser.	57

LIST OF PLATES

PLATE		PAGE
I	Tomato plants showing the effect of various population densities of M. incognita on plant height at midseason, T1 = 0 larvae (control), T4 = 2,000 larvae and T7 = 16,000 larvae per pot.	58
II	Roots of tomato, cv. Enterpriser showing the effect of various population densities of M. incognita on root growth. T1 = 0 larvae (control), T4 = 2,000 larvae and T7 = 16,000 larvae per pot.	58
III	Roots of tomato, cv. Enterpriser showing the effect of soil organic amendment with poultry manure on the degree of damage by M. incognita. T1 = 0t/ha, T2 = 2t/ha, T3, 4t/ha and T4 = 8t/ha.	95.

ABBREVIATIONS, GLOSSARIES AND SYMBOLS

ANOVA	-	Analysis of variance
DF	-	Degrees of Freedom
DMRT	-	Duncan's multiple range test
F	-	F value
LSD	-	Least significant difference
MS	-	Means square
N.S.	-	Not significant
*	-	Significant (P = 0.05)
	-	
Yr	-	Year.

CHAPTER ONE

1.0 INTRODUCTION

Tomato has been grown in Nigeria for a long time, predominantly in gardens and on small farms. Today it is widely grown with production shifting from small scale household consumption to large scale commercial farming. It is grown both as a wet season crop and under irrigation in the dry season.

Tomato is one of the most important vegetable crops in the world. It ranks second in importance after potato in most regions of the world (Purseglove, 1977). The ripe fruit is extensively used in the preparation of stews, soups and other dishes as well as fresh salad. The fruit is known to contain vitamin A, B and C and pellagra preventive factor.

The growing of this crop is greatly impaired by pests and diseases including nematodes. Plant parasitic nematodes cause one of the most difficult problems in its production. Besides causing direct yield losses, they impair the quality, thus lowering the market value, and increase labour input resulting in increased production costs due to attempts to prevent or control them (Idowu, 1979). The root-knot nematodes (Meloidogyne spp.) seem to be the best known and most widely distributed of all the plant parasitic nematodes. Their symptoms on infected plants are conspicuous galls or knots on the roots.

Reports have shown that three root-knot nematode species viz., M. incognita (Kofoid and White, 1919). Chitwood, 1949; M. javanica (Treub, 1885) Chitwood, 1949; and M. arenaria (Neal, 1889) Chitwood, 1949, in that order, are the most important and most prevalent in tropical lands. In Nigeria, M. incognita is most prevalent in the south while M. javanica is most common in the savanna areas of the North.

Root-knot nematodes pose a serious threat to the profitable production of tomatoes in Nigeria. Ogunfowora (1977b) showed that these nematodes can cause a complete crop loss in tomato. In northern Nigeria these nematodes are responsible for causing severe losses in tomato, particularly in irrigated fields where the continuous cropping of susceptible crops and the favourable soil temperature and moisture regimes help in the build-up of nematode populations to damaging levels. According to Wilson (1962) the yields of tomato can be reduced by 75 percent following the attack of root-knot nematodes in Samaru area. Bridge (1972) indicated that the loss in yields of tomato due to root-knot nematodes was as high as 40 percent.

Apart from the damage caused by root-knot nematodes to tomatoes, they tend to alter resistance to certain diseases in plants. Vascular wilts caused by the bacterium, Pseudomonas solanacearum and the fungus,

Fusarium oxysporum f. sp. lycopersici, are important in Nigeria (Erinle, 1979). To reduce the incidence of these diseases on tomatoes, resistant cultivars such as Roma VFN (resistant to F. oxysporum f.sp. lycopersici and CL-119-1-2-0-0 (resistant to P. solanacearum) have been identified and recommended for use by farmers. But root-knot nematodes are known to be capable of breaking down the resistance of crops to these diseases (Sadiku, 1979; Napiere, 1980; Morrel and Bloom, 1981; Sidhu and Webster, 1981). Similarly the host-parasite relationships between root-knot nematodes and crops may also be altered by the presence of other soil pathogens (D'ercole et al, 1982).

In view of the high yield losses in tomato production resulting from the infection of root-knot nematodes, their control must form an intergral part of the production of this crop. Crop rotation is considered as one of the most economical and desirable methods of controlling these nematodes in Nigeria.

Besides crop rotation, chemical control has been used extensively the world over for the control of root-knot nematodes. But these chemicals are expensive and are not readily available to the farmers particularly the small-scale farmers. Their judicious use, therefore, cannot be over-emphasized for this will ensure that they are used effectively and economically in tomato production.

To achieve this, the economic loss threshold for recommended varieties should be worked out. Economic loss threshold represents a percentage of the value of the crop equivalent to the cost of nematode control (Olthof and Potter, 1972). Information is, therefore, required on the relationships between population density of root-knot nematodes and yields of susceptible tomato cultivars so as to ascertain the population level at which it will be profitable to apply nematicide. This information is however, wanting for northern Nigeria.

From reports published, there are indications that the application of inorganic fatilizers and organic manures can be used to change the host-parasite relationships between crops and root-knot nematodes in favour of the crop (Khan, 1969 and 1976; Johnson, 1959 and 1962, Singh and Sitaramaiah, 1966; Johnson et al 1967; Caveness 1967; Omiyi 1976; Babatola, 1982). Detailed information about the role of these nutrient sources in the production of tomatoes in soils infested with root-knot nematodes in northern Nigeria is lacking

Since root-knot nematodes are widely distributed in our soils, it is necessary to determine the nature of their interactions in relation to alledged resistance and susceptibility in tomatoes to these vascular wilts.

OBJECTIVES OF THIS STUDY

Against this background the following investigations were conducted to ascertain the nature of host-parasite relationships between root-knot nematode M. incognita and tomato.

1. To determine the relationship between different population densities of the root-knot nematode M. incognita and yield of the root-knot susceptible tomato cultivar Enterpriser. This is to enable us ascertain the economic loss threshold for this cultivar.

2. To obtain information on the nature of interactions between M. incognita and P. solanacearum E.F. Smith and Fusarium oxysporum f. sp. lycoperisici Synd. and Hansen.

3. To study the effects of organic soil amendments with poultry droppings on the damage caused by the root-knot nematode M. incognita to tomatoes so as to assess its suitability for inclusion in cultural control programmes.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 TAXONOMY, HOST-RANGE AND DISTRIBUTION OF MELOIDOGYNE SPP.

Taxonomy

Although galling of the roots of crop plants by Meloidogyne spp. has probably been observed since the earliest days of cultivation, the first account of the condition was given by Berkeley (1855), who found that small worms (vibrios) occurred within the galled roots of Cucumber in the glasshouse in England. From then on "root-knot" disease has been reported in widely separated parts of the world. Licopoli (1875) reported finding small worms within galls on roots of Sempervivum tectorum L, in Italy. Jobert (1878) described galls on roots of coffee plants in the province of Rio de Janeiro in Brazil. None of the workers attached a name to the parasites involved (Whitehead, 1968). In 1879, however, Cornu first named root-knot nematodes when he attached the name Anguillula marioni to the nematodes inhabiting galls on the roots of Sainfoin (Onobrychis sativa) Lam. Later, root-knot nematodes were reported in different parts of the world and given different names viz., Anguillula radicicola (Greef 1872), Heterodera radicicola (Muller, 1884), H. javanica (Treub, 1985), Meloidogyne

exigua (Goeldi, 1887), Anguillula arenaria (Neal, 1889), A. vialae (Lavargne, 1901b), Gaconema sp. (Cobb, 1924). Goodey (1932) felt that root-knot nematodes should belong to the genus Heterodera, and he named them H. marioni (Cornu, 1879) Goodey (1932). This generic name was generally accepted until the revision by Chitwood in 1949.

Chitwood (1949) revived the name Meloidogyne (Goeldi, 1887). He divided this genus into five species and one sub-species, namely M. javanica (Treub, 1885), M. exigua (Goeldi, 1887), M. incognita incognita (Kofoid and White, 1919), M. incognita acrita, M. hapla, M. arenaria (Neal, 1889).

Chitwood considered the perineal pattern of the adult female as the most important character for specific identification. His work was a great advance in the study of root-knot nematodes. He regarded his work as a basis in which to build more detailed morphological work in future.

Allen (1952) doubted the value of Chitwood's species concept due to considerable variations in the perineal patterns. Dropkin (1953) in support of Chitwood's work, suggested that perineal pattern is hereditary and stable. In addition, Sasser (1954) concluded that Meloidogyne spp. could be reliably identified by the perineal pattern

of females except that it was difficult to distinguish between M. incognita and M. incognita acrita. He found no evidence of the host influencing the perineal pattern. Thus, the study of the perineal pattern appeared to have provided a useful method for the identification of root-knot nematodes. This led Taylor, et al. (1955) to compose a key based on perineal patterns for identifying root-knot nematode species. Later, in 1965, Franklin designed a perineal pattern key which included 13 root-knot nematode species and three subspecies. She observed that M. incognita and M. incognita acrita were often lumped together as M. incognita due to frequent intermediate perineal pattern types and no other morphological distinctions. Similar observations were made by Triantaphyllou and Sasser (1960), and Whitehead (1968) agreed to include M. incognita acrita in M. incognita. By June 1984, 54 species and two subspecies have been described in the genus (Hirschmann, 1985).

Host range

Root-knot nematode species are known to attack a large number of host plants. They are known to parasitize at least 2,000 plant species (Raski, 1959). He listed twenty plant families as susceptible to root-knot nematodes. In Africa, these nematodes have been reported to attack several plant species (Peacock, 1957c; Hemeng and Hemeng, 1976; Swai, 1981).

In Nigeria, the first host list was by Wilson (1962). He listed 108 plant species as hosts of root-knot nematodes in northern Nigeria. He classified members of Cucurbitaceae, Solanaceae, Papilionaceae, Unbelliferae, Chenopodiaceae, Alliaceae, Malvaceae, Basellaceae and Caricaceae as highly susceptible crops. Members of the Cruciferae, Compositae, Solanaceae (e.g. Irish potato), Convolvulaceae and Alliaceae (eg. Onions were given as resistant or tolerant crops.

Caveness (1965) listed 116 plant species which are hosts of Meloidogyne spp. in Nigeria. Bridge (1972) found 14 irrigated crops to be hosts in northern Nigeria. Recently, Babatola (1981) found most varieties of five horticultural crops viz., tomato, okra, jews mallow (Corchorus olitorius), "Sokoyokoto" (Celosia argentea), African spinach (Amaranthus spp.) to be susceptible to root-knot nematodes.

Distribution of Root-knot nematodes

Root-knot nematodes are known to be widely distributed throughout the world. While some are cosmopolitan, others tend to be restricted in their distribution. In cool northern latitudes (35°N and above) where the average temperature of the coldest month of the year is near or below 0°C and the average temperature of the warmest month is about 15°C, the

most common Meloidogyne species is M. hapla. In the tropics, the most common species are M. incognita and M. javanica (Taylor and Sasser, 1978). M. arenaria is also widespread in this region. Thus; as a rule, the part of the world between 35N and south latitudes is widely infected by M. incognita, M. javanica and M. arenaria, while north of 35° latitude, the most common species is M. hapla.

The presence of root-knot nematodes on various crops in Africa have been reported by van der Linde (1956) in South Africa, Martin (1958) in Rhodesia, Hemeng and Hemeng (1976) in Ghana and in Nigeria by Wilson (1962), Caveness (1967), Bridge (1972), Idowu (1979).

Reports by these workers indicate the widespread occurrence of the three tropical Meloidegyne species, with decreasing relative abundance in the order of M. incognita, M. javanica and M. arenaria. Evidences also suggest that M. incognita is more prevalent in the south while M. javanica is predominant in the savanna areas. However, recent surveys conducted by Omiyi and Chindo in 1984 (Unpublished) in Samaru area indicate a more widespread occurence of M. incognita than M. javanica.

2.2 IMPORTANCE OF MELOIDOGYNE SPECIES IN CROP PRODUCTION

Root-knot nematodes are considered to be most important of all species of plant parasitic nematodes in agricultural production (Bridge, 1972, Ogunfowora, 1977b). They constitute one of the major problems

directly responsible for losses in crop yields. General effects on infected plants is damage to the root system, weakening of the host and reduction in yields and quality of produce (Taylor, 1971).

The damage done to tomato by Meloidogyne spp. has been assessed the world over. In Ghana, root-knot nematodes have been considered as a widespread limiting factor in the cultivation of fresh vegetables (Edwards, 1953, Peacock, 1957a-d; and Addoh, 1971). Addoh (1971) showed that root-knot nematodes alone may cause as much as 25 percent crop loss in vegetables. Praquin and Marchand (1970) stated that Meloidogyne spp. and other nematodes seem to be the most severe technical impediment to vegetable crop production in the West Cameroun. They estimated that Meloidogyne alone caused a reduction in yield of 50-70 percent in tomatoes after two successive crops.

Observations recorded by Netscher (1971) in Senegal indicate that tomato yields are reduced to less than half when Meloidogyne is present. Barker et al (1976) comparing the effects of M. incognita and M. hapla at two different locations (mountain site and coastal plain), recorded a maximum yield loss of 20-30 percent at the mountain site for both species and 85% for M. incognita and 50% for M. hapla at the coastal plain. They attributed the high yield losses at this site to M. incognita predisposing tomato to the early blight fungus.

In Nigeria, root-knot nematodes have been shown to be the most serious pests on vegetables (Caveness, 1967; Pridge, 1972; Caveness and Wilson, 1975; Amosu and Babatola, 1976; Ezekwesili and Ogbuji, 1978; Ogunfowora, 1977a and b, and Babatola, 1981). Bridge (1972) indicated that the loss in yields of tomato due to root-knot nematodes was as high as 40 percent. Ogunfowora (1977b) showed that root-knot nematodes can cause complete crop loss in tomato.

In northern Nigeria, these nematodes are responsible for crop losses in tomato, particularly in irrigated fields where the continuous cropping of susceptible crops, and the favourable soil temperature and moisture regimes help in the build-up of nematode populations to damaging levels. According to Wilson (1962), the yields of tomatoes can be reduced by 75 percent following the attack of root-knot nematodes.

Considering the substantial potential damage that can be caused to vegetable crop production in Nigeria, concerted efforts should be aimed at keeping the nematode populations to below damaging levels. Netscher (1971) expressed the opinion that economic vegetable farming is not possible if these nematodes are not controlled.

2.3 HOST-PARASITE RELATIONSHIPS

Meloidogyne spp. are obligate endoparasites. Infection commences when a nematode larva, after entering the root, brings its head into feeding position. The stylet punctures the cell and oesophageal glands secretions are injected into the cell. The secretion liquefies a portion of the cell contents and feeding begins. The susceptible host plant in turn responds to the parasitism by rapid enlargement of cells (hypertrophy) and rapid multiplication of cells (hyperplasia). It has been found that failure of the plant to produce hyperplastice cells prevents maturation, while removal of the nematode causes a cessation of host response (Bird, 1962). This is perhaps the highest order of nematode - host relationship. This complex relationship results in a number of symptoms.

The most obvious symptom of parasitism is the presence of conspicuous galls or knots on the roots. These are of varying sizes. On very small roots, they may be as small as one or two millimetre in diameter; on the larger roots, sizes of two centimetre or more are common (Taylor and Sasser, 1978).

Related to the formation of galls, *Meloidogyne* spp. reduce and deform the root system. Heavily infected roots are much smaller than unifected roots, and have fewer branch roots ("Feeder" roots) and root hairs.

This results in a reduction in the amount of water and food assimilated. Also, vascular elements are broken and deformed and normal translocation of water and nutrients is mechanically hindered (Taylor and Sasser, 1978).

Deformity of the root system is accompanied by a reduction in root efficiency. As a result the infected plant looks stunted, wilts in dry weather and exhibits symptoms of nutrient deficiency even when these are plentiful in the soil. Net result is a reduction in the plant growth, yield and quality of the produce.

Besides structural deformation of the host plants root-knot nematodes induce biochemical changes in plant tissues. Owens and Rubinstein (1966) and Owens and Specht (1966) compared the composition of Meloidogyne infected and healthy tomato roots. Galled tissue had decreased carbohydrate, pectin, cellulose, and lignin contents but increased hemicellulose, organic acid, free amino acid, protein, nucleotide, nucleic acid, lipid and mineral contents. They also reported higher rates of glycolysis in galls and higher rates of metabolism, particularly protein synthesis. Dropkin (1972) reported similar results. Increases were especially marked in protein, free amino acids, RNA and DNA. The relative distribution of these compounds in infected tissues seems to be correlated with the distribution of the

elements that enter into their formation. Maung and Jenkins (1959) found that Meloidogyne incognita acrita infection on tomato resulted in an above-normal accumulation of Nitrogen, Phosphorus and Potassium in the roots. No change was, however, observed in the chemical composition of leaves and stems. Generally there is a positive correlation between the extent of nutrient changes and severity of pathogenic effects (Jenkins and Malek, (1966).

In addition to the composition of roots, studies with exudates from galled tomato roots have shown larger amounts of glucese polysaccharides and reduced amounts of amino acids and organic acids than those of healthy plants (Wang and Bergeson, 1974). They also noted a difference in electrolyte loss from healthy and galled roots, indicating that a mechanism mobilizing minerals to the site of infection (Sink) was operating (Wang et al., 1975).

