CHAPTER 1

1 Introduction

1.1 Coffee production and economic importance

Coffee is the most important agricultural commodity in the world, and is worth up to $14 billion annually. More than 80 countries cultivate coffee, which is exported as raw, roasted or soluble product to more than 165 countries worldwide. More than 50 developing countries, 25 of them in Africa, depend on coffee as an export, with 17 countries earning 25% of their foreign exchange from coffee. The United States Department of Agriculture forecasted coffee production in 2006/2007 at 123.6 million bags (60 kg or 132.276 pounds) which increased nearly 10 percent, or 11 billion bags over the previous year (USDA, 2006).

The plant genus *Coffea* comprises about ninety species but only a few are cultivated. Commercial coffee production relies on two species of coffee, *C*. *arabica* and *C*. *canephora (coffee robusta)*, with *C. arabica* being considered of superior quality and contributing to over 70% of the world's coffee production (Orozco-Castillo et al., 1994; Rani et al., 2000; Waller et al., 2007).

Coffea is a perennial woody shrub with a dimorphic growth characteristic, which consists of vertical and horizontal branches. *C*. *arabica* has its origin in the southwest highlands of Ethiopia (Harlan, 1969), but Thomas (1942) reported the existence of wild *C. arabica* on the Boma plateau in Sudan which have been introduced in the distance past from the Ethiopian highlands (Thomas, 1942). Berthaud and Charrier (1988) also reported the presence of *C*. *Arabica* populations on Mount Imantong in Sudan and Mount Marsabit in Kenya. However, it is generally believed that *C*. *arabica* has its highest genetic diversity in Ethiopia (Waller et al., 2007).

The root system of coffee consists of a short taproot and numerous lateral roots. Some of the lateral roots bend downward and reach depths of up to three meters. The remaining lateral roots form a dense mat of feeder roots which extend about two meters deep and two meters laterally from the stem (Wrigley, 1988; Willson, 1999). Coffee leaves are sensitive to direct sunlight and both high and low temperatures. Shaded leaves are much more photosynthetically efficient than un-shaded leaves. In addition to this, full sunlight can raise the temperature of leaves as much as 20°C above the optimum and can damage them directly (Cannell, 1985; Wrigley, 1988; Willson, 1999; Waller et al., 2007).

While coffee is grown in various areas throughout the tropics, there is a relatively narrow range of environmental conditions under which it will flourish. With few exceptions, coffee is limited to tropical highland areas (Wrigley, 1988) which have climates similar to that of the Ethiopian highlands where coffee originated. The most important factors determining the suitability of an area for coffee cultivation are temperature, moisture and light intensity (Wrigley, 1988).

1.2 Major coffee pests and diseases

Limiting factors of coffee production includes species of fungi, bacteria, viruses, nematodes and insects. The major fungal diseases are coffee leaf rust (*Hemileia vastatrix*), coffee berry disease (*Colletotrichum kahawae*) and coffee wilt disease (*Fusarium xylarioides)* (Waller et al., 2007). The two important bacterial coffee diseases are halo blight of coffee incited by *Pseudomonas syringae* pv. *garcae* (Amaral et al., 1956) and coffee leaf scorch caused by the polyphagous bacterium *Xylella fastidiosa* (Wells et al., 1987). The former disease has been described in Brazil, Kenya, Uganda and China where it is becoming of some concern due to its high incidence and severity (Wen and Chen, 1995; Chen, 2002). Coffee leaf scorch has been recorded only in Brazil and Costa Rica where the bacterium *X. fastidiosa* attacks several other crops with high incidence, particularly in citrus and prunes.

Some records of virus diseases in coffee have sporadically been made in Brazil and Colombia but with no economic significance and of eventual misinterpreted diagnosis (Chen, 2002). However, the coffee ring spot virus CoRSV associated with a mite vector has been reported in several Brazilian states and recently found in Costa Rica. It causes conspicuous ring spot symptoms on leaves, berries, and less frequently on twigs. A similar disease is known in the Philippines, but no information exists about its relationship to CoRSV (Chagas et al., 2003).

Stem and branch borers, berry feeders, bud, leaf, green shoot and flower feeding insects as well as, root and collar feeding insects are the most important insect pests recorded in coffee plantations of the world (Waller et al., 2007).

