Chapter one

GENERAL INTRODUCTION

1. The importance of tomato

Tomato (*Lycopersicon esculentum* Mill.) is a major vegetable crop that has achieved tremendous popularity over the last century. It is grown in practically every country of the world in outdoor fields, greenhouses and in net houses (Wener, 2000). World production of tomato, which ranks as a leading fresh and processed vegetable crop, exceeded 108.5 million metric tons in 2002 and occupied approximately 4.0 million hectares. In table 1.1, the overall level of production of a number of vegetable crops in the four tropical regions of the world is tabulated. World tomato production is valued at 5-6 billion US dollars with international trade amounting to 3-3.5 billion US dollars annually (FAO, 2003).

The tomato plant is a very versatile crop that can be divided into two categories by use; fresh market tomatoes, which are sold for human consumption and processing tomatoes, which are grown only outdoors for the canning industry and are mechanically harvested. In both cases, world production and consumption has grown quite rapidly over the past 25 years (Wener, 2000). Tomato, aside from being tasty, are very healthy as they are a good source of vitamins A and C (Wener, 2000; http://www.ars-grin.gov/npgs/cgcreports/ tomatocgcreport 2003.html).

Increased production is associated with major advances in production and processing technology. In addition, modern breeding methods supported by new molecular techniques are making major strides to shorten the development time for cultivars with plant resistance to nematodes, insects and diseases.

Table 1.1 Area in 1000 ha, yield in metric tonnes and total production in 1000 metric tonnes for select vegetables in regions with large tropical and subtropical climates. [a]

	Africa			C. America			S. America			Asia		
Vegetable	Area	Yield	Prod.	Area	Yield	Prod.	Area	Yield	Prod.	Area	Yield	Prod.
Cabbages	86	17	1,485	22	14	327	59	9	498	2,260	20	44,909
Lettuce	15	20	299	13	21	271	15	13	193	587	19	11,144
Tomato	609	20	12,452	82	28	2,336	149	44	6,628	2,323	25	57,330
Cauliflower	13	20	241	22	12	253	5	16	75	632	19	12,117
Squash	227	8	1,788	39	12	473	5	137	7	858	18	26,469
Cucumbers	4	16	72	1,729	18	3,167	94	13	717	857	14	11,557
Aubergines	46	19	940	3	24	60	1	19	9	1,506	17	26,000
Spinach	4	17	58	2	11	20	1	17	13	702	14	9,869
Pepper	268	8	1,989	146	13	1,814	29	14	397	970	15	14,056
Onions	38	13	466	45	25	1,131	22	5	113	106	20	2,126
Dry onion	281	14	4,012	19	14	260	160	21	3,416	1,971	17	32,575
Garlic	32	12	376	6	8	47	45	8	346	902	12	10,722
Carrots	74	13	952	18	25	432	46	21	935	507	19	9,749
maize	375	4	1,413	19	10	186	86	8	704	133	6	790

[a] From Sikora and Fernandez (2005) FAOSTAT database at: appjs.fao.org/faostat

The increase in the importance of vegetables is especially evident in countries with rapidly expanding populations, e.g. Africa and Asia, where large amounts of land near urban centres are devoted to vegetable production and where production since 1990 has expanded by 32 and 50%, respectively (Sikora and Fernandez, 2005).

The global production of tomato (fresh and processed) has increased by about 300% in the last four decades and is estimated of 100.5 million tons grown on 4,161,295 hectare. China, USA and Turkey are considered the three leading countries in producing tomato. Table 1.2 shows the top ten tomato-producing countries (Costa and Heuvelink, 2005).

Table 1.2 The top ten tomato-producing countries (Costa and Heuvelink, 2005 after FAO, 2003)

Country	Production (million ton)	Area harvested (ha)
China	25.9	1,105,153
USA	12.3	177,000
Turkey	9	225,000
India	7.4	520,000
Italy	6.9	130,932
Egypt	6.4	181,000
Spain	3.8	64,100
Brazil	3.6	59,766
Iran	3	112,000
Russian-Federal	2.2	160,000

Tomato is one of the most important crops in the Middle East where it is also a major income generating crop for small scale farmers. Jordan and Israel are the major producers of fresh or processing of tomato in this region (Costa and Heuvelink, 2005). In Palestine, tomato is grown in both large and small scale farms as an important vegetable and cash crop. Among all vegetables, tomato shares the highest total cultivated area (Table 1.3).