Meon et al. (1978) found higher proline concentrations in M. javanica - infected tomato roots. They proposed that high metabolic activity in the roots associated with giant cell and gall formation, and with egg production exerts a requirement for energy which is supplied by free proline manufactured in the leaves and translocated to the site of nematode activity.

Meloidogyne species also affect the relative distribution of growth regulators in the host plant. Brueske and Bergeson (1972) found that Gibberellins and cytokinin transport was reduced from roots of Meloidogyne - infected plants. They also found a qualitative difference in the types of gibberellins transported out of roots. The general picture seems to be that roots with galls shift their metabolism in the direction of increased protein synthesis and reduced transport of substances to the rest of the plant (Dropkin, 1972). Thus, he hypothesized that "infection with Meloidogyne brings about increased synthesis of proteins in galls, and the attendant disturbance of transport of growth regulators and other compounds between roots and stem results in profound disturbance of top growth".

Meloidogyne species also tend to reduce photosynthesis in infected plants. Wallace (1974) found that incorporation of CO_2 into tomato plants inoculated with 250, 500, 1000 and 2000 M. javanica larvae was markedly less in infected plants than in uninfected plants, whatever the inoculum level.

In addition to the structural and physiological changes, nematode-infected plants undergo cellular changes. Nematodes influence plant cells both by injecting oesophageal gland secretions and by removing the host cytoplasm or parts of it (Gommers, 1981). The

susceptible response may consist of rapid accommodation of the nematode by the plant to removal of materials by the parasite. If the rate of feeding exceeds the rate of response, cell death may result. In all types of feeding sites, cellular responses include increase cytoplasmic density, disappearance of the central vacuole, nuclear and nucleolar hypertrophy, and increase in the number of organelles due to increased metabolism, Differences in host parasite relationship tend to emanate from salivation by the nematode into the plant cell in order to concentrate the plant cell contents prior to ingestion, to complete dependence of sedentary nematodes on their feeding sites for survival, growth and reproduction (Gommers, 1981).

The response of a tomato plant (resistant or susceptible) to infection by Meloidogyne spp. may be influenced by the presence of other pathogens. Such combinations usually result in effects that are more than additive, such as the breaking of resistance, or the production of symptoms differing from those usually produced by either organisms alone. The role of the nematode in such an association is either that of an incitant or aggravator (Mountain, 1960). As an incitant, the nematode would not, by itself, cause a disease but would attack healthy plant tissue to provide infection courts for other organisms. The nematode aggravates the disease by entering lesions or wounds caused by other nematodes or agents. Once within the host tissue the

metabolic products of the aggravator could cause plant injury, predispose plant tissue to invasion by other organisms or provide a medium upon which harmful organisms might grow.

Numerous combinations of nematode - fungus, nematode - bacteria, nematode - virus, and nematode - nematode relationships have been reported on various crops including tomato. Sidhu and Webster (1974) and 1977) reported a break in resistance of tomato to Fusarium wilt fungus in the presence of Meloidogyne spp. Sadiku (1979) and Sidhu and Webster (1981) reported an increase in the severity of wilting caused by Fusarium sp. and Pseudemonas solanacearum in the presence of Meloidogyne spp.

Thus, the host-parasite relationships of nematodes and the host plant, range from structural destruction of the plant to physiological alterations that lead to a net impairment of the efficiency of the host plant, resulting in a reduction in yield. Furthermore, the presence of nematodes in the soil aggravates the severity of some phytopthogenic micro-organisms.

2.4 FACTORS INFLUENCING THE HOST-PARASITE RELATIONSHIP

In the soil ecosystem, several factors influence the degree of damage caused by root-knot nematodes on plants. While some act directly on the nematodes, others do so on the plants thereby making them more vulnerable or resistant to the attack by nematodes. Thus, the interelationship is a complex ecological situation and, therefore it becomes difficult to wholly incriminate these factors as acting directly on the nematode and its charactersitics that determine its effect on the plant. Some of the important factors are initial population density, the type of crop(s) to be grown, soil temperature and moisture, nutritional status of the soil, soil type, plant age and the presence and/or absence of other pathogens.

Initial population density

A very important aspect of plant nematology is an understanding of the relationship between nematode population density and the degree of crop loss. This provides the farmer with a key to ascertain the population density at which it will be economical to apply control. This led to the adoption of the term "economic loss threshold" (Olthof and Potter, 1972). This is the percentage of the value of the crop equivalent to the cost of nematode control, and this will be attained at a given

nematode density for a given crop. The effect of the initial population density (P_i) on the growth and yield of the crop is a resultant effect of the population on nematode characteristics viz., invasion, reproduction and development of the nematodes. These studies have been conducted in various countries of the world with various nematode species including Meloidogyne spp. on various crops including tomato (Olthof et al., 1973; Barker et al., 1976). In Nigeria however, little has been done on this vital subject except for the work of Ogunfowora (1977b) on M. incognita and tomato, Ezekwesili and Ogbuji (1978) on M. incognita and smooth amaranthus. These reports are, however, based on work carried out in the southern parts of the country.

Various workers have reported a direct relationship between nematode density and crop losses (Oostenbrink, 1966; Olthof and Potter, 1972; and 1977; Potter and Olthof 1974). Barker et al. (1976), while comparing effects of M. incognita and M. hapla on tomato at two different locations (mountain site and coastal plain), demonstrated a suppression of yield by both species, with the highest reduction at the coastal plain. They attributed the high losses at this site to Meloidogyne spp. predisposing tomato to the early blight fungus. They also established a threshold density for both species at the two different sits i.e. 500 to 1000

larvae and eggs/50 cm^3 of soil for the mountain site, and 20 larvae/500cm^3 of soil in the coastal plain.

Ogunfowora (1977b) found that yields of all seven cultivars of tomato tested by him, were inversely correlated with nematode density. He recorded a yield loss of 58 percent for Rossol to 89 percent for Ife I.

The yield loss of a crop by root-knot nematodes is closely related with the initial population density. Potter and Olthof (1972), working with several vegetable crops, found that any nematode density that causes loss exceeding 5% of the yield is considered sufficient to warrant soil fumigation. They established that economic loss by root-knot species is caused at an initial population density of 2000 larvae/kg of soil. Thus, populations below the economic loss threshold do not warrant control while populations above it do.

Results from different population density studies on the growth of crops indicate a positive host-parasite relation at population densities below economic loss threshold. Results by Olthof and Potter (1972 and 1977) and Potter and Olthof (1974) and Ogunfowora (1976) indicate that low populations stimulate growth whereas high numbers suppress vegetative growth. Olthof and Potter (1977) showed that both shoot and root weights of veebrite tomato were significantly increased at the

260 larvae/kg soil. Also the number and cummulative weight of fruits tended to be highest in the presence of fewest nematodes whereas, the cummulative fruit weight was suppressed by 10-40 percent at the highest P_i densities. Similarly fruit ripening was delayed at highest P_i densities. The increase in growth and yield at the lower densities appeared to be due to an increase in the size of the root system.

Similar results have been reported by Wallace (1971). He, however, observed three different effects in three groups of plants. In one group there was growth stimulation by low numbers of M. javanica. In a second group no change was observed and in the third, shoot weight decreased linearly with increasing nematode numbers. He attributed the difference in the response of plants to infection of M. javanica to the interaction between inhibitory and stimulatory processes in the plant. Where there is a decrease in growth and yield, inhibitory processes dominate and vice versa. Plants in which top growth remains constant up to a particular nematode density, the tolerance level shows a balance in the two processes.

Closely associated with population density is the effect on invasion, reproduction and development. These characteristics have been found to be reduced with increase in nematode density (Triantaphyllou, 1960; Oostenbrink, 1966; Wallace, 1969; Olthof and Potter

1977). Besides a decrease in embryonic development, high proportions of males have been found to appear as nematode density increases. The preponderance of males results from insufficient food supply and competition for infection sites (Wallace, 1971).

Type of crop

The development of nematodes to damaging levels is influenced by the availability of food. Thus the availability of a host plant and its efficiency determines the performance of the nematode. An efficient host for root-knot nematodes is that which allows the nematode to build up to damaging densities, whereas, an inefficient host or non-host either does not allow the nematode to reproduce or allows it to reproduce slightly (Omiyi, 1976). Thus growing an efficient host under suitable environmental conditions leads to development of high population levels and vice versa.

In South Africa, van der Linde (1956) found that population of root-knot nematode species occurring either singly or in mixed populations can be markedly reduced by growing non-host plants, Eragrostis curvula and Crotalaria spectabilis. Sauer and Giles (1957) have shown that growing susceptible tomatoes year after year in the same soil leads to a build-up of root-knot nematodes to dangerous levels. However, growing

resistant hybrid tomatoes guaranteed good yield but did not reduce the nematode population sufficiently enough to make land suitable for the next susceptible crop as the resistance was not complete. In Ghana, Peacock (1957c) considered groundnut an immune crop because substantial reduction in root-knot nematode population was observed by growing this crop. Also, Birrat (1969) showed that growing susceptible crops like Okra and Cucumber continuously for four seasons resulted in the rapid multiplication of M. javanica. Adeniji and Cheda (1971), reported that growing giant star grass, Cynodon sp. for two years in a field plot markedly reduced the incidence of root-knot.

Under the Nigeria Savanna conditions, crops such as rice, cotton, groundnut, sorghum, millet and maize do not seem to allow the nematodes to multiply and damage does not occur (Bos, 1978). Groundnuts are thought to trap the root-knot nematodes thereby reducing population levels much more drastically than non-hosts.

In the southern part of the country, Caveness (1976a) showed that Stylosanthes gracilis and Centrosema puhescens, both valuable as green manure or fodder crops, drastically reduced populations of root-knot nematodes in fields near Ibadan during a growing season of between half and two years. Research at Kadawa (in Kano state) also confirmed the effectiveness of

S. gracilis in reduction of Meloidogyne populations (Bos, 1978).

Soil temperature, soil moisture and pH.

These are very important abiotic factors that determine the size of nematode populations in the soil. Generally, the nearer the soil temperature, moisture and pH are to the optimum for development of the nematode, the faster is its growth.

Bergeson (1959) observed that eggs and larvae of M. incognita acrita survived for over a year at 10°C but survival time was reduced to less than half at 10-16°C. At 21°C some of the nematodes survived for four months, and at 0°-4°C, larvae died in one to two weeks. High temperatures of 32-37.7°C led to rapid death of larvae, and eggs lost their viability after a few days. Bird (1972) reported that the optimum temperatures for hatching, movement, invasion and growth of M. javanica are 25°C, 15-30°C and 25-30°C respectively. In addition, Thomason and Lear (1961) found that the reproduction of M. javanica and M. arenaria was highest at 30°C, and lowest at 15.6°C. Above 32°C egg production was decreased. Thus, temperatures above 32°C and below 15°C are unfavourable for embryonic development of these nematodes.

In addition to its effects on survival, grow' and reproduction, temperature is a critical factor in the determination of nematode movement and infection. For example, Prot and Van Oudy (1981) demonstrated that about 17 percent of M. hapla juveniles were able to migrate 20cm at 11|. C and infect tomato roots in 10 days while only 3 percent of the M. incognita were capable of migration at that temperature.

The amount of moisture is of paramount importance in the movement and survival of nematodes. Daulton and Nusbaum (1961) found that survival rates of eggs of M. javanica and M. hap la were higher at 1 .I4. percent moisture than at 6.1 percent. Wallace (1965 and 1970) found that the optimum soil mositure for hatching, movement and invasion was in the region of field capacity where most of the larger pores have drained of water whereas reproduction is maximum in relatively finer soil.

Soil pH determines the chemical activity of the soil. Thus it affects the availability of nutrients to the plant. Nematode multiplication and activity appears to be lower at both extremes of pH than at neutral region* Ogbuji and Okonkwo (1977) found that root galls developed at all pH levels but egg mass production occurred only at pH 5.6 and 7.6. Wallace (1965) indicated that soil pH has a major influence on

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root infection. Generally, if the pH is within the favourable range for plant growth, the nematodes are active (Wallace, 1970).

Age of the plant

Susceptible plants are more susceptible at young age but tend to tolerate infection at older age (Wallace, 1970). Ogunfowora (1977) found that percent invasion of M. naasi increased as the age of the host plant (barley) at inoculation increased from one to three weeks, but the rate of development and the sex ratio were not greatly influenced.

Soil types

The various characteristics of different soil types affect the physical properties of soil viz., aeration, water-holding capacity and hydraulic conductivity. These in turn influence the movement, development and survival of the nematodes. Thus, the soil type that favours the expression of these characters is preferred. Reports from the U.S.A. and elsewhere indicate preference of Meloidogyne spp. for sandy loam to laomy-clay (Sasser, 1954), and coarse textured to fine texturered soil (O'Bannon and Reynolds, 1961). However in East Africa, Whitehead (1969) found no correlation between the soil texture and root-knot

development. There is however, a general agreement that root-knot nematodes reproduce and develop better in loamy to sandy-loam soils.

Sleeth and Reynolds (1955) reported that the level of infestation of M. javanica on Sesbania exaltata was greater in coarse than in fine-textured soils. Wallace (1969) indicated that reproduction of these nematodes was highest in coarse sand while invasion was highest in fine sand. Also root growth was highest in the fine sand and lowest in the coarse sand. He attributed the decrease in reproductive rate with increase in the particle size to a combination of reduced invasion and root growth as the particles become larger. The pores in soil with finer particles may somewhat inhibit nematode movement (Wallace, 1971). He found the optimum pore size for movement and invasion of nematodes to be about 75-120 um.

Although in Nigeria there are reasons to believe that root-knot damage to crops is worse on sandy soils (Olowe, 1978), no record is available of their soil type preferences. Available data suggest wide occurrence irrespective of soil type (Bridge, 1972; Caveness, 1976a; Ogbuji, 1976; Bos, 1978). This is borne out in various other places e.g. parts of Kano state and Dadin Kowa, Bauchi state (Erinle, personal communication).

The Nutritional status of the soil

The nutritional status of the soil affects the density of the nematode population. Reports indicate that soils rich in nutrients tend to reduce nematode populations (Wallace, 1969; Spiegel et al., 1982). The augmentation of the inherent soil fertility with the use of organic and inorganic fertilizers decreases the severity of root-knot nematodes (Johnson, 1959; Caveness, 1967; Khan, 1976; Omiyi, 1976; Babatola, 1982). Dacusin and Davida (1971-1972) successfully controlled root-knot nematodes on tomato by using poultry manure.

Interaction between Meloidogyne spp. and other pathogens.

While nematodes alone are capable of causing severe plant injury and reduction in crop production, they are often involved with other organisms which cause diseases. These combinations often result in more than additive effects such as the breaking down of resistance or the production of symptoms differing from those usually produced by either organisms alone. Such associations are sometimes referred to as "disease complexes". Combinations include nematodes with fungi, bacteria, viruses, mycoplasmas and even other nematodes.

The earliest reported association of pathogens was between nematodes and vascular wilt pathogens.

Atkinson (1892) reported that root-knot nematodes increased the severity of Fusarium wilt on cotton. Since then this observation was confirmed for various other nematode-fungus associations on a wide range of host species (Bergeson, 1972; Powel, 1979). Bowman and Bloom (1966), Good and McGuire (1967), Jenkins and Cousern (1957) found that a tomato plant genetically susceptible to Meloidogyne spp. but resistant to Fusarium wilt fungus loses its resistance to the fungus in the presence of the nematode. They also found that breaking of resistance is associated with large number of larvae (about 5000-6000). Sidhu and Webster (1981) showed that severity of Fusarium wilt on tomato increased with nematode density up to 5,500-6,500 larvae/kg soil, thereafter, showed variable response.

Other workers have reported the influence of Meloidogyne spp. on disease expression. Napiere (1980) reported that seedlings of tomato, cultivar Yellow plum, inoculated with Pseudomonas solanacearum and M. incognita developed symptoms of bacterial wilt earlier than seedlings inoculated with the bacterium alone. An increase in the number of M, incognita eggs caused increased seedling mortality. Similar results were obtained by Napiere and Quimio (1980) and Almeida (1980) with a reduction in yield of tomatoes. In Nigeria, Sadiku (1981) found that severity of wilting increased

with mixed populations of M. incognita and M. javanica with P. solanacearum.

In disease complexes involving nematodes and other pathogens, the role of the nematode is varied. The nematode in many cases serve as a vector (particularly for bacteria and viruses), in others as a mechanical aid to entry, and in still others by inducing certain specific host changes to provide for growth of the associated pathogen (Jenkins and Taylor, 1967).

Though the role of the nematode - pathogen relationship appears to be largely a wound relationship, it is possible that much more is involved in some reactions. In breeding tomato varieties for resistance to Fusarium wilt, Young (1939) reported that resistance was decreased in the presence of Heterodera marioni (= Meloidogyne exigua) and later found that the control of the nematode did not control the fungal disease. This meant that root-knot nematodes had little effect on the incidence of Fusarium wilt of tomato. However, working with three tomato varieties the highly susceptible Red Beefsteak, the moderately resistant Rutgers, and the highly resistant Chesapeake (Jenkins and Coursern, 1957) demonstrated a total loss of resistance to Fusarium wilt in all the varieties with M. incognita acrita, and a partial loss with M. hapla. Further, in the intermediate variety, Rutgers, the time for expression of wilt symptoms was decreased in the presence of root-knot

nematodes to about the same number of days as in the highly susceptible variety. According to these authors the role of the nematodes was more than merely providing an entry for the fungus through wounding especially with endogenous nematodes such as Meloidogyne spp. (Pitcher, 1965; Bergeson, 1972; Garber et al., 1979. For instance, it appears that when bean (Phaseolus vulgaris) is infected by both the obligate foliar parasite Uromyces phaseoli and the obligate root parasite M. incognita, the reproduction of each parasite is decreased by the presence of the other (Bookbinder and Bloom, 1980). Field and plot records suggest that Meloidogyne modifies the host's mineral composition and physiology and, consequently, slows host growth, and in many instances breaks the host's resistance to other parasites. Conversely, the plugging of xylen vessels by a wilt fungus prevents nutrient and water uptake, and so decreases the host vigour and apparently makes them more vulnerable to challenges by other pathogens, such as Meloidogyne spp. (Webster, 1985).