Furthermore, many genera and species of nematodes were found associated with coffee in many countries of the world. Root-knot nematodes, *Meloidogyne spp*., are among the most important parasites. They are widely distributed throughout the world in coffee plantations and are more frequently encountered than any other group of nematodes. The most important root-knot nematode species in terms of their damage and distribution are *M. exigua*, *M. incognita*, *M. coffeicola* and *M. paranaensis, w*hereas, *M. africana, M. decalineata, M. megadora, M. arabicida*, *M. javanica*, *M. arenaria* and *M. hapla* are less widespread (Campos and Villain, 2005).

1.3 Coffee production and its economic importance in Ethiopia

Since the establishment of agriculture 2000 years ago in Ethiopia, *C. arabica* has been grown in the natural forests of the south-western massive highlands of the Kaffa and Buno districts of the country. *C. arabica* has its center of origin in the highlands of southwest and southeast Ethiopia where wild coffee populations grow naturally in the undergrowth of the Afromontane rain forests at altitudes of 1370-1830 m (Waller et al., 2007).

The agriculture-based Ethiopian economy is highly dependent on *C. arabica* which provides employment in rural areas and is the means of livelihood for over 15 million people in Ethiopia. Ethiopia is currently the seventh largest coffee producer worldwide. Coffee is by far Ethiopia’s most important export crop which contributes 40% to the country’s foreign currency income (Tadesse et al., 2002; Denich and Gatzweiler, 2006).

The potential for coffee production in Ethiopia is very high, because of the country's suitable altitude, ample rainfall, optimum temperatures and fertile soil. The total area covered by coffee is about 400,000 hectares, with a total production of 200,000 tones of coffee per annum.

In Ethiopia, coffee grows at various altitudes and the bulk of *C. arabica* is produced in the eastern, southern and western parts of the country, which have altitudes ranging from 1300 to 1800 m. Annual rainfall in the coffee growing regions of the country varies from 1500 to 2500 mm. Where precipitation is lower, as in the eastern part of the country, production is supplemented with irrigation. Rainfall distribution in the southern and eastern parts of the country is bimodal and in the western part monomodal. These distribution patterns enable the country to harvest coffee at different times of the year, ensuring a supply of fresh beans all year round.

All the coffee growing regions have fertile, friable, loamy soils, with a depth of at least 1.5 m. The topsoil is dominantly dark brown or brownish in color, with a pH ranging from 5 to 6.8. One outstanding characteristic of the soil is that fertility is maintained by organic recycling, i.e., through litter fall, pruning and root residue from the perennial, coffee and shade trees. In addition, the small-scale coffee farmers, who are the major producers, use organic fertilizers to supplement the natural fertility of the soil.

1.4 Coffee production systems in Ethiopia

In Ethiopia, coffee is grown under four main production systems. These include plantation coffee, forest, semi-forest and garden, which account for 5, 10, 35 and 50% of the total volume produced in the country, respectively (Tadesse et al., 2002; Mekuria, 2004; Anonymous, 2006).

Plantation coffee (5%) is grown on plantations owned by the state and some well managed smallholder coffee farms. In this production system, selected seedlings are used and proper spacing, mulching, weeding, shade regulation and pruning is practiced (Tadesse et al., 2002; Mekuria, 2004; Anonymous, 2006).

Forest coffee (10%) is found in south and south-western Ethiopia. These are considered the centers of origin of *C. arabica*. Forest coffee is self sown and grown under the full coverage of natural forest trees. It has a wide genetic diversity (Tadesse et al., 2002; Mekuria, 2004; Anonymous, 2006).

Semi-forest coffee production systems (35%) are found in the south and south-western parts of the country. Farmers acquire forest land for coffee farms, and then thin and select the forest trees to ensure both adequate sunlight and proper shade for the coffee trees. They slash the weeds once a year to facilitate the coffee bean harvest (Tadesse et al., 2002; Mekuria, 2004; Anonymous, 2006).

Garden coffee (50%) is grown in the vicinity of farmer's residences, mainly in the southern and eastern parts of the country. The coffee is planted at low densities, ranging from 1,000 to 1,800 trees per hectare, is mostly fertilized with organic waste and is intercropped with different food crops (Anonymous, 2006; Mekuria, 2004).

1.5 Major coffee pests and diseases in Ethiopia

Limiting factors of coffee production in Ethiopia include diseases, such as coffee leaf rust, coffee berry disease (CBD) and coffee wilt disease (Derso et al., 2000).The antestia bug, *Antestiopsis intricata*, the blotch leafminer, *Leucoptera caffeine* and the coffee berry borer, *Hypothenemus hampei* are among the most prevalent insect pests of coffee in Ethiopia. However, they do not usually reach economic threshold levels because of the lack of environmental conditions conducive for their population growth (Million and Bayisa, 1985).