Table 1.3 The area and production of major vegetables in Palestine (1995-2000) Area/ Donum (1000m^2), Production/ Ton (1000kg)

Year	1995-1996		1996-1997		1997-1998		1998-1999		1999-2000	
Crop	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.	Area	Prod.
Squash	27394	41546	29430	44284	31612	39251	26244	39119	28647	44827
Tomato	29831	122457	29203	140729	25918	153934	22896	172010	25392	196096
Cucumber	17555	91344	19187	106617	17516	99949	22000	104757	23099	130806
Watermelon	2895	7573	6605	15451	8381	19760	3220	13274	2688	7578
Cauliflower	7509	15972	8317	15150	8364	20394	8104	22240	7891	19208
Eggplant	6088	30715	9463	42973	7634	36339	8030	37088	8371	39716
Peas	3321	1242	2909	1556	5157	2414	2326	1037	--	--
Hot Pepper	4644	11410	5995	15739	5038	14650	3564	9945	4110	10967
Spinach	2135	3866	1784	2128	1697	2225	1332	2057	1360	2509
Onion	--	--	2765	6739	1475	3149	1709	3225	2101	4654
Carrot	648	1601	931	2992	118	3702	938	2615	723	1812
Radish	1461	3292	1558	3521	1074	2540	1341	2439	957	2070
Lettuce	694	1441	802	2365	972	2852	1151	3040	1018	3154
Paprika	353	1249	956	3805	773	3275	1334	4879	528	1131
Maize	--	--	--	--	655	838	548	1724	10295	11942

2. Importance of plant parasitic nematodes

At present, 24 genera of plant parasitic nematodes contain species that are economically important pests of crop plants. Other species and genera of plant parasitic nematodes may gain importance in the future as their host-parasite relationships become better understood. It has been estimated that some 10% of world crop production is lost as a result of plant nematode damage, which is one third of the losses generally attributed to pest and diseases (Whitehead, 1998).

Vegetables in both tropical and subtropical areas are highly dependent on good nematode control (Sikora and Fernandez, 2005). Plant damage increases with the number of nematodes feeding on the root system. Also yield and quality are reduced with increasing numbers of nematodes (figure 1.1), (Noling, 2005). Survival of plant parasitic nematodes depends on the availability of a suitable host plant (Sasser, 1979a, b), though they can survive unfavourable environments in several ways in the absence of the host. The eggs may resist low temperature or drought that juveniles or adults often cannot. Eggs may be retained in the dead body of the females, which becomes a tanned, protective envelope or cyst. Some nematodes can withstand adverse environmental conditions by entering resting stages. The types of quiescence they enter include: low temperature (cryobiosis), high temperature (thermobiosis), lack of oxygen (anoxybiosis), osmotic stress (osmobiosis), and drying or dehydration (anhydrobiosis) (Wright and Perry, 2006)

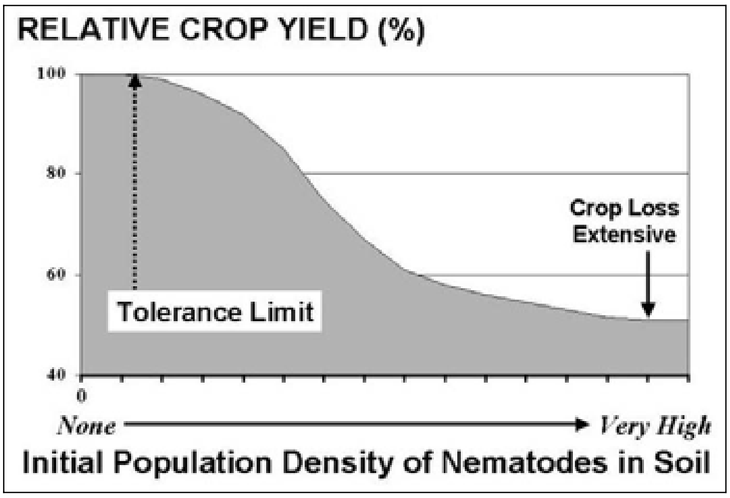

Figure 1.1 Typical nematode induced crop damage relationship in which crop yields, expressed as a percentage of yields that would be obtained in the absence of nematodes, decline with increased population density of nematodes in soil. The tolerance level is identified as the initial or minimal soil population density at which crop damage is first observed (after Noling, 2005).