Contrary to positive relationships between disease severity and the presence of root-knot nematode, some reports indicate a negative relationship. Harrison and Young (1941), Bindar and Hutchinson(1959) and Kawamura and Hirano (1967) indicated that monogenic resistance to Fusarium wilt was not affected by the root-knot nematode. Jones et al., 1976) found that root-knot nematodes whether applied simultaneously with the

Fusarium inoculum or two weeks prior to the Fusarium inoculum did not reduce the resistance of the tomato cultivar manapal (resistant to race I and susceptible to race 2 of F. oxysporum f.sp. lycopersici) to race I, nor the resistance of the cultivar florida MH-I (resistant to both races) to race I and 2. Also Abawi and Barker (1984) found that resistance of four tomato cultivars Manapal, Floradel, Florida MH-I and Nematex to Fusarium wilt was not broken due to the presence of M. incognita. Wilting was however, enhanced in susceptible plants: Furthermore, attempts to reisolate F. oxysporum f. sp. lycopersici from stem tissues of inoculated plants at the end of the experiment were negative.

2.5 CONTROL OF ROOT-KNOT NEMATODES

The objective of nematode control is to improve growth and yield of crop plants. This involves a reduction of the nematode population in the soil or plants, or making it much ineffective thereby reducing damage. For any control measure to be practicable and profitable, it must be of economic value, that is, the increase in monetary value of the crop must be more than enough to offset the cost of control measure. According to Taylor and Sasser (1978), the expected benefits should exceed the expenses by a ratio of at least three to one (3:1), and preferably more. Various control measures

have been applied the world over, some, with or without much success. Control measures fall into four broad categories viz; Cultural, Biological, Physical and Chemical.

2.5.1 CULTURAL CONTROL

This involves the manipulation of suitable agronomic practices with ultimate aim of reducing nematode populations to safe levels before a susceptible crop is grown again. This is achieved through the following ways.

Crop Rotation

The principle involved in crop rotation is that non-host crops (both resistant or immune), and susceptible crops are alternated at suitable intervals as will allow a reduction in the nematode population to safe levels, each time, for the susceptible crop. Reduction in the population results from starvation of the nematodes for food due to the growing of resistant plants. This measure has been found to be very effective in controlling root-knot nematodes and other diseases.

Crop sequences which give good control of root-knot nematodes have been reported by various investigators. In South Africa, van der Linde (1956) reported that population of several species of root-knot nematodes can be markedly reduced by growing the non-host plants,

Eragrostis curvularia or Crotalaria spectabilis). Peacock (1957a) showed that root-knot infestations could be considerably reduced by a ploughed bare fallow, but this was less effective in the wet than in the dry season. Omiyi (1976), Smit and Bos (1976) and Ogunfowora (1981) also showed that growing non-host or resistant varieties such as wheat and onion reduced root-knot infection with economic increase in yield of tomato. Merny (1976) mentioned that one year of tomato and two years of rice (Oryza sativa) had given effective control of Meloidogyne populations and facilitated commercial tomato production in Ivory Coast.

In crop rotation trials in Senegal, it was found that a crop of peanut (groundnut) Arachis hypogea or strawberry (Fragaria sp.) grown prior to tomato in soil heavily infested with root-knot nematodes greatly increased yields of tomato compared to those of a previous crop of tomato (Netscher and Taylor, 1976). Experiments in Florida, U.S.A. resulted in reduction in populations of M. incognita, M. javanica and Sting nematode; Belonolaimus longicaudatus after growing hairy vetch (Indigofera hirsuta). Snap beans grown in the field had average yields of 8923 kg/ha compared with 3387 kg/ha following sorghum (Sorghum bicolor), and 5592 kg/ha following Sesbania macrocarpa (Taylor and Sasser, 1978).

Inspite of its goodness, crop rotation is pregnant with problems. Most important is the difficulty in finding

suitable crops for a rotation system (Bridge, 1972). This, according to him, is further accentuated by the limited number of crops that can be grown under irrigation due to economic reasons and continuous cropping in some lands throughout the year. Nevertheless, a carefully planned and strictly followed rotation programme will reduce these problems, and, according to Keay (1967) will reduce a rapid multiplication of destructive soil organisms.

Dry fallow

The principle of controlling nematodes by fallowing is closely related to crop rotation i.e. nematode populations will decrease in the absence of food, but in addition to starvation, heat and desication contribute to the reduction in the nematodes populations during the fallow periods. Cases of success have been reported by Peacock (1957a) and Omiyi (1976). The practicability of this method today is, however, dwindling due to shortage of land as a result of population explosion. Secondly, intensive farming through rapid mechanisation renders it obsolete. A third disadvantage is the total absence of income from the land being fallowed and the potential increase in soil erosion in the absence of plant growth (Jenkins and Taylor, 1967).

Soil Desiccation

Perhaps the best control measure for root-knot nematodes lies in desication of soil as they are easily killed by high temperatures. The method involves repeated ploughing of the land during the dry season. This exposes the eggs and larvae to sun scorching. Caveness (1967) reported that root-knot nematodes can be effectively controlled by monthly ridging of the soil during the dry season in Oyo State. It, however appears that monthly ridging of the soil is difficult and expensive and thus, renders it relatively inpracticable with small scale farmers. The method is also rendered inefficient in irrigated lands where the land is under continuous crop culture with susceptible varieties, and favourable moisture and temperature regimes that favour a rapid build-up of nematode populations.

Sanitation or Quarantine

This method involves the prevention of spread of nematodes from one farm to another or within the same farm by machines, irrigation water, or workers boots. Removal of weeds and volunteer plants, use of clean "seeds", removal of old stalks and roots are also done to check the spread of nematodes. All these practices reduce the source of inoculum for the subsequent crop. Odihirin and Adesida (1974) reported that weeds belonging to more than 20 plant families harboured root-knot

nematodes after the annual crop matured in southern Nigeria,

Use of resistant varieties

One of the best methods of nematode control is the use of resistant varieties of crop plants. To be of value, a variety must be resistant in the region concerned, and, in addition, should have acceptable agronomic qualities e.g good yield, and in general be as profitable for the farmer as the standard varieties (Taylor, 1971).

Efforts to develop cultivars of tomatoes resistant to root-knot nematodes started in the early forties. Since then extensive work to confirm and use this resistance to breed resistant varieties has been conducted in various parts of the world. Many cultivars, which are resistant to different Meloidogyne spp. have been produced, tested and utilized in various parts of the world with tremendous success. Reports have indicated that Ronita, Rossol and Nemared show promising resistance to root-knot nematodes (Anon, 1970).

In Nigeria, several cultivars of tomato have been screened for their resistance to Meloidogyne spp. Amosu and Babatola (1976) found that Atkinson, Nematex, Rossol VFN 8 and Ife I (Improved line 76) were resistant to M. incognita; Ronita, Puunui and Nemared showed some level of tolerance. Also in his work, Ogunfowora (1976) found that of the 27 tomato cultivars screened, none was

completely immune to the root-knot nematodes. Ronita was found to be the most resistant. Rossol, Nemates and Enterpriser showed slight resistance; Nemared was moderately susceptible while all others were susceptible.

In northern Nigeria not much has been done on screening of tomato cultivars for resistance. Enterpriser, which Ogunfowora (1976) reported as slightly resistant, has been found to be highly susceptible (Omiyi, 1984). From trials conducted at Tomas and Jakarde, both in Kano state, he found that tomato cultivars Ronita, Rossol and Roma VFN were highly resistant to the populations of root-knot nematodes.

2.5.2 PHYSICAL CONTROL

Physical control of plant parasitic nematodes employs the use of heat, electricity and radiation. However, the most commonly used method is heat, employed in form of steam, hot-water treatment, or dry heat, using a flame. While steam and dry heat are used for soil sterilization, hot water is used for planting material. In the later nematodes are subjected to temperatures of the range of 40 to 55°C for a short time. This is the thermal inactivation point of animal enzyme (Jenkins and Taylor, 1967). Steam sterilization of soil is, however, an expensive measure and used exclusively in glasshouse operations, gardens, experimental pots and high-value crops.

The hot-water treatment is widely used for transplanting stocks. The plant material (roots, tubers, bulbs or other infected parts) are immersed in hot water for a time period long enough to kill the nematodes. For satisfactory results, the temperature and time of expesure to the heat is important. This varies from 240 minutes at 43.3°C to one minute at 54.4°C (Taylor, 1971). Taylor (1971) catalogued the time and temperature recommendation for hot water treatment of different plants for different nematode species.

2.5.3 BIOLOGICAL CONTROL

A large proportion of plant parasitic nematodes are killed by natural enemies existing in all agricultural soils. These include insects bacteria, fungi and even viruses. These parasites/predators have been shown to be able to reduce nematode populations.

Dolfus (1946) reported many protozoan infections of nematodes. Since Mieoletzky (1925) first described Dubescquia, several species have been reported parasitizing plant parasitic nematodes. Williams (1960) found 34 percent of 174 Meloidogyne females examined from sugarcane fields in Mauritius to be filled with spores of a sporozoan that resembled Duboscquia penetrans. In a glasshouse [illegible] experiment, an unidentified sporozoan was found to severely attack the larvae of M. javanica and M. incognita (Prassad

and Mankau, 1969).

Bacteria can be lethal to nematodes. Dolfus (1946) recorded that cell-free extracts of Pseudomonas sp. caused a high mortality of Meloidogyne spp.

Viruses may also be lethal to nematodes. Lowenberg et al., (1959) demonstrated the existence of a virus in larvae of M. incognita, causing larval sluggishness and inability to cause galls.

Perhaps the most useful biological control agents are fungal parasites an predators. Several fungi have been reported to parasitize and reduce nematode populations in greenhouse conditions. However results of field trials have been inconclusive, and, for most cases, dissappointing and inconsistent due to several abiotic factors like pH, moisture and temperature. Thus, their establishment and multiplication in the agricultural soil become limiting due to their lack of adaptability and competitiveness as well as their slow multiplication and dissemination rate (Jatala, 1985).

Fungal parasitism/predation is achieved in either one of the following ways:

a) adhesive processes and mechanical ring traps.

b) Production of toxins by the fungus that kills the nematodes before fungal hyphae penetrate the cuticle

c) Non-trap forming endoparasitic fungi. The non-trapforming endoparasitic fungi usually enter the nematodes by a germ

tube that penetrates the cuticle from a sticky spore. Once inside the nematode, the hyphae ramify throughout the body, absorb the contents and spore-bearing hyphae then emerge from the nematode cadaver (Webster, 1972).

Several fungi have been reported to perasitize nematodes (Tribe, 1977; Stirling and Mankau, 1978; Nigh, 1979; Tribe, 1979). With the recent discovery of the egg parasite, Paecilomyces lilacinus and its success in the control of root-knot nematodes in greenhouse and field experiments (Jatala et al., 1979; Jatala et al., 1980; Franco et al., 1981), biological control studies seem to be paying dividends. From a series of studies conducted with M. incognita on potato, Jatala (1985) observed a 70 percent reduction in root galls and egg masses in the plants from fungus-treated tubers due to destruction of the eggs by the fungus. Plants inoculated with the fungus had a lower root galling index than did those grown in the nematicide-treated plots. Reduction in the galling index led to a concomitant increase in the yield of potato tubers in the fungus-treated plots. These results point to P. lilacinus as a suitable alternative to chemical control.

2.5.4 CHEMICAL CONTROL

Nematodes are chemically controlled by nematicides. Nematicides constitute one of the most important and reliable means of controlling a wide variety of nematodes.

Nematicides have been in large-scale use since 1940 and such use has been on the increase every year. Widespread use of nematicides started about 1950 and has increased to a business estimated at nearly $100,000,000 per year (Taylor and Sasser, 1978). These chemicals are used on approximately 1.7 million acres, which is less than one percent of the cultivated agricultural land in the United States (Johnson, 1985).

The oldest nematicides are liquid soil fumigants which are injected beneath the soil surface. They evaporate to produce fumes which kill nematodes in the soil pores. Newer nematicides are water-soluble non-fumigant chemicals. They are distributed through the soil by percolation of water and enter the nematode bodies through the cuticle.

The newest types are the systemic nematicides. They are taken up by plants through the roots after application to the soil, or through foliage after spray application and are then translocated to the roots to kill the nematodes feeding on them, or prevent nematodes from feeding on the roots.

Nematicides have been used all over the world with considerable success. Peacock (1957b) found a significant control of nematodes through the application of 1,2-dichloropane and 1,3-dichloropropene (D-D), ethylene dibromide (EDB) and tetrachlorobutadiene. Minz (1957) achieved considerable yield increases with DD. Sieff

(1959) increased tomato yields by 40 percent using EDB. Philis (1974) found an overall nematode reduction of 77-85 percent. In his study on the effects of several nematicides on the infection of M. incognita and growth of tomato plants, Hemeng (1975) found a general low infection of root-knot nematodes with significant differences in plant growth and yield. DD reduced infection by 75 percent while nemagon and vapam reduced the infection by about 50 percent. Okatahi (1980) found a singificant reduction in root galling at Hunkuyi and Samaru in northern Nigeria using four chemicals viz., Basamid, Mocarp, Vydate and DD.

Factors like soil temperature, soil moisture, soil texture etc. play an important role in the success of soil fumigation. Holdemann (1954) reported that successful fumigation for nematode control is achieved when soil temperature is between 10° and 30°C. Also, time of application of the nematicide is of great importance. An effective control is achieved at transplant production phase. Good and Steel (1958) observed that fumigation, two weeks before planting, produced transplants of good stand and higher mean plant weight than control. Similar results were obtained for plants in the fruit production phase.

Recent advances in the control of nematode have indicated that less costly, less persistent, less

phytotoxic and less hazardous lipid antioxidants can be used successfully to control root-knot nematodes. Since root-knot nematodes oxidize lipids to be pathogenic (Fawole, 1981), it is believed that their damage can be reduced by protecting roots of host plants with lipid anti-oxidants which inhibit the oxidation of lipids in the plant roots. If the lipids in roots are not available for oxidation, the nematodes will be forced to use their own lipid reserves. A reduction in the lipid reserves in the nematode leads to a decrease in nematode activity and infectivity. The nematodes start aging and will eventually die.

In vivo tests conducted by Fawole (1981) with two lipid anti-oxidants Ascorbic acid (AA) and Piperonyl butoxide (PB) on control of root-knot nematodes on tomato, showed some reduction in nematode numbers and increase in biomass, especially when higher concentrations were used. In addition, treated plants produced more flowers and much earlier than untreated ones. According to him, this physiological advantage can be used to force early production of tomato fruits, especially where they enjoy a high premium.

Also in vitro tests with methionine, xylocaine AA, and Sodium Benzoate decreased hatching rate with increase in concentration of each lipid anti-oxidant. Larval mortality also increased with increase in its

concentration. However, efficient use of lipid anti-oxidants requires relatively large and appropriate dosages.

From the foregoing discussion, it is clear that nematicides will continue to play a major role in nematode population management for the production of a number of crops and for use in regulatory and quarantine programmes. The shift from traditional farming systems towards mechanized and specialised farms call for ever increasing shift toward mono-cropping and/or intensive cropping systems that invariably lead to increased crop losses by nematodes. Therefore, use of nematicides is a necessary adjunct to continuous cropping of land, or to a greatly narrowed crop rotation base (Good 1972). Such a system will require the development of highly effective nematicides that will control nematodes with lower amounts of active ingredient per unit of land (Johnson, 1985).

EXPERIMENTS CARRIED OUT

CHAPTER 3

THE EFFECT OF DIFFERENT POPULATION DENSITIES OF MELOIDOGYNE INCOGNITA ON THE GROWTH AND YIELD OF TOMATO cv. ENTERPRISER

3.1 INTRODUCTION

Investigations in Nigeria have shown that root-knot nematodes are a serious threat in tomato production and it will be profitable to control them. However, the nematode population levels at which it will be economical to do so have not been well worked out. Thus, this tends to increase total cost of production whenever the population is not high enough to cause economic loss. This is because the marginal revenue will be lower than the marginal cost.

In developed agricultural economies, attempts have been made to define population levels of root-knot nematodes that are capable of causing economic loss on various crops (Oostenbrink, 1966; Olthof and Potter, 1972; Potter and Olthof, 1974; Barker et al., 1976). In Nigeria, little of this work has been done except for the work of Ogunfowora (1977) and Ezekwesili and Ogbuji (1978). These investigations were, however, very limited and restricted to the southern parts of the country.

In northern Nigeria, tomato production is rapidly assuming commercial scale. At the same time, root-knot

nematodes have been found to cause severe crop losses particularly in irrigated fields where conditions are congenial enough for the rapid build-up of populations to damaging levels. It thus becomes pertinent to define a population density.that is capable of causing economic loss to this crop so as to achieve economic control of these nematodes. The objective of this study is therefore to determine the relationship between different population densities of M. incognita on the growth and fruit yield of tomato, cv. Enterpriser.