The only available information on coffee nematodes in Ethiopia is a general survey report that only covered two coffee growing areas. According to the report, seven genera of plant-parasitic nematodes were encountered (O'Bannon, 1975). Among these, the three genera *Meloidogyne*, *Pratylenchus* and *Rotylenchulus*, were identified as parasites of coffee.

1.6 Nematodes as plant parasites

Nematodes are round worms belonging to the phylum Nematoda and are present in almost every niche on the planet. They are aquatic animals found in marine and freshwater environments, in films of water in the soil, and as parasites within plant and animal tissues. The first recorded history of phytoparasitic nematode was reported by Turbevill Needham in England in 1743 later called the wheat gall nematode, *Anguina tritici* (Mai, 1971). Next came the discovery of the root-knot nematode as a cause of galls on cucumber roots in 1855 by Berkeley. In 1859, Hermann Schacht described the sugar beet nematode that threatened the sugar industry of Germany. The sugar beet nematode was named *Heterodera schachtii* by Schmidt in 1871. These nematodes were easily associated with their hosts as they are all endoparasitic nematodes that cause distinct galling and symptoms on the plants (Mai, 1971).

Plant-parasitic nematodes are greatly affected by moisture, temperature and oxygen levels within the soil environment in which they persist. Distribution of parasitic nematodes is usually patchy, suggesting no specific pattern to their population distribution. They are vertically distributed within the top 30 cm of soil, but the highest numbers of nematodes are typically found in the top 15–20 cm (Norton, 1978). Nematode concentration is greatest near plant roots, as many are attracted to the root exudates. Nematodes move short distances in soil approximately 30 cm while long distance spread is primarily from equipment, irrigation, birds, and other animals or humans (Wallace, 1964).

Plant-parasitic nematodes have biological characteristics that distinguish them from other organisms that affect growth of plants. They spend at least part of their life cycle within the soil where they are dependent upon all events that happen in and on the field in which they live. Also any agronomic factor, such as organic matter content or cultivation technique will also affect nematode behavior (Yeates, 1984). Nematodes are highly dependent on the presence of host plants but also are influenced by biological, chemical and physical components of the soil environment.

Plant-parasitic nematodes are functionally divided into two major categories based on feeding habit as endoparasitic and ectoparasitic. Endoparasitic nematodes feed by either partially or completely entering root or shoot tissue whereas ectoparasitic nematodes feed on the surface. They inject their stylet into the epidermal cells of the root to feed from the outside. Economically, endoparasitic nematodes cause the greatest damage. Although direct mechanical injury from nematode feeding is usually negligible, cell dysfunction as a result of the plant-nematode interaction leads to symptoms that include root-knots or galls, root lesions and deforming injured root tips and breakdown of the root tissue. In addition, indirect symptoms such as chlorosis, stunting and wilting often appear aboveground due to the root‘s inability to absorb and distribute water and nutrients needed for plant growth Furthermore, wounds created by the nematodes can act as entrance sites for secondary plant pathogens (Manzanilla-Lopez et al., 2003). In general, crop losses due to plant-parasitic nematodes are estimated annually to reach approximately 12% or approximately US$ 100 billion (Sasser and Freckman, 1987).

1.7 Nematode distribution in the soil

Most of the nematodes that feed on plants spend the majority of their lives in films of water between soil particles (Dropkin, 1980). Therefore, in addition to host availability, the physical and chemical characteristics of the soil environment play an important role in the survival and reproduction of plant-parasitic nematodes (Norton, 1979; 1989; Castro et al., 1990).

Population densities of plant-parasitic nematodes in the soil vary greatly in time and space. Patchy or aggregated spatial distribution of nematodes and changes of the typical polyspecific communities over time pose major sampling problems. The inherent tendency of nematode populations to increase or decrease, which is often enhanced by climate and other factors, is partly responsible for their patchy distribution. Some of the ecological factors that affect nematode population density and distribution in the soil are: soil texture, temperature, moisture, organic matter, pH, plant susceptibility and microorganisms (Norton, 1979; 1989).

Prevalence and virulence of many plant-parasitic nematodes of economic importance vary predictably in soils of different texture (Barker, 1998) because texture is related to soil porosity, water potential and other chemical and physical properties affected by particle size. Most plant-parasitic nematodes show higher population densities in sandy-loam soils than in clay soils. For example, the sting nematode (*Belonolaimus spp*), root-knot nematode (*Meloidogyne spp*.), needle nematode (*Longidorus spp*.), and stubby root nematode (*Trichodorus spp*) are found