The high reproductive capacity of plant parasitic nematodes is one of the features which make them such a significant pest, and also makes them very difficult to control. The life cycle of the majority of the important species takes only a few weeks at optimum temperatures, and each female has the capacity to lay hundreds of eggs (Stirling, 1991; Manzanilla-Lopez, 2004).

3. Root-knot nematode

Root-knot nematodes (*Meloidogyne* spp.) are an extremely important group of plant parasitic nematodes that have world-wide distributions, extensive host ranges and are able to interact with plant diseases to form complex disease syndromes (Hussey and Janssen, 2002; Manzanilla-Lopez, 2004; Karssen and Moens, 2006). Root-knot nematodes cause high losses in vegetables production worldwide. The estimated overall average annual yield loss of the world's major crops due to damage by plant parasitic nematodes is 12.3% (Sasser and Freckman, 1987). Species of *Meloidogyne* also cause severe damage to many other crop plants, i.e. legume, rice, etc. (Mai, 1985; Sikora et al., 2005). Tomato in particular, is heavily infected with *Meloidogyne* spp. in the tropics and subtropics as well as under greenhouse conditions in subtropical and temperate regions (Taylor and Sasser, 1978; Potter and Olthof, 1993; Whitehead, 1998; Sikora and Fernandez, 2005).

Four species, *Meloidogyne incognita*, *M. javanica*, *M. arenaria* and *M. hapla*, count for 95% of all root-knot nematode infestations in agricultural land. Of these, *M. incognita* is the most economically important species. These highly successful pathogens cause an estimated average crop loss of 5% worldwide and are one of the major obstacles to production of adequate supplies of food in many developing countries (Hussey and Janssen, 2002).

Meloidogyne incognita is the most prominent and most widely distributed representative of this genus. It has a very wide host range, and can reproduce on more than 2000 plant species. *M. incognita* has 4 races identified by their host spectrum with different host preferences (Table 1.3) (Taylor and Sasser, 1978; Sasser, 1979a; Lamberti, 1979; Trudgill, 1997; Manzanilla-Lopez, 2004; Sikora and Fernandez, 2005).

Table 1.3 *Meloidogyne incognita* differential host test identification table

M. incognita races	Differential host plant cultivars*					
	Tobacco NC 95	Cotton Delta-pine 16	Pepper California Wonder	Watermelon Charleston Grey	Peanut Florrunner	Tomato Rutgers
Race 1	-	-	+	+	-	+
Race 2	+	-	+	+	-	+
Race 3	-	+	+	+	-	+
Race 4	+	+	+	+	-	+

*Tobacco (*Nicotiana tabacum*) cv NC 95; cotton (*Gossypium hirstutum*) cv Deltapine 16; pepper (*Capsicum frutescens*) cv California Wonder; watermelon (*Citrullus vulgaris*) cv Charleston Grey; peanut (*Arachis hypogaea*) cv Florrunner; tomato (*Lycopersicon esculuntum*) cv Rutger (Taylor and Sasser, 1978).

The life cycle of *Meloidogyne* spp. involves five developmental stages. Embryonic development in the egg results in formation of the vermiform first-stage juvenile (J1), which later molts into the J2 stage. The J2 hatch from the eggs by breaking the shell with repeated thrusting of their stylists, which then become the only infective stage. All other stages occur inside the root tissue (Mai and Abawi, 1987). Hatching of *Meloidogyne* eggs is temperature driven and occurs without requiring stimulus from plant roots, however, root stimulates sometimes stimulates hatching (Karssen and Moens, 2006).

Infective second stage juveniles (J2) migrate in the soil and are attracted to root tips where they penetrate behind the root cap. The juveniles migrate intercellulary in the cortical tissue to the region of the root where the vascular cylinder is differentiating. They inject secretory proteins produced in their oesophageal gland cells through the stylet into five to seven undifferentiated procambial cells to transform these root cells into very specialized feeding cells called giant-cells, which become the permanent feeding sites for the parasites throughout their life cycle (Dropkin, 1989; Trudgill, 1997; Jung and Wyss, 1999; Hussey and Janssen, 2002; Karssen and Moens, 2006).