3.2 MATERIALS AND METHODS

3.2.1 Preparation of inoculum of M. incognita

Tomato plants infested with root-knot nematodes were collected from farmers' plots near Zaria Dam. These were examined for females and single eggmasses under the dissecting microscope after thorough washing under a stream of tap water. Females of Meloidogyne spp. were distinguished using perineal patterns (Taylor et al., 1955) Egg masses of identified M. incognita females were inoculated singly onto tomato plants, cv, Enterpriser growing in clay pots filled with heat-sterilized soil (composed of 3:2:1 parts of loam: sand: manure). Inoculation was done by placing the eggmasses in a hole close to the growing tip of the roots. After eight weeks, females were isolated from these plants and perineal patterns were made to ascertain the purity of

the culture. Thereafter, pure cultures were multiplied in drums with three plants grown in each. These were used for all subsequent experiments.

3.2.2 Experimental Procedure

The experiment consisted of seven different initial population densities (Pi) viz., 0, 500, 1,000, 2,000, 4,000, 8,000, 16,000. Uniform eggmasses with an average of 300 eggs per eggmass were used to provide the Pi. Each Pi constituted a treatment replicated five times and arranged in a completely randomized design. Heat-sterilized soil constituted the zero Pi. The experiment was carried out both in the glasshouse in clay pots and in the field in microplots.

Clay pots measuring 23cm in diameter and 20 cm high were filled with heat-sterilized soil to which had been added 15g of NPK (15: 15: 15). Four-week old tomato seedlings (10-15cm in height) raised in heat-sterilized-soil were transplanted singly to each pot. Watering was done as often as was necessary.

In the field experiments microplots were plunged in the field in rows 50cm apart and 50cm within the rows and each filled with 6 kg of soil. Inoculation was done by pouring the inoculum in a hole made at the centre of the pot in which was placed the tomato seedling. The soil was then levelled. Adequate amount of water was then applied. Observation was made for insect attack and

foliar diseases.

At midseason (40-45 days after transplanting), soil samples were taken up to a depth of 15-20cm with auger from all the pots of each Pi to determine the nematode population. Height of plants for each Pi were also measured.

When tomato vines became prostrate, they were staked to prevent ripening fruits from coming in contact with the soil. Foliar diseases like Septoria leaf spot, were controlled with a mixture of Dithane M45 and Benlate at the rates of 2.5kg and 0.7kg a.i./ha respectively.

The ripe fruits (about 10 weeks after transplanting) were picked, counted and weighed according to each treatment. Soil samples were taken for each Pi to determine the final nematode population (Pf) in the soil. Roots were washed under a gentle stream of water, blotted-dry and rated for galling according to the method described by Daulton and Nusbaum (1961) shown in table 1 below.

Table I. Galling Index (after Daulton and Nusbaum, 1961).

Infection class	Index value	Description of Index value
0	0	Free from galls
1	1	Trace, less than 5 galls.
2	5	Very slight, trace to 25 galls.
3	10	Slight, 26 to 100 galls
4	25	Moderate, galls numerous, mostly discrete.
5	50	Moderately heavy, galls numerous many coalesced

Infection class	Index value	Description of Index value
6	75	Heavy, galls numerous, mostly coalesced; root growth slightly retarded.
7	90	Very heavy, mass invasion, slight root growth.
8	100	Extremely heavy, mass invasion, no root development.

Plant growth and yield data were subjected to statistical analysis using the technique of Analysis of variance (ANOVA)

3.3 RESULTS

At midseason, plant height progressively declined with increasing Pi (Fig I and Plate I). Significant reduction in plant height was observed with intial population density of 2,000 larvae/kg of soil. However, there was no significant difference in the height of plants inoculated with either 8,000 or 16,000 larvae.

Both the number and total weight of tomato fruits decreased with increases in Pi (Figs 2 and 3). Yield reduction was not significant at low Pi except at high Pi. The mean weight/fruit at the low nematode population (500-1,000) was higher than the check but progressively declined with increases in Pi (Fig. 4). Percentage yield loss varied from 1.6% at 500 larvae/kg of soil to 85.34% at 16,000 larvae/kg of soil.

Table 2.0. Effect of various initial population densities of M. incognita on its reproduction and on root growth of tomato (Lycopersicon esculentum) CV. Enterpriser.

Initial population density (Pi)	Nematode *Population at midseason				Nematode *Population at harvest (Pf)				mean root gall index[a]	mean root weight[a]
	Glass-house	R	Microplots	R	Glass-house	R	Micro-plots	*R		
0 (Control)	-	-	-	-	-		-	-	0	32.2
500	4,000	8	4,100	8.2	9.800	19.6	9,500	19.0	3.5	142.5
1000	9,500	9.5	8,700	8.7	12,000	12.0	16,200	12.3	5.0	190.0
2000	12,000	6.0	12,400	6.2	16,000	8.0	17,200	8.1	5.3	185.8
4000	16,300	4.1	16,000	4.0	17,500	4.4	17,800	4.5	6.4	112.6
8000	16,600	2.1	16,400	2.1	15,400	1.9	16,000	2.0	6.9	94.8
16000	17,600	1.1	17,100	1.1	14,500	0.9	14,800	0.9	7.8	85.5

R = Reproduction factor = $\frac{pf}{pi}$ where pi = Initial nematode population density and
(Oostenbrink, 1966) Pf = Final nematode population density

a = Mean of five replicates.

* = Mean of two years.

Combine analysis of the data on plant height and fruit yield showed that there was no significant difference between results of the two years. Thus, results of one year each for glasshouse and microplot experiments are presented in Figs 1 - 3.

At termination of experiments, root weight increased with increasing Pi up to 2,000 larvae/kg of soil but declined thereafter (Table 2.0). Proliferation of adventitious roots was higher at low Pi than at high Pi.

The root gall index showed a direct relationship with increasing initial population densities and the degree of galling (Table 2.0. and Plate II). Small, discrete galls were observed at lower Pi whereas, at high initial population densities, galls became larger and coalesced. At harvest roots from plants inoculated with 8,000 and 16,000 larvae/kg of soil had started decaying.

Foliar diseases like septoria leaf spot, were minimal in glasshouse experiments but relatively severe in the field. However, these were controlled with spray applications of Benlate and Dithane M45.

An economic loss threshold of 10.6% was established. This was based on the market value of the crop during the two experimental periods (1984/1985) (Erinle, Personal communication) and the cost of nematode control. Average value of the crop during the two years was ₦1369.43, while the cost of chemical control stood at ₦145.25/ha.

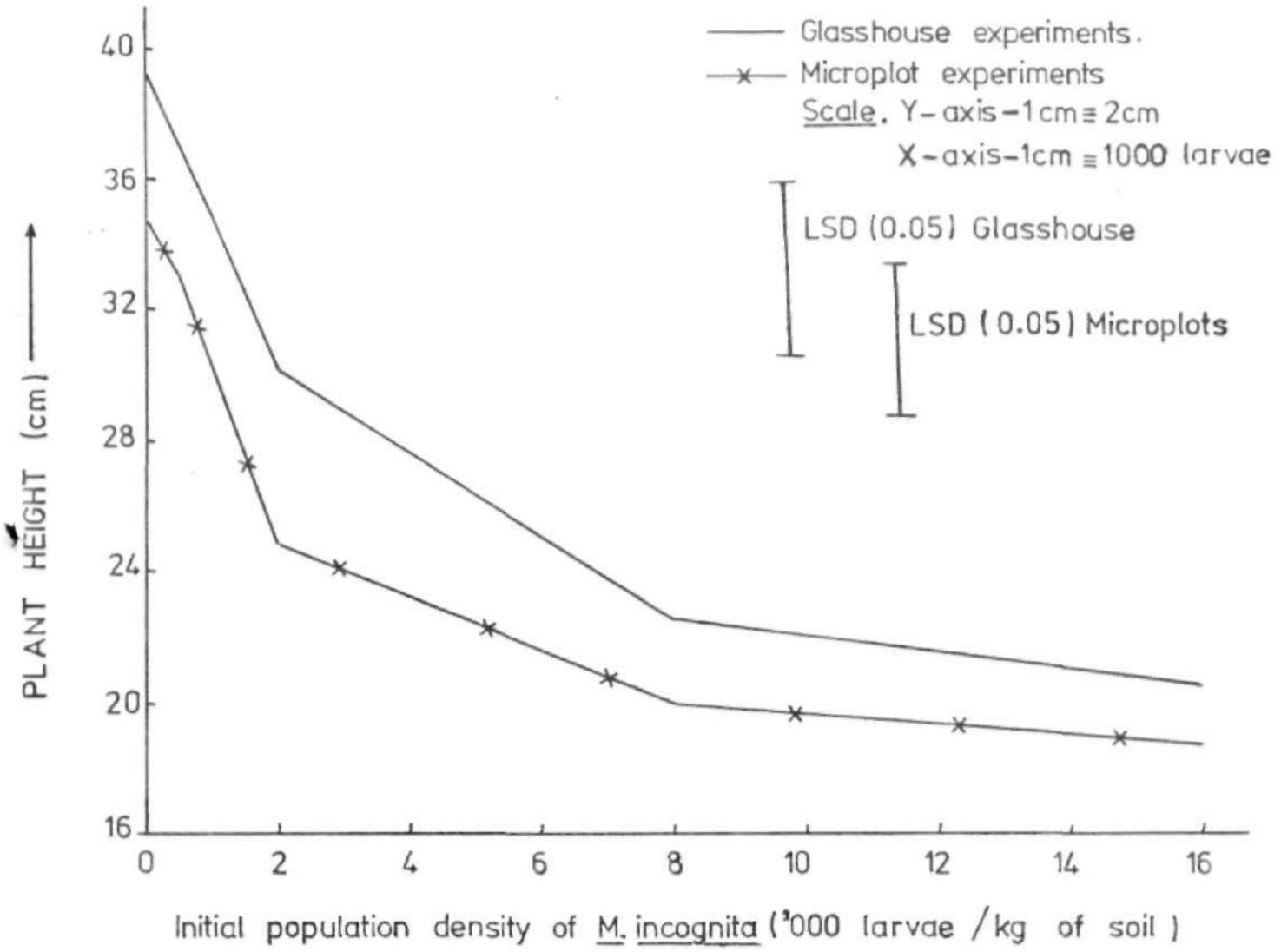


Fig. 1. Effect of various population densities of M. incognita on plant height (at midseason) of tomato L. esculentum cv. Enterpriser

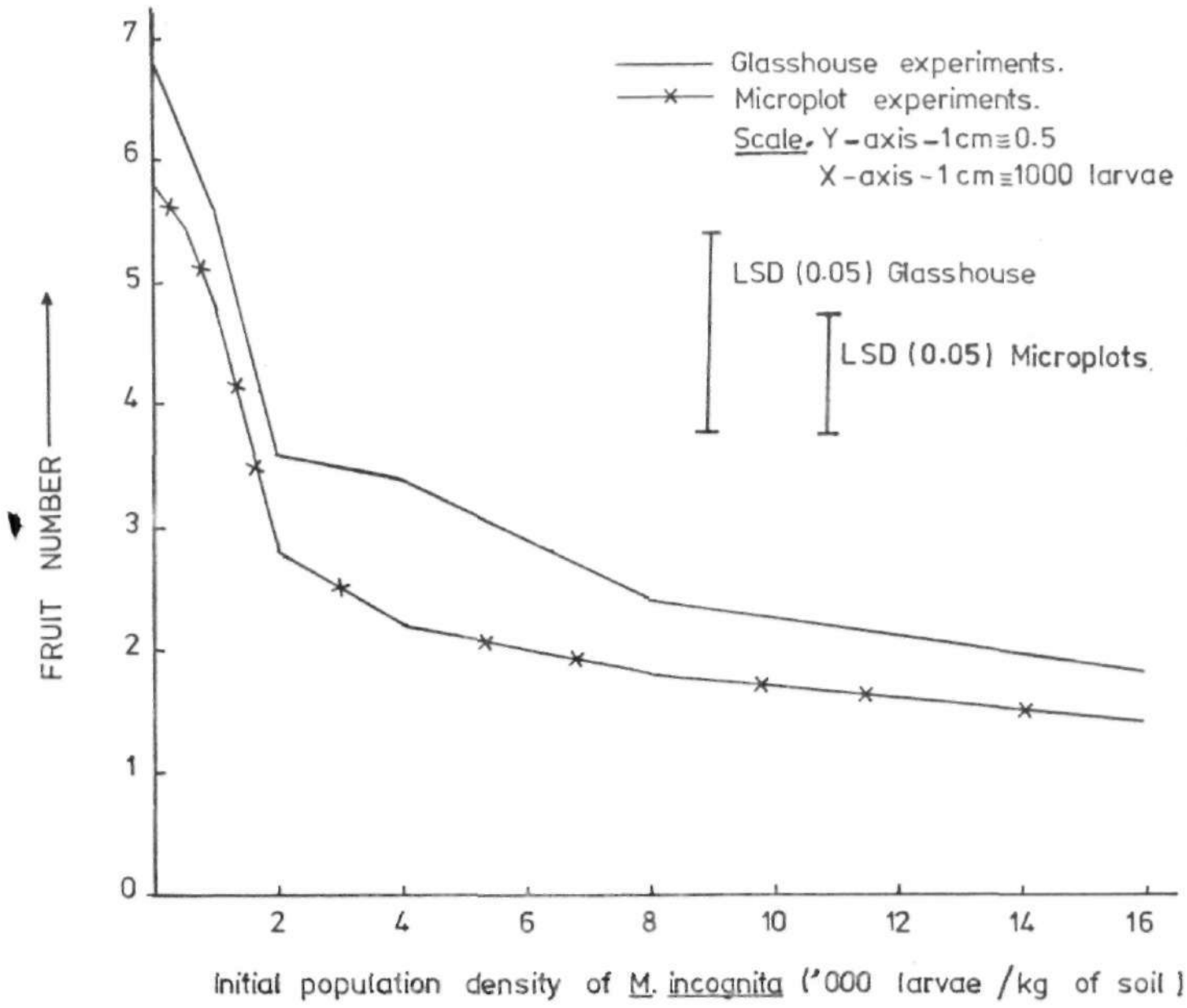


Fig. 2. Effect of various population densities of M. incognita on fruit number of tomato (L. esculentum) cv. Enterpriser after harvest.

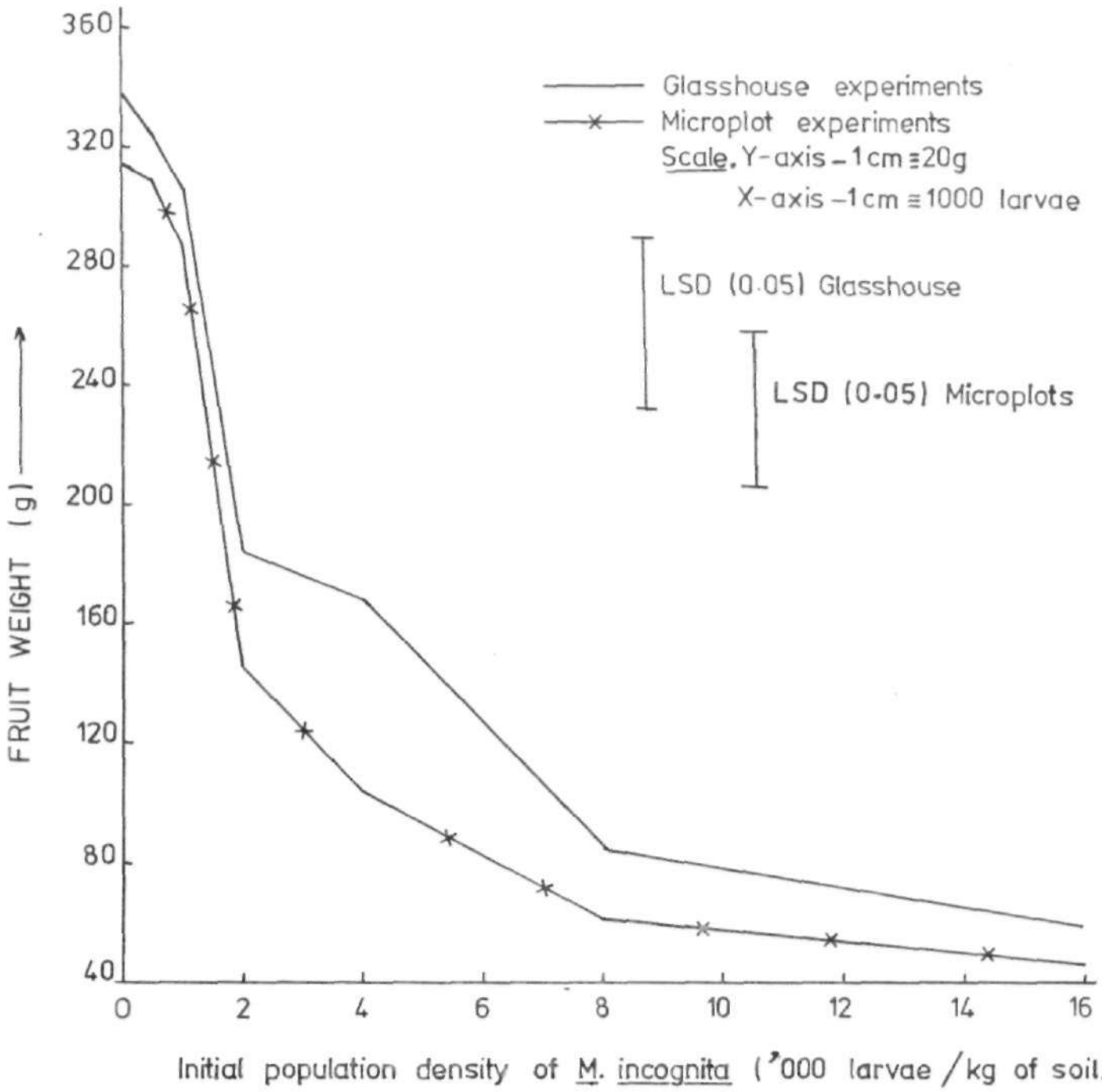


Fig.3. Effect of various population densities of M. incognita on fruit weight of tomato (L. esculentum) cv. Enterpriser after harvest.

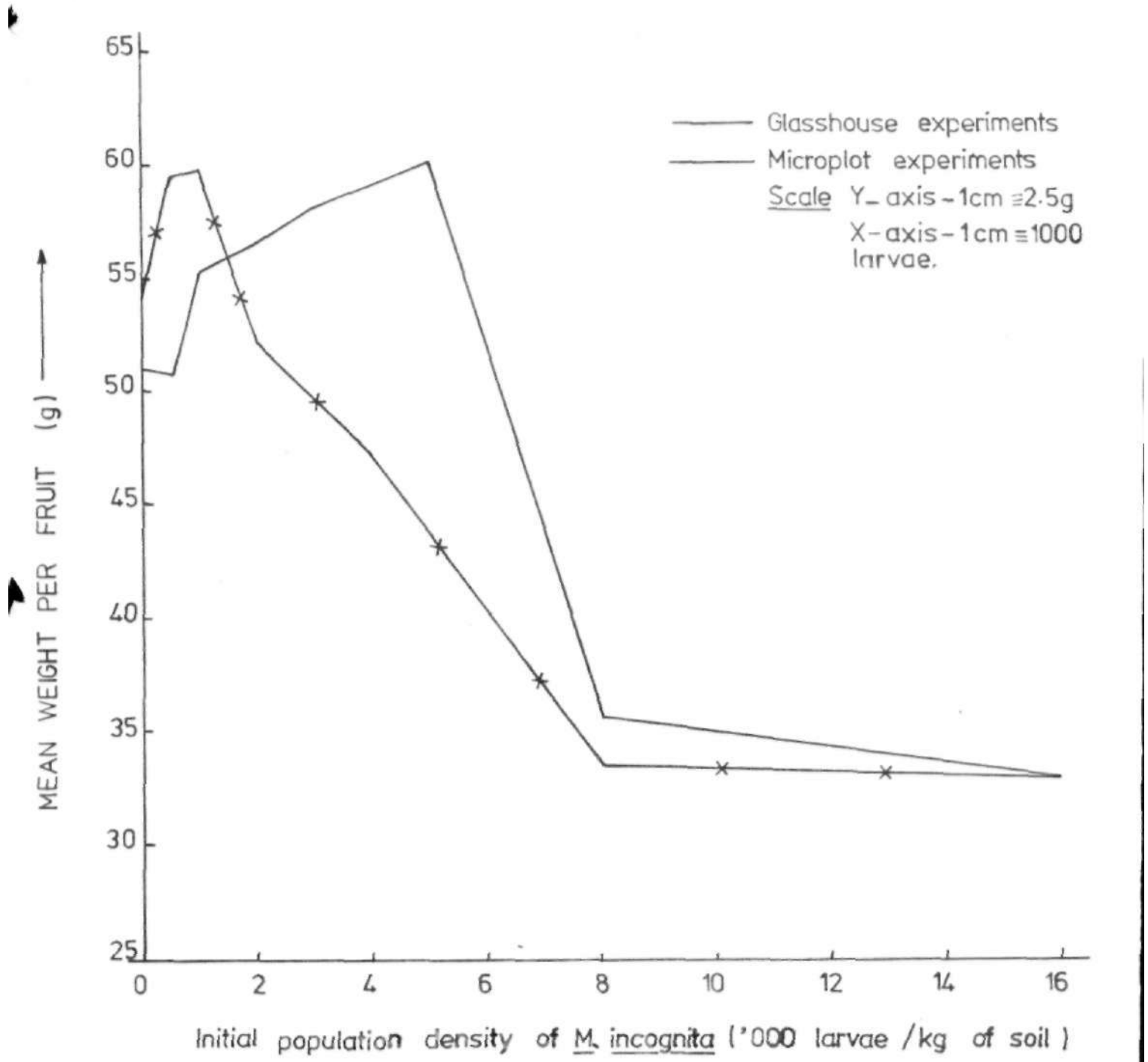


Fig.4. **Effect** of various population densities of M. incognita on mean weight per fruit of tomato (L. esculentum) cv. Enterpriser after harvest.

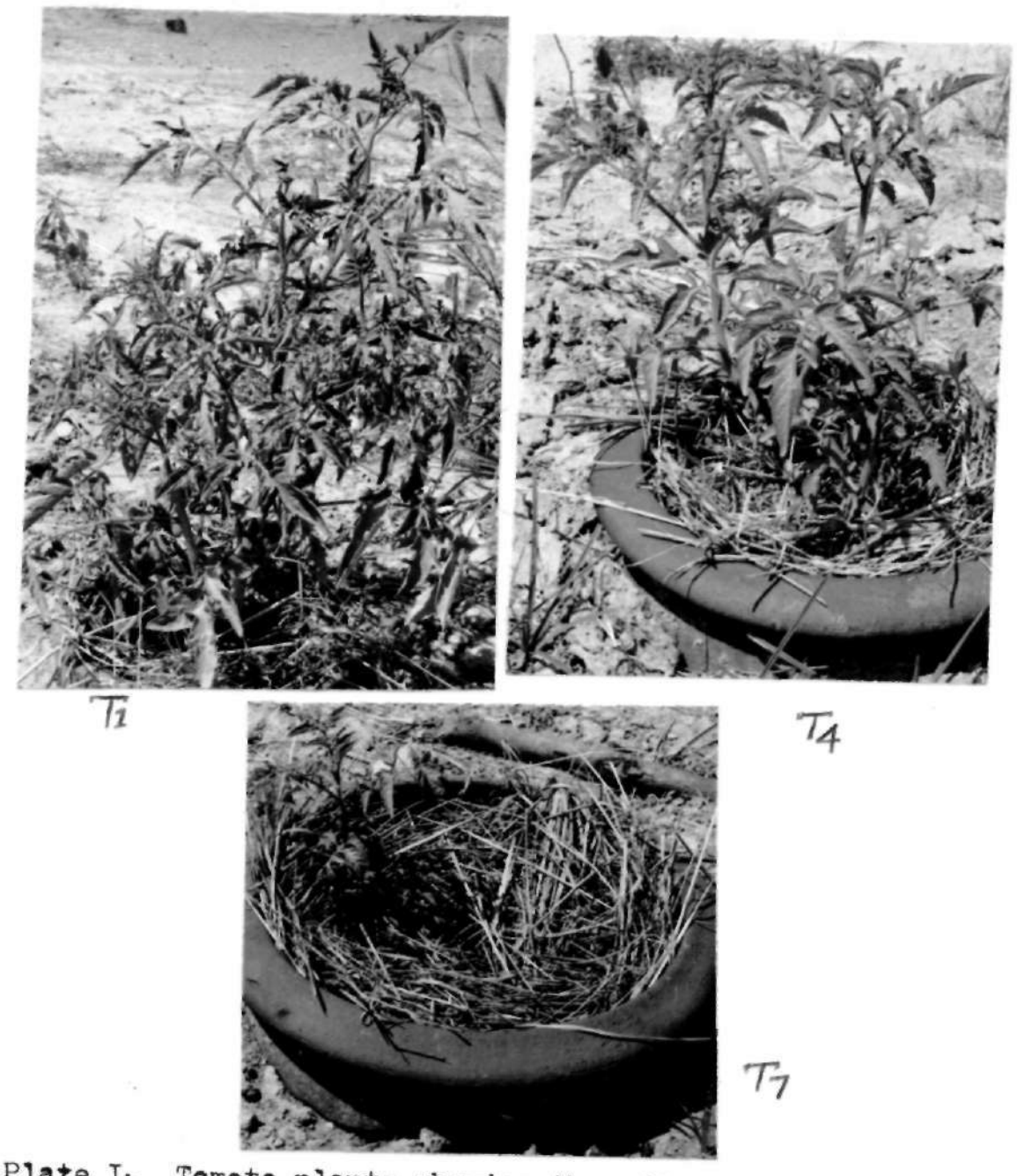


Plate I. Tomato plants showing the effect of various population densities of M. incognita on plant height at midseason. T1 = 0 larvae (control), T4 = 2,000 larvae and T7 = 16,000 larvae/pot.

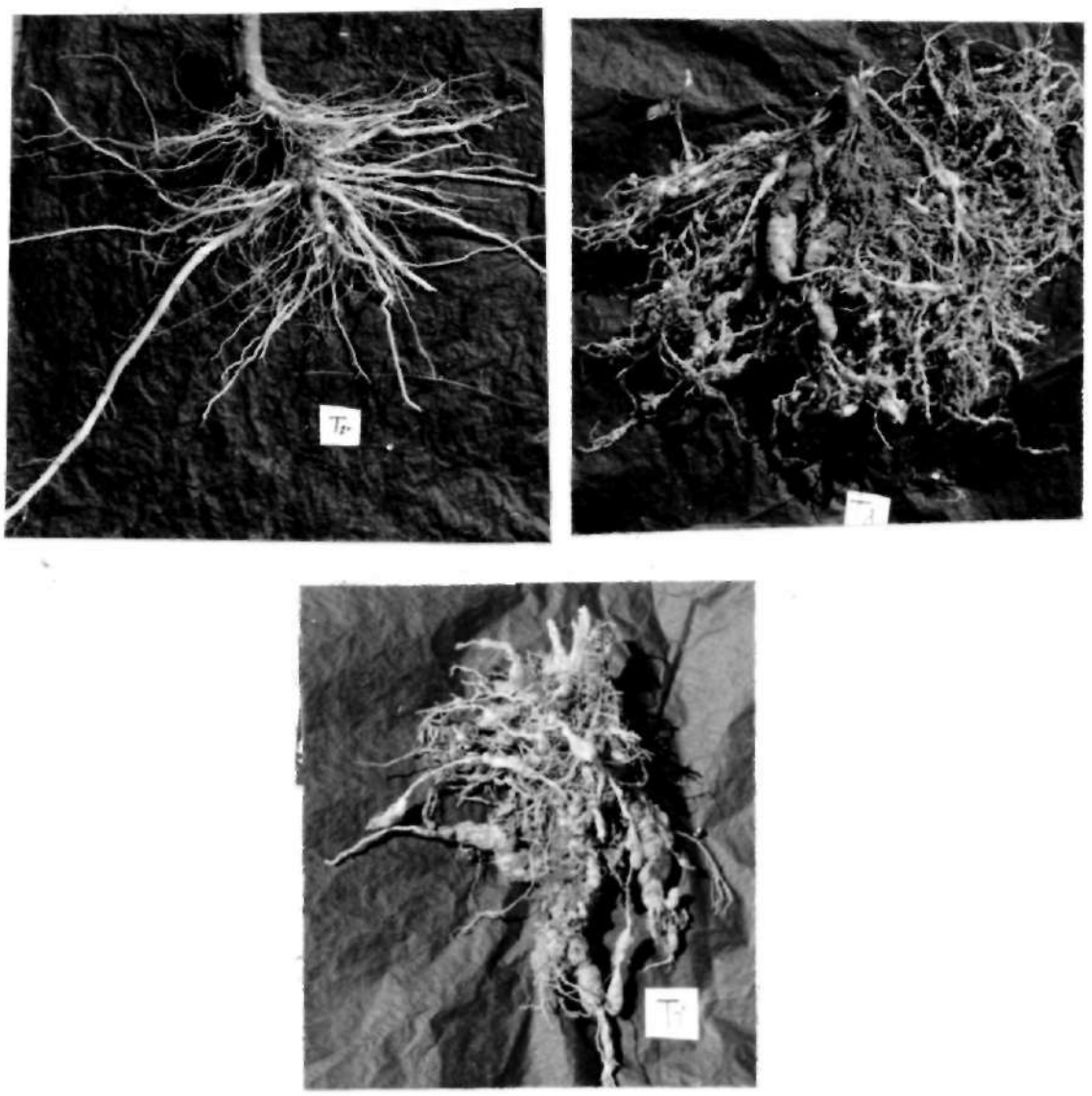


Plate II. Roots of tomato, cv. Enterpriser showing the effect of various population densities of M. incognita on root growth T1 = 0 larvae (control), T4 = 2,000 larvae, and T7 = 16,000 larvae/pot.

Nematode population at midseason increased (Table 2.0). The increase was however, higher at lower Pi than at high Pi. The population also increased at harvest although it was minimal at high Pi. At the highest Pi, the population declined to below the Pi level.

3.4 DISCUSSION AND CONCLUSION

Results of this study showed that the yield of tomato progressively declined as the population of M. incognita increased. Yield loss was as high as 85% at the highest Pi (16,000 larvae/kg of soil). The yield reduction could be ascribed to either a modification of the host physiology to the advantage of the nematode (Bookbinder and Bloom, 1980) or to severe root destruction resulting in retardation of plant growth with a concomitant loss in crop yield (Olthof et al. 1973). Plant height at midseason (Plate 1) and degree of galling after harvest (Plate II) provided evidence of growth retardation.

Root weight at low population densities was greater than in the check, but declined beyond 2,000 larvae/kg of soil (Table 2.). The increase in root weight at low Pi could be due to an increase in the number of adventitious roots (Plate II) as have been observed by Sayre and Toyama (1964).

That yield progressively declined with increase in nematode numbers (Fig. 3) tends to contradict the findings of Chitwood (1951), Sayre and Toyana (1964) and

Olthof and Potter (1977). According to these authors yield of tomato are increased at low population densities (less than 2,000 larvae/kg of soil) but decline thereafter. Such an increase in yield at low populations of nematodes was not observed in this study. However, it was observed that the mean weight/fruit increased up to 2,000 larvae/kg of soil and declined thereon (Fig.4). This suggests that the increase in the number of adventitious roots at the low Pi resulted in increased nutrient absorbtion and plant vigour which culminated in heavier fruits than the control. Moreover, the yield difference between the control and treatments with Pi of less than 2,000 larvae/kg of soil was not statistically different. This work therefore, tends to support the findings of the above authors. Chitwood (1951), Sayre and Toyama (1964 and Olthof and Potter (1977).

It is suggested that the yield increase at low nematode numbers is due to a stimulatory mechanism (Sayre and Toyama 1964; Seinhorst, 1965; Wallace, 1971) which enables the plant to compensate for the damage done by the nematodes. Compensation is achieved by the many adventitious roots formed in the galled root areas. In this study, it was observed that plants inoculated with low nematode numbers formed more adventitious roots than those in the check and at high nematode numbers. In general, these results tend to support the hypothesis of Wallace (1971) in which he explained the effect of M. javanica on its host plants in terms of a balance between stimulatory and inhibitory processes.

Since the main objective of this experiment was to provide information on which to base root-knot nematode

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Moreover, the yield difference between the control and treatments with Pi of less than 2,000 larvae/kg of soil was not statistically different. This work therefore, tends to support the findings of the above authors. Chitwood (1951), Sayre and Toyama (1964)and Olthof and Potter (1977).

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Since the main objective of this experiment was to provide information on which to base root-knot nematode

control on tomatoes, an economic loss threshold was therefore, worked out. An economic loss threshold of 10.6% was established and this occurs at a pre-plant population density of between 1,000 to 2,000 larvae per kg of soil. This is in agreement with the work of Ogunfowora (1977) where he found an economic loss threshold of 10% at 741 larvae/litre of soil for the susceptible tomato varieties tested. Thus, it will be economical to apply chemical control at this population density. However, this value is variable and will change with a change in market value of the crop.

It was observed at midseason that the rate of increase of nematode population was more at lower Pi than at higher Pi. At harvest, the rate of increase in population also increased at low Pi than at high Pi as evidenced by the reproduction factor (R) (Oostenbrink, 1960). At the highest Pi, the population decreased to below the Pi. This is explained by the fact that at high Pi, there is competition for invasion and feeding sites (Wallace, 1971). The decay of the roots at the highest Pi might also have accounted for a decrease in population to below the Pi as there were no roots to feed on.

The rapid multiplication of nematodes at low numbers gives warning signals to farmers whose habit is to grow root-knot nematode susceptible crops in succession. Such a rapid build up will eventually lead to complete loss of a particular crop. This will however, depend on

the cultural practices employed by the farmer (Johnson, 1959; Caveness, 1967; Wallace, 1967; Omiyi, 1976). Results of this study show that the growth and yield of tomato are decreased as the population density increases. The population capable of causing economic loss in yield lies between 1,000 to 2,000 larvae per kg of soil.