Concurrent with the formation of giant cells, root tissue in the vicinity of nematode feeding undergo hyperplasia or hypertrophy. Together with the swelling female these changes at the cell level become apparent outside the root as galls or root-knots. Continuing developing in the root, the J2 goes through 3 moults in quick succession to the adult stage. The vermiform male leaves the root, whereas the female develops into a globose adult (Dropkin, 1989; Jung and Wyss, 1999; Manzanilla-Lopez, 2004). Usually *M. incognita* females reproduces via mitotic parthenogenesis, whose eggs are deposited in a gelatinous matrix on the outer surface of the galled roots (Hussey and Janssen, 2002). Between 100-500 eggs are produced in the same gelatinous matrix. The first juvenile stage moult inside the egg to be released as a J2 whenever favourable conditions involving temperature and moisture exist (Dropkin, 1989).

The presence of galls on the root system is the primary symptom associated with *Meloidogyne* infection. The size and form of the gall depend on the species involved, the number of nematodes in the tissues, host and plant age. These galls disturb root function and affect nutrient and water uptake and consequently shoot growth which is suppressed by wilting especially under hot dry conditions as well as nutritional deficiency symptoms like chlorosis (Jenkins and Taylor, 1967b; Sikora and Fernandez, 2005).

Where seedling infection has taken place, numerous plants may die in the seedbed, seedlings do not survive transplanting, or weakened plants are strongly reduced in growth in the field (Sikora and Fernandez, 2005).

Figure 1.2 Galling symptoms of root-knot nematode *Meloidogyne incognita* race 3 infection on tomato roots

Figure 1.3 Eggs of root-knot nematode *Meloidogyne incognita* race 3 deposited in a gelatinous matrix or egg sac.

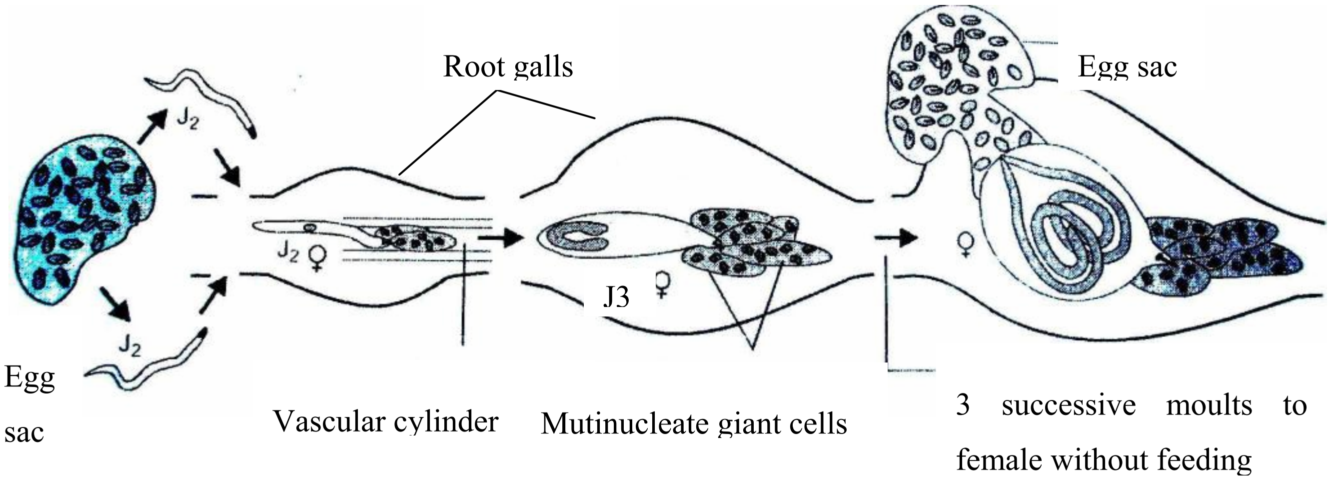

Figure 1.4 Life cycle of root-knot nematode (Jung and Wyss, 1999)

4. Root-knot nematode management techniques

The main aim of plant parasitic nematode management is to prevent significant losses of yield and quality in vulnerable crop plants, and in the long term, to keep nematode populations below the threshold level (Whitehead, 1998).