This study, confirms earlier reports that root-knot nematodes are of major importance in tomato production in norther Nigeria (Bridge, 1972, and Bos, 1978). Further work therefore needs to be done on the following.

a) Determination of the minimum nematode density capable of causing economic loss in yield.
b) Determination of the effects of the second most important root-knot nematode species, M. javanica on the growth and yield of tomato.
c) Determination of economic loss thresholds for recommended tomato varieties commonly grown in northern Nigeria. This will go a long way in helping the planning of a crop rotation programme.
d) Determination of economic loss threshold for various vegetable crops that are always intercropped with tomato.

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c) Determination of economic loss thresholds for recommended tomato varieties commonly grown in northern Nigeria. This will go a long way in helping the planning of a crop rotation programme.
d) Determination of economic loss threshold for various vegetable crops that are always intercropped with tomato.

CHAPTER 4

4. INFLUENCE OF THE ROOT-KNOT NEMATODE, M. INCOGNITA ON THE SEVERITY OF TWO VASCULAR DISEASES OF TOMATO INCITED BY PSEUDOMONAS SOLANACEARUM AND FUSARIUM OXYSPORUM f.sp. LYCOPERSICI

4.1. INTRODUCTION

Apart from the direct damage caused by root-knot nematodes to host plants, they have been found to be associated with certain disease complexes (Atkinson, 1892; Napiere, 1980; Sidhu and Webster, 1981; Webster, 1985). These associations have been shown to be harmful to the host plant.

In northern Nigeria, the above mentioned vascular diseases constitute a limiting factor to tomato production (Erinle, 1979). Root-knot nematodes are widely distributed in most of the area where tomato is grown (Bridge, 1972). Many tomato-growing sites in northern Nigeria are also heavily infested with both the root-knot nematodes and P. solanacearum and F. oxysporum f.sp. lycopersici, the pathogens that cause bacterial and fusarium wilts respectively (Erinle, personal communication). Elsewhere, these nematodes have been found to break resistance of tomatoes to these diseases (Morrel and Bloom, 1981; D'ercole et al., 1982). The harmful effects of the interactions of these organisms which have not been studied in northern Nigeria, may pose a serious threat to profitable tomato production. The present study was, therefore,

conducted to ascertain the possible interaction between M. incognita and P. solanacearum and f. oxysporum f. sp. lycopersici.

4.2. INFLUENCE OF THE ROOT-KNOT NEMATODE, M. INCOGNITA ON THE SEVERITY OF BACTERIAL WILT OF TOMATO INCITED BY P. SOLANACEARUM.

4.2.1 MATERIALS AND METHODS

4.2.1.1 Preparation and standardization of inoculum of P. solanacearum

The pathogen, P. solanacearum, was isolated from diseased tomato plants grown in the glasshouse. Diseased stem tissues were cut upto 1 cm from the root zone and thoroughly washed in sterile water. The washed stem tissues were then suspended in 9ml sterile distilled water and left to stand for 15-30 minutes to allow for bacterial ooze. The milky suspension was plated on tetrazolium chloride agar (TCA) (Kelman, 1953) and incubated for 24 hours in the incubator at 30C. The bacterial colonies were distinguished on the basis of colony appearance (Kiraly et al., 1970). Virulent isolates of P. solanacearum looked fluidal white with little or no pink colouration at the centre of colonies; avirulent colonies developed a reddish centre with a narrow white halo surrounding the colonies. Based on colony appearance, virulent isolates were selected and

plated on five plates of sucrose peptone agar (SPA) and incutated for 48 hours in the incubator at 30°C. This provided the inoculum for the trials.

To standardize the inoculum for inoculation, the bacterial culture was suspended in 10ml sterile water contained in McCarteney bottle using a sterile loop. This gave a turbid suspension of dilution 10^{-1}. Using a sterilie pipette, 1ml of this suspension was transferred to another bottle containing 9ml of sterile water to give a dilution of 10^{-2}. These serial dilutions were made to give dilutions of up to 10^{-7}. By using a spectrophotometer at 540nm, the percentage transmittance of the dilutions was determined and the number of colony forming units (c.f.u.) in each bottle was ascertained. From these determinations, a transmittance of 46 percent containing 6.4×10^{7} cells/ml was used for inoculations.

4.2.1.2. Inoculation of plants

Two tomato cultivars viz., Hunkuyi local (susceptible to both M. incognita and P. solanacearum) and CL-119-1-2-0-0 (alledgedly resistant to P. solanacearum but susceptible to M. incognita) were used for this experiment.

The treatments were as follows:

T1 = no pathogen (control)

T2 = M. incognita + P. solanacearum inoculated

simultaneously.

T3 = M. incognita + P. solanacearum one week after.

T4 = M. incognita + P solanacearum two weeks after

T5 = M. incognita alone

T6 = P. solanacearum alone

The treatments were replicated five times in a completely randomized design. The experiment was carried out in two consecutive years in the glasshouse where temperature ranged between 21° to 31°C.

In the first year, single 4-5 week old seedlings of the two tomato varieties were transplanted into pots measuring 13cm in diameter and 10cm high, already filled with heat sterilized soil to which had been added 15g of NPK (15:15:15). In the second year, 3 -4 week old seedlings were used to ensure that the seedlings were young at transplant. Ten uniform egg masses (giving an average of 3,000 juveniles) suspended in 10ml of tap water were inoculated into each pot by pouring them in a hole made round the plant close to the growing points of the roots. 6.4×10^7 bacterial cells per ml suspended in 50ml of sterile water were similarly inoculated.

The Number of wilted plants was observed and counted. At the end of the experiment (40 days after inoculation), plants were rated for degree of vascular discolouration (browning) on a scale of 1-5 (Erinle, personal communication) as follows.

1 = no visible discolouration at base of plant

2 = Slight discolouration not extending more than 1cm up the stem.

3 = as in 2 above but also with slight pith congestion

4 = discolouration 1 - 5 cm in the stem with pith slightly congested

5 = discoluration 1 - 5cm in the stem with severe pith congestion and decay.

4.2.1.3 RESULTS

(a) L. esculentum cv. Hunkuyi local. Wilting of plants was not observed during the first year. In the second year however 60 percent of the plants wilted within 10 days when M. incognita and P. solanacearum were inoculated simultaneously, 20 percent within 15 days when P. solanacearum followed M. incognita one week after and 20 percent within 12 days of inoculation of P. solanacearum alone. Wilting was not observed in the other treatments.

When the plants were scored for degree of vascular discolouration, some degree of interaction between the nematode and vascular pathogen was observed. In the first year there was no significant difference between plants inoculated with either nematode plus vascular pathogen simultaneously (T2) or nematode plus vascular pathogen one or two weeks later (T3 and T4 respectively).

However in the second year plants inoculated with both M. incognita and P. solanacearum simultaneously (T2) showed a significantly higher degree of vascular

browning than when inoculation with P. solanacearum followed M. incognita one or two weeks later (Table 3). Wilt severity in T2 was, however, significantly higher than in T6 (vascular pathogen alone).

(b) L. esculentum cv, CL-119-1-2-0-0

No wilting was recorded in either of the years. Vascular discolouration was however, observed in treatments involving M. incognita and P. solanacearum, and more in treatments without M. incognita. The discoluration was most severe in T2 and T3 and none in T4 (Table 3).

Combined analysis (ANOVA) of the data for the two varieties shows that there was no statistical difference between the two observation periods (years), hence only one year data for each cultivar is shown in table 4). But there was a significant difference between the treatments (Table 4). Treatment/year interaction was also found to be significant when the treatment means were compared using LSD (P= 0.05) (Table 4). In cv. CL-119-1-2-0-0, T2 and T3 did not differ statistically from one another, but differed significantly from the other treatment. (Table 4)

4.3 INFLUENCE OF THE ROOT-KNOT NEMATODE, M. INCOGNITA ON THE SEVERITY OF FUSARIUM WILT OF TOMATO

4.3.1 MATERIALS AND METHODS

Table 3. Effect of M. incognita on the severity of bacterial wilt of tomato (L. esculentum incited by P. solanacearum, 40 days after inoculation.

Treatment	Description	Wilt severity *Degree of vascular discoluration on: L. esculentum cv. Hunkuyi local	L. esculentum cv. CL-119-1-2-0-0
T1 =	No pathogens (control)	1.0	1.0
T2 =	M. incognita + P. solanacearum inoculated simultaneously	3.2	2.2
T3 =	M. incognita followed by P. solanacearum one week after	2.0	1.4
T4 =	M. incognita followed by P. solanacearum two weeks after	2.0	1.0
T5 =	M. incognita alone	1.0	1.0
T6 =	P. solanacearum alone	2.4	1.2
LSD (0.05)		053	0.45

* Mean of five replicates.

4.3.1.1. Preparation and standardization of inoculum of F. oxysporum f. sp. lycopersici.

The pathogen, F. oxysporum f. sp. lycopersici was isolated from infected tomato plants, earlier inoculated with F. oxysporum f.sp. lycopersici and showing symptoms of the the disease. Five 1cm long diseased stem tissues were cut from near the root zone, washed seperately with sterike distilled water and surface sterilized with 0.1 percent chlorus for three minutes. Each of the cut stem tissue was divided longitudinally into approximately four equal parts and plated on Potato dextrose agar (PDAs) to which was added streptomycin to check the growth of bacteria. The plates were incubated at room temperature for 5-7 days. By this time some sporulation had occured. Colonies of F. oxysprum f.sp. lycopersici were distinguished from other species of fungi on morphological and cultural characteristics as described by Booth (1971) F. oxysporum f. sp. lycopersici was sub-cultured onto 10 plates of PDAs. and incubated at room temperature for 5-7 days. The spores and mycelia were then washed off the plates with sterile distilled water into a clean beaker. The mycelium - spore suspension was homogenized in a blender. By means of a haemocytometer, the actual fungal inoculum was standardized to give 5.3×10^7 spores per ml (Erinle, personal cummunication).

4.3.1.2 Inoculation of plats

The experiment was carried out as in 4.2.1.2, However, instead of susing CL-119-1-2-0-0, ROMA VF

(alleagudly resistant to F. oxysporum f.sp. lycopersici but susceptible to M. incognita) was used.

4.3.1.3 RESULTS.

The presence of the nematode significantly increased the severity of fusarium wilt (vascular browning) on the fusarium wilt-sunceptible tomato cultivar, Hunkuyi local (Table 5). The results also show that the fusarium wilt-resistant cultivar, Roma VF, became susceptible to F. oxysporum f.sp. lycopersici. Inoculating the plants with vascular pathogen either one or two weeks after inoculation with nematodes, however, made no difference in either of the varieties. Combine analysis of the data (ANOVA) for cv. Hunkuyi local did not show a significant difference in vascular discolouration between the two observation periods. Hence only one year data is shown in table 5. In cv. Roma VF, however, year one exhibited a higher degree of vascular discolouration than year two (Table 5).

4.4 INTERACTION BETWEEN M. INCOGNITA, P. SOLANACEARUM AND F. OXYSPORUM f. sp. LYCOPERSICI ON TOMATO cv. HUNKUYI LOCAL

4.4.1 MATERIALS AND METHODS

4.4.1.1 Preparation and standardization of inocula of the two vascular pathogens, P. solanacearum and F. oxysporum f.sp. lycopersici.

Pure cultures of the vascular pathogens were prepared

Table 4. Effect of M. incognita on the severity of fusarium wilt incited by F. oxysporum f. sp. lycopersici on two cultivars of tomato (L. esculentum).

Treatment	Description	Wilt severity *Degree of vascular discolouration on: L. esculentum cv. Hunkuyi local	L. esculentum cv. ROMA VF. Year I	Year II
T1 =	No pathogen (control)	1.0	1.0	1.0
T2 =	M. incognita + F. oxysporum inoculated simultaneously.	2.6	1.8	2.0
T3 =	M. incognita followed by F. oxysporum f. sp. lycopersici one week after	2.4	2.0	1.4
T4 =	M. incognita followed by F. oxysporum f. sp, lycopersici two weeks after	2.0	1.6	1.0
T5 =	M. incognita alone	1.0	1.0	1.0
T6 =	F. oxysporum f. sp. lycopersici alone	2.4	1.0	1.0
	LSD (0.05)	0.51	0.38	0.29

* Mean of five replicates.

and standardized for inoculations as described in 4.2.1.1 and 4.3.1.1.

4.4.1.2. Inoculation of plants.

Only one tomato cultivar, Hunkuyi local (susceptible to both M. incognita and the two vascular pathogens) was used for this experiment. The experiment was carried out in one year only. The treatments were as follows.

T1 = no pathogen (control)

T2 = M. incognita + P.solanacearum and F. oxysporum f.sp. lycopersici inoculated simultaneously.

T3 = M. incognita followed by P. solanacearum and F. oxysporum f. sp. lycopersici one week later

T4 = M. incognita followed by P. solanacearum and F. oxysporum f. sp. lycopersici two weeks later

T5 = M. incognita alone

T6 = P. solanacearum + F. oxysporum f. sp. lycopersici alone.

Three to four week old seedling of tomato cv. Hunkuyi local, were transplanted to pots measuring 13 cm in diameter and 10cm high, already filled with heat sterilized soil to which had been added 15g of NPK (15:15:15). Ten uniform egg masses (giving about 3,000 juvenites) suspended in 10ml of tap water were inoculated into each pot by pouring them in a hole made around the plant close to the growing points of the roots. 6.4×10^7 bacterial cells and 5.30×10^7 spores per ml of F.

oxysporum f. sp. lycopersici each suspended in 50ml of sterile water were similarly inoculated.

The number of wilted plants was counted and percent wilting calculated. At the end of the experiment (40 days after inoculation) plants were rated for degree of vascular discolouration as described in 4.2.1.2.

4.4.1.3 RESULTS

The results presented in table 5, show that vascular browning was highest when the two vascular pathogens were inoculated simultaneously with the root-knot nematode. As in the previous treatments wilt severity decreased with time of expesure of the plant to the nematode before inoculation with the vascular pathoges was made.

Percentage of wilted plants indicates a higher degree of interaction in T2. Sixty percent of the plants wilted within 8 - 10 days when the nematode and the two vascular pathogens, P. solanacearum and F. oxysporum f. sp. lycopersici were inoculated simultaneously, while 40 percent wilted in T3 14-15 days when the two vascular pathogens were inoculated one week after inoculation with M. incognita. Wilting was not observed in the other treatments except when the vascular pathogens were inoculated alone (i.e 40 percent in 10 days. Thus, the presence of the nematode increased the severity of the vascular wilt. Also the time required for the wilting to occur in the treatments involving nematode and vascular pathogens was

Table 5: Effect of *M. incognita* on the severity of wilt incited by mixed populations *P. solanacearum* and *F. oxysporum* f. sp. *lycopersici* on tomato cv. Hunkuyi local.

Treatment	Description	Severity of wilt *Degree of vascular discolouration
T1 =	No pathogen (control)	1.0
T2 =	*M. incognita* + *P. solanacearum* and *F. oxysporum* f. sp. *lycopersici* inoculated simultaneously	2.8
T3 =	*M. incognita* followed by *P. solanacearum* f. sp *lycopersici* one week later	2.6
T4 =	*M. incognita* followed by *P. solanacearum* and *F. oxysporum* f. sp. *lycopersici* two weeks later	2.2
T5 =	*M. incognita* alone	1.0
T6 =	*P. solanacearum* and *F. oxysporum* f. sp. *lycopersici* alone	2.6
_ LSD (0.05)		0.53

lower than that required when the vascular pathogens were inoculated seperately (Table 6).

4.5 DISCUSSION AND CONCLUSION

Only two parameters viz., number of wilted plants and degree of vascular discolouration, were considered as a measure of pathogenicity of the two vascular diseases viz., P. solanacearum and F. oxysporum f. sp. lycopersici. Results of the study on these parameters indicate that there was interaction between M. incognita and the two vascular pathogens

Nematode - bacterial interaction

In the nematode - bacterial interaction, two cultivars viz., Hunkuyi local and CL-119-1-2-0-0 were tested. During the first trial, wilting was not observed in cv. Hunkuyi local. But in the second trial wilting occured. Percentage wilting was highest when nematode and bacteria were inoculated simultaneously and lowest when bacterialwas inoculated two weeks later. Only 20 percent of the plants inoculated with the bacterium alone wilted. Wilting was not observed either in the control or when the plants were inoculated with nematode alone.

When the plants were rated for degree of vascular discolouration at the end of the experiments (40 days after inoculation), There was evidence of interaction between M. incognita and P. solanacearum. Degree of vascular

discolouration was highest when the nematode and bacteria were inoculated simultaneously, thereafter decreased with time of exposure to the nematode before bacterial inoculation. The degree of vascular browning was higher in the second trial. Vascular browning was also lowest when the bacterium was inoculated alone.

The absence of wilting in the first trial and the difference in vascular browning between the two trials may be ascribed to the age of the plants at transplant. Plants were about five weeks old at transplant in the first trial compared to 3 -4 weeks old in the second trial. Also, plants inoculated with the vascular pathogen one or two weeks after nematode inoculation might have become too woody for meaningful ingress of the bacterium into the host tissue. According to Pitcher (1974), symptom expression is greater in "young" than in "old" plants.

A second factor might be the initial population density of M. incognita (3,000 juveniles), which presumably was quite low in such a trial. Bergeson (1972) Powel (1979) and Sidhu and Webster (1981) observed that severe wilting is associated with large number of larvae, about 5,000 to 6,5000.

The negative interaction that may result, when such pathogens are together, might contribute a third factor. Bookbinder and Bloom (1980) observed a reduction in the reproduction of both Uromyces phaseoli and M. incognita when both were present on beans,

Phaseolus vulgaris.

In case of tomato cv. CL.-119-1-2-0-0, wilting was not observed in any of the trials. Plants inoculated with nematode and bacteria, however, showed evidence of browning. Browing was absent in treatments with either the nematode alone orthe bacterium alone. Being a resistant variety to P. solanacearum, the occurence of vascular discolouration must have been due to the presence of of M. incognita which probably modified the mineral composition and physiology of the host in favour of the bacterium (Bookbinder and Bloom, 1980; Webster, 1985).

Nematode-fungus interaction

The nematode - fungus treatment exhibited similar response as in nematode - bacterium treatments. In both varieties, degree of vascular discolouration was lowest when F. oxysporum f. sp lycopersici was inoculated two weeks after nematode inoculation and highest when both nematode and fungus were inoculated simultaneously. Vascular discolouration was, however, higher in the first trial than in the second. This may be ascribed to a lower degree of infestation of the plants by the nematodes which was observed in the second trial.

Nematode - bacterium - fungus interaction

The nematode - bacterium - fungus interaction gave similar results. However, unlike in 4.2.1.3. plants

tended to wilt much earlier when inoculated with the nematode and mixed population of P. solanacearum and F. oxysporum f. sp lycopersici (8 - 10 days as against 10 days after inoculation). However, treatments with the nematode, followed by bacteria and fungus one week later gave 40 percent wilting as against 20 percent for treatment with nematode followed by bacteria or fungus also one week later. This suggests a synergistic effect of the two vascular pathogens (table 6).

CONCLUSION

This study appears to confirm earlier reports that root-knot nematodes are capable of aggravating plant diseases (Powel, 1979, Dercole et al., 1981; Sidhu and Webster, 1981; Sadiku, 1981; Webster, 1985).

In all experiments, the treatments viz., T2 ((Nematode + vascular pathogen(s) inoculated simultaneously) and T6 (Vascular pathogen(s) alone) which were started at the same time were significantly different from each other in degree of vascular discolouration. This difference must have been due to the presence of the nematodes in T_2. L.esculentum cvs. Roma VF and CL-119-142-0-0 which are alledged to be resistant to Fusarium wilt and bacterial wilt respectively, both showed evidence of vascular browning in the presence of M. incognita. This suggests a break in the host resistance to these diseases which might have been brought about by certain changes in the host physiology.

Table 6: Effect of M. incognita on the severity of wilt incited by either P. solanacearum F. oxysporum f.sp. lycopersici or mixed populations of P. solanacearum and F. oxysporum f. sp. lycopersici

Treatment	Days to wilting under:			% wilting of tomato under		
	N+B	N+F	N+B+F	N+B	N+F	N+B+F
No pathogen (control)	-	-	-	-	-	-
M. incognita + vascular pathogen(s) simultaneously	10	10	8	60	60	60
M. incognita followed vascular pathogen(s) one week later.	15	15	14	20	20	40
M. incognita followed by vascular pathogen(s) two weeks later	-			-	-	a
M. incognita alone	-			-	-	-
Vascular pathogen(s) alone	12	12	10	20	20	40

N+B = M. incognita + P. solanacearum

N+F = M. incognita + F. oxysporum f. sp. lycopersici

N+B+F = M. incognita + P. solanacearum + F. oxysporum f. sp. lycopersici

Bearing in mind the danger these nematodes might pose to profitable tomato production in the savanna zones of Nigeria particulaly the irrigated fields, certain suggestions come to focus . These are:

(a) Where these vascular diseases are known to occur, effort should be made to reduce the nematode population to the barest minimum

(b) Further studies need to be conducted with higher nematode populations, using very young seedlings to be able to ascertain actual plants lost in ideal transplanting age.

(c) Possible interaction of these nematodes with these pathogens and other important pathogens of tomato should be considered to be able to determine the complex relationship that prevails among diseases in natural field conditions.

(d) These studies should be extended to the field so as to gain an insight as to what happens under natural conditions.

CHAPTER 5

EFFECT OF SOIL AMENDMENT WITH POULTRY MANURE ON THE DAMAGE CAUSED BY THE ROOT-KNOT NEMATODE, MELOIDOGYNE INCOGNITA ON TOMATO

5.1 INTRODUCTION

The use of organic amendments as an effective tool for the control of plant-parasitic nematodes has been reported by several workers (Johnson, 1959; Singh and Sitaramaiah, 1966; Johnson et al., 1967; Khan, 1976; Jagdale et al., 1985). These alter the host-parasite relationships in favour of the crop.

Different types of organic amendments abound, and are often used mainly as nutrient sources in crop production. They have also been found to control certain root-diseases of plants. With these beneficial effects in mind, the following experiments were designed to exploit the possibilities of employing poultry manure in plant-plantparasitic nematode control practices in northern Nigeria. These are:-

(a) Effect of water-soluble fractions (WSF) of poultry manure on the hatch and survival of M. incognita larvae.

(b) Influence of soil amendment with poultry manure on the severity of root-knot nematode, M. incognita infection on tomato both in the glass house and in the field.

5.2 Influence of poultry manure on the severity of root-knot nematode, M. incognita on tomato

5.2.1 Materials and Methods

Four levels of poultry manure viz., 0, 7.5, 15.0 and 30g per pot equivalent to 0, 2, 4 and 8 t/ha) were used for this experiment. The poultry droppings were obtained from the National Animal Production Research Institute (NAPRI) Shika, ABU, Zaria poultry farm.

Pots, measuring 23cm in diameter and 20cm in height, were filled with heat-sterilized soil to which had been added 15g of NPK (15:15:15) fertilizer. To each pot was added poultry manure at the rate of either 7.5, 15.0 or 30g/pot and mixed with soil thoroughly. Calculations of amount/pot were based on 15cm top soil layer. Heat-sterilized soil alone (0t/ha) served as control. Each treatment was replicated five times in a completely randomized design.

Prior to transplanting, the pots were watered heavily and excess water was allowed to drain off. Four week-old seedlings of tomato cv. "Enterpriser" of uniform size were transplanted singly into each pot. Ten eggmasses, giving an average of 3,000 juveniles, were inoculated into each pot as the initial population density. The pots were arranged on the glasshouse floor in a

completely randomized design. Watering was done as frequently as was necessary. To minimize evaporation of soil moisture, the pots were mulched. The plants were checked regularly for diseases and insect pests. At midseason (40-45 days after transplant), data on plant height and nematode population were taken. At harvest, ripe fruits were picked, counted and weighed. After the final picking, final nematode population was estimated. The roots were removed, washed thoroughly under the tap with a gentle stream of water and scored for galling using Daulton and Nusbaum (1961) index.

The experiment was conducted for two years.

5.2.2. RESULTS

In both the observation periods (year I and II), plants in the amended soil grew taller than those in unamended soil. Plants in soil amended with 4 and 8t/ha poultry manure grew significantly taller than those in 0 and 2 t/ha (Table 7).

The effect on fruit number and fruit weight is given in table 5.1. Fruit number was found to increase with increasing levels of poultry manure. The dosages of both 4 and 8t/ha yielded significantly higher fruit number than 0 and 2t/ha. The response of fruit weight was similar to that of fruit number. Mean weight/fruit had a positive relationship with the levels of poultry manure.

The data show that there was a drastic reduction in the nematode population at the emiddle of the season with increasing levels of poultry manure, but the population later picked up towards harvest.

Severity of damage was higher in the unamended than the amended soil as evidenced by the root-gall index and root weight (Table 5.1).

Combine alalysis of the results agrees with the individual year analysis. The dose of 8t/ha gave taller plants than 4t/ha which were also significantly taller than 0 and 2t/ha. Results of the two years however did not differ statistically.

Analysis of the data on fruit numbers indicates significant differences between the two years, with year two yielding significantly higher fruit numbers than year one.

Analysis of fruit weight gave similar results as for fruit numbers, but there was no significant difference between the two years.

Table 7: Effect of different levels of poultry manure on root growth, shoot and fruit yield of tomato cv. Enterpriser infested with M. incognita

Levels of poultry manure (g/pot)	Root gall index[a]	Root weight[a] (g)	[b]Plant height (cm)	[b]Fruit number	[b]Fruit weight (g)	[c]Mean weight per fruit (g)	
0	6.	62.0	31.8	5.6	202.0	36.0	
7.5	5.0	54.6	34.6	6.2	235.0	37.9	
15	3.1	48.2	42.4	9.0	406.0	45.1	
30	1.0	39.1	47.8	9.6	464.0	48.3	
LSD (0.05)	5%			7.3	1.7	105.0	

a = Mean of five replicates

b = Mean of five replicates

c = Mean of total number of fruits

Table 8: Effect of different levels of poultry manure on the population of M. incognita on tomato cv. Enterpriser at midseason and at harvest

Level of Poultry manure (g/pot)	*Population of M. incognita (Larvae/kg soil at	
	Midseason*	Harvest
0	12,500	17,900
7.5	1,600	8,300
15.0	600	3,100
30	540	2,800

* Each value is a mean of five replicates.

5.3 Effect of soil amendment with poultry manure on the damage caused by root-knot nematode, M. incognita on tomato, cv. Enterpriser in the field.

5.3.1 Experimental site

Field experiments were conducted on land that had been left fallow for three years in Samaru. The land was cleared and inoculated with soil infested with M. incognita, using tomato cv. Enterpriser as the host plant Inoculation was done by placing 50g of M. incognita - infested soil round each seedling. Prior to the experiment, the initial nematode population density (Pi) and soil chemical properties were noted (Appendix 3 and 5). To determine Pi, soil samples were collected at random with Auger, composited, and mixed thoroughly. Five 100ml subsamples were processed by a modified Whitehead and Hemming (1965) tray method for 24 hours at room temperature.

5.3.2 Materials and Methods

Poultry manure was applied at the rate of 0, 800g, 1.6kg and 3.2kg per plot equivalent to 0,2, 4 and 8t/ha.

The design was a completely randomized design with each treatment repeated five times on plots of 4m x 1m.

Prior to incorporation, the poultry droppings were air-dried to a constant weight. Large clumps were broken into smaller and uniform sizes to ensure uniform distribution in the field. A day before transplanting the appropriate rates were applied together with inorganic fertilizer at the rate of 100g per row and thoroughly raked in. To each row were transplanted 10,

four to five week-old tomato seedlings. Seedlings were replaced in the event of death within one week from the date of transplanting. Experiment was carried out during the 1984 and 1985 wet season.

When the final harvest was done, soil samples were taken and processed as in 5,3.1 to determine the final nematode population density.

Foliar diseases like septerialleafspot were controlled by spraying Benlate at the rate of 0.7kg a.i/ha. Plant height, fruit number and fruit weight were taken for each treatment as in 5.2.1

5.3.3 RESULTS

Data on growth and yield as influenced by organic amendment is presented in table 5.3.

There were no significant differences in height of plants between the two trials. Fruit number increased with increase in poultry amendment. This was true of bolth the trials. The dosages of either 4 and 8 t/ha, 2 and 4 t/ha and 2 and 0 t/ha were not significantly different. However in case of fruit weight, both 4 and 8 t/ha gave significantly higher fruit weight than 0 and 2 tonnes/ha. Mean weight/fruit increased with increase in levels of poultry manure (table 8).

Combine analysis of the data for the two years shows that there was no significant difference in plant height between the two trials. There were, however, significant differences between the treatments.

Both fruit numbers and fruit weight exhibited the same response to the treatments. Year/year and year/treatment interaction was not significant. However, the treatments had significantly different effects on fruit yield. Plants amended with 4 and 8 t/ha of poultry manure gave significantly higher marketable yield than those amended with 0 and 2 t/ha. Yield increase averaged 26.8% (for 2t/ha) to 71.8% for 8 t/ha.

Nematode population at midseason showed a decline with increasing levels of poultry manure (Table 5.4 The nematode population declined sharply but picked up towards harvest. The increase was not remarkable in case of 4 and 8 t/ha.

The difference in nematode numbers, both at midseason and at harvest, was reflected in the severity of attack (root gall index; Table 5), and plate III).

Table 8: Effect of different levels of poultry manure on root growth, shoot and fruit yield of tomato cv. Enterpriser infested with M. incognita

Level of poultry manure t/ha	*Root gall index	*Root weight (g/ plant)	[a]Plant height at mid-season (cm/ plant)	[a]Total fruit number at harvest	[a]Fruit weight at harvest (kg)	[b]Mean weight per fruit (g)
0	5.6	81.0	254.4	148.0	4.9	33.03
2	4.6	73.5	261.4	188.0	7.16	38.10
4	2.3	70.6	278.2	239.0	16.54	69.11
8	1.3	65.5	289.2	241.0	19.04	79.14
LSD (0.05)			N.S	61.47	5.35	

* = Mean of three replicates

a = Mean of four replicates

b = Mean of total number of fruits for each treatment.

N.S. Not significant.

Table 9: Effect of different levels of poultry manure on the soil population of M. incognita on tomato cv. Enterpriser at midseason and at harvest

level of poultry manure (t/ha)	*Population of M. incognita (larvae/kg soil at	
	midseason	harvest
0	15,000	19,000
2	8,700	11,200
4	4,700	7,200
8	2,800	3,400

* Each value is a mean of five replicates

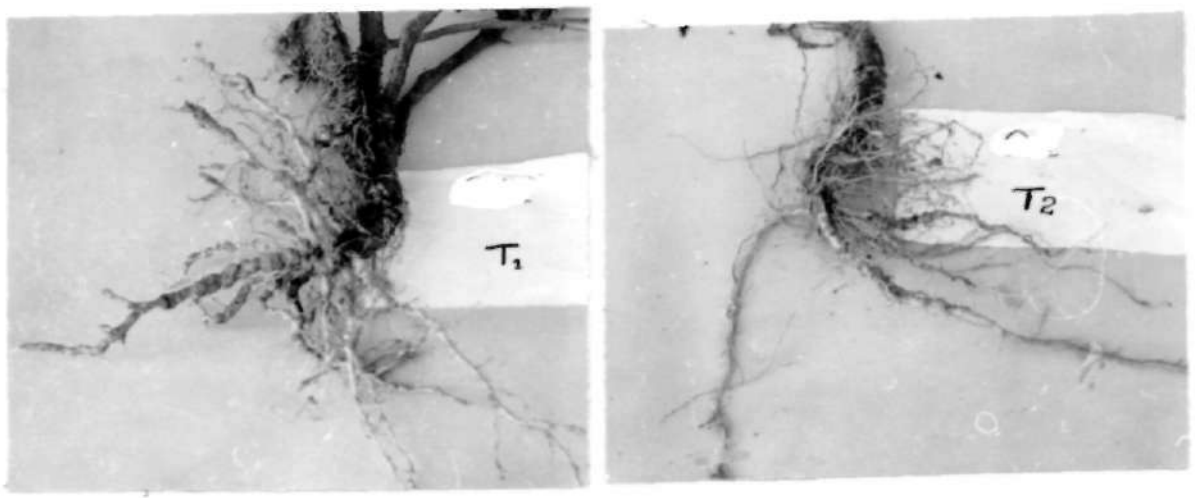


Plate III. Effect of poultry manure as soil organic amendment on tomato root damage by M. incognita T1 = 0t/ha, T2 = 2t/ha, T3 = 4t/ha and T4 = 8t/ha.

5.4. Effect of water-soluble fractions (WSF) of poultry manure on the hatch and survival of larvae of M. incognita in vitro

5.4.1. Materials and Methods

Hatching response and rate of mortality of larvae of M. incognita were determined in WSF of poultry manure. The WSF were prepared by adding 1g (for 2t/ha), 2g (for 4t/ha) and 4g (for 8t/ha) of the manure in 100 ml of distilled water contained in 250ml Erlenmeyer flasks. After 10 days of decomposition, the suspensions were filtered with filter paper and 10ml of each suspension was transferred into nematode counting dishes.

One hundred freshly hatched larvae of M. incognita were transferred to each of the dishes and covered with Petridishes to prevent evaporation. At intervals of 12, 24 and 48 hours the number of nematode larvae that had been immobilized or killed was counted and percent mortality determined. The immobilized larvae were again placed in distilled water for 24 hours to ascertain whether or not they regained mobility.

For determining cumulative larval hatch, five average sized eggmasses were transferred into the counting dishes containing the WSF. After five days the number of larvae that hatched out was counted.

Hatching and mortality in distilled water served as control in both cases. Each of the experiments was repeated twice at room temperature of 24 ± 2°C.

The chemical constitution of the suspensions was not determined.

5.2.2 RESULTS

The results show that WSF of poultry manure after 10 days of decomposition brought about a high percentage of inhibition of larval hatch of M. incognita (Table 10). Percent inhibition varied from 66.67% for 2t/ha to 99.67% for 8t/ha. Only few of the nematodes that hatched out survived.

Similar results were obtained for their effect on larval mortality (Table 11). Larval mortality increased with increasing levels of poultry manure and was maximum (100%) at 8t/ha. Also, at all levels of poultry manure, larval mortality increased with increase in time of exposure. At 8t/ha larval mortality had already attained 100% within 12 hours of exposure. (Table 12)

5.5 DISCUSSION AND CONCLUSION

Control of plant-parasitic nematodes has been achieved by chemical, biological and cultural practices which include the use of resistant varieties and land management practices. The latter includes amending the soil with agricultural wastes. Since Lindford (1937)

Table 10: Effect of water-soluble fractions (WSF) of poultry manure on larval hatch of M. incognita in vitro

Treatment (t/ha)	Cumulative hatch after 5 days	*% hatch	% mortality after 5 days
0	1246	83.06	0
2	500	33.33	23.00
4	19	1.27	84.21
8	5	0.33	100.00

* Calculation based on an estimated average of 1500 larvae.

Table 11: Effect of water-soluble fractions of poultry manure on the mortality of larvae of M. incognita in vitro

Treatment (t/ha)	Decomposition period (Days)	% mortality after		
		12 hours	24 hours	48 hours
0	10	0	0	0
2	10	25.0	63.0	70.0
4	10	82.0	95.0	98.0
8	10	100.0	100.0	100.0

and Johnson (1959) first provided evidence on the advantageous use of organic matter to reduce the activity of plant-parasitic nematodes, several agricultural wastes such as farm yard manure, cowdung and crop residues have been tested (van der Laan, 1956); Johnson, 1959; Omiyi, 1976). In most cases diseases caused by nematodes have been controlled resulting in increased growth and yield of the crop.

In the present studies, the efficacy of the agricultural waste, viz., poultry manure, in controlling the root-knot nematode, M. incognita on tomato in the glasshouse, the field and in vitro was considered. In both glasshouse and field experiments, remarkable reduction in the nematode population was achieved with a concomitant increase in growth and yield of tomato. In vitro studies on hatch and survival of larvae revealed in part that reduction in nematode population was due to toxic products of decomposition of poultry manure. Eggs were permanently inhibited from hatching and larvae were killed. These results are in general agreement with those of Khan (1976). None of the larvae immobilized in water-soluble suspension of the poultry manure regained its mobility when transferred into distilled water.

Several theories, though unresolved, have been advanced to explain the mechanism of action of organic

amendments on nematodes. Soil nematode population could be reduced by one of more of the following processes:

a) The decomposition products of organic amendments are directly toxic to the nematodes (Patrick et al., 1965; Hunt et al., 1973~~a and b~~; Khan, 1976; Helder et al., 1982).

b) the increase in plant growth and yield as a result of the amendment may be ascribed to increase in nutrient availability to the plant (Druzina et al., 1983).

c) amending the soil with organic matter brings about an increase in the number of a wide array of natural enemies of nematodes (Lindford et al., 1938).

d) decomposition of organic matter results in changes in biotic and abiotic environment of plants which ultimately alter the host-parasite relationship (van der Laan, 1956) to the advantage of the host.

e) organic amendments improve soil condition for greater root growth, thereby enhancing the utilization of soil nutrients as a consequence of which the nematode damage is markedly minimized (van der Laan, 1956).

The degree of control of root-knot nematodes, or any plant disease for that matter, by any method is dependent on a miriad of factors coming into play.

None of the above mentioned mechanisms or factors can be singly responsible for the control of the nematodes. Since parasitic nematodes were not recovered during the experiments, soil nematode reduction with a concomitant increase in growth and yield could have been due to one or all of the other four factors. The *in vitro* studies on hatch and survival of larvae tend to indicate a reduction in nematode population due to toxic products released during decomposition.

Be that as it may, the present study presents tremendous potentials of poultry manure as an effective means of controlling plant-parasitic nematodes. Despite its advantages, the use of poultry manure in agricultural production is pregnant with problems. While small amounts of inorganic fertilizers are required per unit area, poultry manure and most organic amendments are required in large amounts. In tomato and most vegetable production, about 250kg NPK (15:15:15:) and 500kg P_2O_5 is required per ha. This contrasts with 4-8t/ha and 28-112t/ha of poultry manure and cowdung respectively (Omiyi, 1976). This may not be readily available for the relatively large-scale farmer. Where it is available the haulage may make it prohibitively expensive. Thus, its use at the moment may be more practicable with the small-scale farmer.

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The efficacy of poultry manure in nematode control is governed by the composition and degree of decomposition of the manure. Relatively undecompesed organic matter results in negative effects on plant growth (Erinle, personal communication). In case of poultry manure, this is probably due to a high urea content.

To achieve meaningful control of plant-parasitic nematodes with poultry manure, it is pertinent that:

a) a clear mechanism of action is worked out. This requires chemical analysis of the contituents in water-soluble suspensions.

b) a recommended dose both for the control of the nematodes and profitable growth of the plant should be worked out. In this study, this appears to be in the region of 4t/ha.

c) a conscious effort is made by the governments to encourage farmers in the use of organic amendments in crop production.

d) an intergrated disease control approach, which is aimed at utilizing both poultry manure and inorganic fertilizers at levels below those presently recommended should be vigorously pursued, This will ultimately reduce the cost of inputs and increase profits.

CHAPTER 6

SUMMARY AND CONCLUSIONS

This study was undertaken to first determine the effect of different population densities of M. incognita on the growth and yield of tomato and to ascertain the population density at which it will be economical to apply chemical control. Secondly, the effect of the root-knot nematode, M. incognita on the severity of two vascular diseases of tomato was studied. Thirdly, the potential of poultry manure in the control of M. incognita was, therefore, investigated with a view to incorporating it in an integrated control programme of root-knot nematodes on tomato.

Results of these investigations show that:

1. Both the growth and fruit yield of tomato, cv. Enterpriser, was inversely related to initial population density of M. incognita. About 85% yield loss was incurred at the initial population density of 16,000 larvae/kg of soil. Low populations of 500 and 1,000 larvae/kg of soil, however, did not reduce yield significantly. At 2,000 larvae/kg of soil, tomato yield was reduced significantly.

2. Under conditions of these experiments, an economic loss threshold of 10.6% was established, and this occurred at between 1000-2000 larvae/kg of soil. It is concluded therefore, that it may be uneconomical to apply chemical control to M. incognita on tomatoes at populations below 1,000/kg soil, whereas, populations above this will require control measures. This figure, (10.6%) however is variable.

3. The nematode M. incognita aggravated the vascular diseases in tomato varieties that are susceptible to it, and tended to break the resistance in those varieties that are resistant to these diseases, P. solanacearum and F. oxysporum f.sp. lycopersici. This agrees with earlier reports by Atkinson (1892), Bergeson (1972) Powel (1979), Morrel and Bloom (1980), and Sidhu and Webster (1981). In all the experiments, both wilting and vascular discolouration were higher in treatments where the nematode and vascular pathogens occured together. However, degree of wilting and vascular discolouration declined with increase in the time of exposure to the nematode before inoculation of the vascular pathogens.

4. Both glasshouse and in vitro studies plus field experiments revealed that poultry manure has tremendous potentials for the control of plant-parasitic nematodes. There was a progressive decline in nematode population and severity of damage (gall index) as the level of poultry manure increased. Significant

increases in nematode population were achieved at 4 t/ha. In vitro studies on the effect of WSF suggest that the mechanism of action is that of toxic products of decomposition of poultry manure on the nematodes.

Because of its tremendous potentials in nematode control, more research is needed to elucidate the true mechanism of this vital agricultural by-product and to determine optimum levels of application for adequate nematode control without jeorpadising the growth of the plant. Because of the high nitrogen content, high levels may tend to promote vegetative growth with little fruit development. In this study 4 t/ha appeared to be a compromise level both for the control of root-knot nematodes and plant growth. This is in consonance with local agricultural extension recommendations on the use of poultry manure in crop production (Majambu, personal communication).

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* Original paper not seen.

APPENDICES

1. ANOVA of Parameters on the effects of initial population density of M. incognita on the growth and yield of tomato.

Glasshouse Experiments - Year I and II

1.1 Height of Plants

Source	DF	SS	MS	F
Treatment	6	1533.49	255.581	17.926**
Residual	28	399.19	14.257	
Total	34	1932.69		

1.2 Fruit Number

Treatment	6	113.485	18.914	10.764**
Residual	28	49.2	1.757	
Total	34	162.685		

1.3 Fruit weight

Treatment	6	407943	67990.0	8.078**
Residual	28	235658	8416.36	
Total	34	643601		

1.4 Height of Plants

Treatment	6	1522.29	253.714	17.142**
Residual	28	414.398	14.799	
Total	34	1936.69		

1.5 Fruit Number

Treatment	6	111.885	18.647	16.115**
Residual	28	32.399	1.157	
Total	34	144.285		

1.6 Fruit weight

Source	DF	SS	MS	F
Treatment	6	386302	64383.7	12.57 **
Residual	28	143415	5121.96	
Total	34	529717		

Microplot Experiments - Year I

1.7 Height of Plants

Treatment	6	1201.88	200.314	14:5 **
Residual	28	386.8	13.814	
Total	34	1588.69		

1.8 Fruit Number

Treatment	6	79.085	13.18	19.631**
Residual	28	18.8	.671	
Total	34	97.885		

1.9 Fruit weight

Treatment	6	426887	71147.9	29.409**
Residual	28	67738.5	2419.23	
Total	34	494626.0		

Year 2

2.0 Height of Plants

Treatment	6	1200.29	200.047	20.9**
Residual	28	267.998	9.571	
Total	34	1468.29		

2.1 Fruit Number

Treatment	6	96.571	16.095	28.166 **
Residual	28	16	.571	
Total	34	112.571		

2.2 Fruit weight

Source	DF	DF	SS	MS	F
Treatment	6		424614	70769.1	45.233**
Residual	28		43806.9	1564.53	
Total	34				

Appendix 3. Nematode populations present in the soil before transplanting.

Nematode genera	Population/kg soil
Meloidogyne spp	10,000
Ditylenchus spp.	3,000
Tylenchus spp.	4,000
Aphelenchus spp.	3,000
Pratylenchus spp.	3,000
Aphelenchoides spp.	2,000
Helicotylenchus spp.	1,000

Appendix 4. *Nematode populations in the soil immediately after harvest.

Nematode genera	Level of poultry manure (t/ha) 0	2	4	8
Meloidogyne spp.	18,800	11,100	7,900	4,050
Ditylenchus spp.	6,500	3,000	400	100
Tylenchus spp.	9,000	4,300	200	98
Aphelenchus spp.	6,200	5,000	200	175
Pratylenchus spp.	7,500	3,000	150	120
Aphelenchoides spp.	8,000	2,000	180	100
Helicotylenchus spp.	3,000	1,000	200	100

* Mean of two years.

Appendix 5. Soil chemical analysis.

Parameter	Pre-planting	Post-harvest
pH	6.5	5.8
N	0.05075%	
P	0.26%	0.34%
C	0.52%	0.44%

Appendix 6. Environmental oconditions during the experimental periods.

Months	1984 Temperature (°C) Max.	Min.	R.H	1985 Temperature (°C) Max.	Min.	*R. H
June	31.5	20.5	62.05	30.0	18.7	67.5
July	28.9	19.2	71.0	27.8	17.3	30.0
August	29.8	19.5	70.1	28.8	15.5	75.55
September	28.0	18.0	68.	29.3	17.8	72.65

Appendix 7. ANOVA of parameters of interaction between M. incognita and two vascular diseases of tomato.

Interaction between M. incognita and P. solanacearum

Year I

7.1 CV. - Hunkuyi local

Source	DF	SS	MS	F
Treatment	5	9.767	1.953	13.022**
Residual	24	3.600	0.150	
Total	29	13.367	0.461	

7.2 Variety - CL-119-1-2-0-0

Source	DF	S	MS	F
Treatment	5	4.700	0.940	4.70*
Residual	24	4.800	0.200	
Total	29	9.500	0.328	

Year II

7.3 Variety - Hunkuyi local

Treatment	5	17.867	3.573	21.440**
Residual	24	4.000	0.167	
Total	29	21.867	0.754	

7.4 Variety CL-119-1-2-0-0

Treatment	5	5.500	1.100	9.429**
Residual	24	2,800	0.117	
Total	29	8.300	0.286.	

Interaction between M. incognita and F. oxysporum f.sp. lycopersici.

Year I

7.5 Variety - Hunkuyi local

Treatment	5	18.700	3.740	22.440**
Residual	24	4.000	0.167	
Total	29	22.700	0.783	

7.6 Variety - ROMA VF

Treatment	5	5.200	1.040	12.480**
Residual	24	2.000	0.083	
Total	29	7.200	0.248	

Year II

7.7 CV. Hunkuyi local

Source	DF	SS	MS	F
Treatment	5	13.100	2.620	17.467**
Residual	24	3.600	0.150	
Total	29	16.700	0.576	

7.8 CV. ROMA VF

Treatment	5	4.167	0.833	16.667**
Residual	24	1.200	0.050	
Total	29	5.367	0.185	

Combined Analysis

Interaction between N. incognita and P. solanacearum

7.9 CV. - Hunkuyi local

Year	1	0.417	0.417	1.923N.S
Residual	8	1.733	0.217	1.477N.S
Treatment	5	25.350	5.070	34.568**
Year/Treatment	5	2.283	0.457	3.114*
Residual	40	5.867	0.147	

8.0 CV. CL-119-1-2-0-0

Year	1	0.600	0.600	3.273N.S
Residual	8	1.467	0.183	1.196N.S
Treatment	5	7.800	1.560	10.174**
Year/Treatment	5	2.400	0.480	3.130*
Residual	40	6.133	0.153	

Interaction between M. incognita and f. oxys. f.sp. lycopersici.

8.1 CV. Munkuyi local

Source	DF	SS	MS	F
Year	1	0.600	0.600	4.50**
Residual	8	1.067	0.133	0.816N.S
Treatment	5	30.400	6.080	37.224**
Year/Treatment	5	1.400	0.280	1.714N.S
Residual	40	6.533	0.163	

8.2 CV. ROMA VF

Year	1	0.417	0.417	8.33**
Residual	8	0.400	0.050	0.714N.S
Treatment	5	7.883	1.577	22.524**
Year/Treatment	5	1.483	0.297	4.238*
Residual	40	2.800	0.070	
Total	59			

Interaction between M. incognita, P. solanacearum and F. oxys. f.sp. lycopersici

8.3 C.V. Munkuyi local

Treatment	5	16.967	3.393	20.360**
Residual	24	4.000	0.167	
Total	29	20.967	0.723	

Appendix 9. ANOVA of parameters on the effects of poultry manure on the damage caused by root-knot nematode, M. incognita on tomato - Glasshouse. experiments.

Year I

9.1 Height of Plants

Source	DF	SS	MS	F
Treatment	3	788.15	262.72	14.822**
Residual	16	283.60	17.73	
Total	19	1071.75	56.41	

9.2 Fruit Number

Treatment	3	50.550	16.850	11.049**
Residual	16	24.400	1. 525	
Total	19	74.950	3.945	

9.3 Fruit weight

Treatment	3	129620	43207	7.895**
Residual	16	87561	5473	
Total	19	217181	11431	

9.4 Height of Plants

Treatment	3	800.55	266.85	8.932**
Residual	16	478.00	29.87	
Total	19	1278.55	67.29	

9.5 Fruit Number

Treatment	3	59.600	19.867	11.686**
Residual	16	27.200	1.700	
Total	19	86.800	4.568	

9.6 Fruit wieght

Source	DF	SS	MS	F
Treatment	3	245166	81722	13.334**
Residual	16	98065	6129	
Total	19	343231	18065	

Field Experiments

9.7 Height of Plants

Treatment	3	8947	2982	2.446N.S
Residual	16	19511	1219	
Total	19	28458	1498	

9.8 Fruit Number

Treatment	3	38142	12714	5.364*
Residual	16	37923	2370	
Total	19	76065		

9.9 Fruit wei ht

Treatment	3	718.42	239.47	14.438**
Residual	16	265.38	16.59	
Total	19	983.80	51.78	

Year II

10.0 Height of Plants

Treatment	3	3753	1251	0.842N.S
Residual	16	23764	1485	
Total	19	27517	1448	

10.1 Fruit Number

Source	DF	SS	MS	F
Treatment	3	29662	9887	4.705*
Residual	16	33624	2102	
Total	19	63286	3331	

10.2 Fruit weight

Treatmant	3	719.75	239.92	15.093**
Residual	16	254.33	15.90	
Total	19	974.08	51.27	

COMBINE ANALYSIS

Glasshouse Experiments

10.3 Height of Plants

Year	1	8.10	8.10	0.726N.S
Residual	8	89.30	11.16	0.398N.S
Treatment	3	1588.40	529.47	18.901**
Year Treatment	3	0.30	0.10	0.004N.S
Residual	24	672.30	28.01	

10.4 Fruit Number

Year	1	4.225	4.225	8.450*
Residual	8	4.000	0.500	0.252N.S
Treatment	3	109.875	0.914	18.466**
Year Treatmnet	3	0.275	36.625	0.046N.S
Residual	24	47.600	1.983	

10.5 Fruit weight

Source	DF	SS	MS	F
Year	1	10902	10902	1.441N.S
Residual	8	60522	7565	1.451N.S
Treatment	3	363048	7936	23.216**
Year Treatment	3	11738	121016	0.751N.S
Residual	24	125105	3913	

Field Experiments

10.6 Fruit Number

Year	1	1082	1082	0.351N.S
Residual	8	24646	3081	1.576N.S
Treatment	3	67032	22344	11.431**
Year Treatment	3	772	257	0.132N.S
Residual	24	46901	1954	

10.7 Fruit weight

Year	1	2.26	2.26	0.088N.S
Residual	8	205.70	25.71	1.965N.S
Treatment	3	1438.04	479.35	36.636**
Year Treatment	3	0.13	0.04	0.003N.S
Residual	24	314.01	13.08	